SONOMA COUNTY TRANSPORTATION AUTHORITY

2009 COMPREHENSIVE TRANSPORTATION PLAN

FINAL ENVIRONMENTAL IMPACT REPORT

SCH No. 2008082011

sonoma county transportation authority

Prepared for:

SONOMA COUNTY TRANSPORTATION AUTHORITY
490 MENDOCINO AVENUE, SUITE 206
SANTA ROSA, CA 95401

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1.0 Introduction

This Final Environmental Impact Report (Final EIR or FEIR) was prepared in accordance with the California Environmental Quality Act (CEQA) and the State CEQA Guidelines (Section 15132). The Sonoma County Transportation Authority (SCTA) is the lead agency for the environmental review of the proposed 2009 Comprehensive Transportation Plan (2009 CTP) and has the principal responsibility for approving the project. This FEIR identifies the expected environmental impacts resulting from adoption and implementation of the proposed 2009 Comprehensive Transportation Plan (CTP), as well as responds to comments received on the Draft Environmental Impact Report (Draft EIR).

1.1 BACKGROUND AND PURPOSE OF THE EIR

OVERVIEW OF CEQA REQUIREMENTS FOR PREPARATION OF AN EIR

The SCTA, serving as the lead agency, has prepared this Environmental Impact Report (EIR) to provide the public and responsible and trustee agencies with information about the potential environmental effects of the proposed 2009 CTP. As set forth in the provisions of CEQA and implementing regulations, public agencies are charged with the duty to consider the environmental impacts of proposed development and to minimize these impacts where feasible while carrying out an obligation to balance a variety of public objectives, including economic, environmental, and social factors.

State CEQA Guidelines Section 15121(a) states that an EIR is an informational document for decision-makers and the general public that analyzes the significant environmental effects of a project, identifies possible ways to minimize significant effects, and describes reasonable alternatives to the project that could reduce or avoid its adverse environmental impacts. Public agencies with discretionary authority are required to consider the information in the EIR, along with any other relevant information, in making decisions on the project.

CEQA requires the preparation of an environmental impact report prior to approving any project which may have a significant effect on the environment. For the purposes of CEQA, the term "project" refers to the whole of an action which has the potential for resulting in a direct physical change or a reasonably foreseeable indirect physical change in the environment (CEQA Guidelines Section 15378[a]). With respect to the proposed 2009 CTP, the SCTA has determined that the proposed development is a "project" within the definition of CEQA.

BACKGROUND OF ENVIRONMENTAL REVIEW PROCESS OF THE PROJECT

The following is an overview of the environmental review process for the 2009 CTP that has led to the preparation of this FEIR.

Notice of Preparation and Initial Study

In accordance with Section 15082 of the State CEQA Guidelines, the SCTA prepared a Notice of Preparation (NOP) of an EIR for the project on August 1, 2008. The SCTA was identified as the lead agency for the proposed project. The notice was circulated to the public, local, state, and federal agencies, and other interested parties to solicit comments on the proposed project. Two scoping meetings was held on August 14, 2008, to receive additional comments. Concerns raised in response to the NOP were considered during preparation of the Draft EIR. The NOP and responses by interested parties are presented in Appendix A of the Draft EIR. An Initial Study for the project was prepared and released for public review along with the NOP. Its conclusions supported preparation of an EIR for the project. The Initial Study is also included in Appendix A of the Draft EIR.

Draft EIR

The Draft EIR was released for public and agency review on April 16, 2008, with the review period set to end on June 22, 2009. The Draft EIR contains a description of the project, description of the environmental setting, identification of project impacts, and mitigation measures for impacts found to be significant, as well as an analysis of project alternatives. The Draft EIR was provided to interested public agencies and the public and was made available for review at SCTA's office, on SCTA's website, and at the following libraries: Santa Rosa Main, Petaluma, Rohnert Park, Windsor, Sebastopol, Sonoma Healdsburg, and Cloverdale.

Final EIR

The SCTA received 17 comment letters from agencies, interest groups, and the public regarding the Draft EIR. This document responds to the written comments received as required by CEQA. This document also contains minor edits to the Draft EIR, which are included in Section 4.0, Minor Revisions to the Draft EIR. This document constitutes the FEIR.

Certification of the Final EIR/Project Consideration

The SCTA Board of Directors will review and consider the FEIR. If the SCTA finds that the FEIR is "adequate and complete," the SCTA may certify the FEIR. The rule of adequacy generally holds that the EIR can be certified if: (1) it shows a good faith effort at full disclosure of environmental information; and (2) it provides sufficient analysis to allow decisions to be made regarding the project in contemplation of its environmental consequences.

Upon review and consideration of the Final EIR, the SCTA may take action to adopt, revise, or reject the proposed 2009 CTP. A decision to adopt the 2009 Comprehensive Transportation Plan would be accompanied by written findings in accordance with State CEQA Guidelines Section 15091 and Section 15093. Public Resources Code Section 21081.6 also requires lead agencies to adopt a mitigation monitoring and reporting program to describe measures that have been adopted or made a condition of project approval in order to mitigate or avoid significant effects on the environment.

1.2 TYPE OF DOCUMENT

The State CEQA Guidelines identify several types of EIRs, each applicable to different project circumstances. This EIR has been prepared as a Program EIR pursuant to CEQA Guidelines Section 15168. According to Section 15168:

> *A program EIR is an EIR which may be prepared on a series of actions that can be characterized as one large project and are related either:*
>
> *(1) Geographically,*
>
> *(2) As logical parts in the chain of contemplated actions,*
>
> *(3) In connection with issuance of rules, regulations, plans or other general criteria to govern the conduct of a continuing program, or*
>
> *(4) As individual activities carried out under the same authorizing statutory or regulatory authority and having generally similar environmental effects which can be mitigated in similar ways.*

The program-level analysis considers the broad environmental effects of the overall proposed 2009 Comprehensive Transportation Plan (2009 CTP). The EIR will be used to evaluate subsequent projects and activities under the proposed 2009 CTP. Additional environmental review under CEQA will be required and would be generally based on the subsequent project's consistency with the 2009 CTP and the analysis in this EIR, as required under CEQA. When individual projects or activities under the 2009 CTP are proposed, the lead agency would be required to examine the projects or activities to determine whether their effects were adequately analyzed in the program EIR (State CEQA Guidelines Section 15168).

1.3 INTENDED USES OF THE EIR

This EIR is intended to evaluate the environmental impacts of the project to the greatest extent possible. This EIR should be used as the primary environmental document to evaluate all subsequent planning and permitting actions associated with projects within SCTA's authority that are consistent with the 2009 CTP. Subsequent actions that may be associated with the proposed 2009 CTP are identified in Section 3.0, Overview of the 2009 Comprehensive Transportation Plan, of the Draft EIR.

1.4 ORGANIZATION AND SCOPE OF THE FINAL EIR

This document is organized in the following manner:

SECTION 1.0 – INTRODUCTION

Section 1.0 provides an overview of the EIR process to date and what the FEIR is required to contain.

SECTION 2.0 – EXECUTIVE SUMMARY

Section 2.0 includes an updated Executive Summary that provides a brief project description and presents a summary table of probable environmental effects edited as a result of comments received on the DEIR and minor staff edits.

Section 3.0 – COMMENTS AND RESPONSES TO COMMENTS ON THE DRAFT EIR

Section 3.0 provides a list of commenters, copies of written comments (coded for reference), and the responses to those written comments made on the Draft EIR.

SECTION 4.0 – MINOR REVISIONS TO THE DRAFT EIR

Section 4.0 provides a list of minor edits made to the Draft EIR as a result of comments received and/or staff-initiated edits to clarify the information in the Draft EIR.

2.0 Executive Summary

This section provides an overview of the proposed Sonoma County Transportation Authority 2009 Comprehensive Transportation (2009 CTP or proposed project) and the environmental analysis of the proposed project. For additional detail regarding specific issues, please consult the appropriate chapter of Draft EIR Sections 4.1 through 4.13 (Environmental Setting, Impacts, and Mitigation Measures).

2.1 PROJECT CHARACTERISTICS

The 2009 CTP updates past transportation planning priorities and provides a guide to multi-modal transportation investments over the next 25 years. The goals of the CTP are to (1) maintain the system, (2) relieve congestion, (3) reduce emissions, and (4) plan for safety and health. The CTP is a financially constrained plan that looks at the growth projections for the region and prioritizes projects and programs that can reduce existing and future congestion. As such, the 2009 CTP includes the following components. Section 4.0 provides a detailed list of improvements:

- Highway Capital Improvements. Seven capital improvements listed in the Measure M Strategic Plan and projects funded from other sources, mostly focused on carpool lane improvements on the U.S. 101 freeway corridor.

- Local Road Improvements. Several of local road improvements listed in the Measure M Strategic Plan and also funded from other sources are included. These often focus on road widening or signalizing of intersections.

- Transit Improvements. These include investments in the Measure M Strategic Plan and the Sonoma-Marin Area Rail Transit (SMART) passenger rail project.

- Non-Motorized Transportation Improvements. Projects in the 2008 Countywide Bicycle and Pedestrian Master Plan are included. This includes independent bike trails (Class I), striped bike lanes (Class II), and bike routes (Class III).

- Additional Improvements. This includes funding for maintenance of local streets, traffic safety and safe routes for schools, local projects funded through developer-related Transit Impact Fees, right-of-way and dedication improvements by developers.

- Regional Operations Programs. The CTP includes ongoing, financially constrained regional operations programs administered by the Metropolitan Transportation Commission (MTC). Funding for these programs is included in MTC's Draft Transportation 2035 Plan.

- Land Use and Pricing Assumptions. The CTP is designed to provide transportation infrastructure that accommodates the projected growth of Sonoma County and the larger region. The socioeconomic forecasts used in the CTP are based on the Association of Bay Area Governments' (ABAG) Projections 2005 with adjustments based on local forecasts and the release of its Projections 2007. ABAG population and employment forecasts were used as control totals for jurisdictions and county planning areas. Sub-allocation of control totals to traffic analysis zones within jurisdiction boundaries or county planning areas was based on local planning agencies and input from SCTA staff.

This EIR assesses the expected environmental impacts resulting from adoption and subsequent implementation of the proposed 2009 CTP at a program level of analysis, as permitted by CEQA. The environmental issues addressed in the Draft EIR were established through review of environmental documentation developed for the project, environmental documentation for nearby projects, and public and agency responses to the Notice of Preparation (NOP). **Table 2.0-1** summarizes the anticipated impacts of the CTP on the existing environment. **Table 2.0-1** does not list impacts that have been identified as less than significant prior to mitigation, but where mitigation has been included.

2.2 PROJECT ALTERNATIVES SUMMARY

Section 15126(d) of the State CEQA Guidelines requires that an EIR describe a reasonable range of alternatives to the project or to the location of the project that could feasibly accomplish the basic objectives of the project, and to evaluate the comparative merits of the alternatives. Section 4.0 provides a list of transportation improvements associated with each alternative

These alternatives are evaluated at a qualitative level of detail and are summarized below.

- **Alternative 1: *No Project/No Action Alternative*** – This alternative assumes that all reasonably foreseeable projects and programs (i.e., projects that are fully funded, programmed, and/or have cleared the environmental phase) from the adopted 2004 CTP and 2009 Regional Transportation Improvement Program are implemented, but that all other projects and programs do not proceed forward.

- **Alternative 2: *CTP Vision Scenario, Financially Unconstrained Capital Improvement Scenario*** – This scenario assumes the entire list of possible proposed CTP projects, including all transportation projects and programs included in the project, are added to the transportation system independent of financial constraints.

- **Alternative 3: *VMT Reduction – Transit Expansion/Smart Growth Focused Scenario*** – This alternative assumes that future transportation policy and improvements are focused on land use change and accompanying transit expansion to reduce vehicle miles traveled (VMT). It includes implementation of all capital highway improvements included in the project.

- **Alternative 4: *VMT Reduction – Pricing Policy Focused Scenario*** – This alternative focuses on using pricing measures and policy as a means of reducing travel demand and trip reduction. It includes the same capital highway and transit improvements and growth assumptions as the project.

- **Alternative 5: *Comprehensive/"Do Everything" Scenario*** – This scenario includes the entire list of possible proposed CTP projects independent of financial constraints and all previously identified measures to reduce VMT (Smart Growth-related land use changes and pricing measures).

2.3 SUMMARY OF ENVIRONMENTAL IMPACTS

Table 2.0-1 displays a summary of impacts for the proposed 2009 CTP and proposed mitigation measures that would avoid or minimize potential impacts. In the table, the level of significance is indicated both before and after the implementation of each mitigation measure.

For detailed discussions of all mitigation measures and of proposed 2009 CTP policies that would provide mitigation for each type of environmental impact addressed in this EIR, refer to the appropriate environmental topic section in the Draft EIR (i.e., Sections 4.1 through 4.13). Changes to mitigation measures from comments received on the Draft EIR are shown in revision marks (underline/~~strikeout~~.)

TABLE 2.0-1
PROJECT IMPACTS MITIGATION TABLE

Impact	Mitigation Measures		Significance After Mitigation
Aesthetics			
Impact 4.1-1 Construction and operation of CTP projects, particularly freeway interchanges, could temporarily and/or permanently block panoramic views.	**MM 4.1-1a**	The lead agency and/or project sponsor for subsequent projects under the CTP shall ensure that the project's design is consistent with design guidelines and local policies, programs, and standards that preserve scenic views and corridors.	**Less than significant**
	MM 4.1-1b	The lead agency and/or project sponsor for subsequent projects under the CTP shall be designed to minimize contrasts in scale and massing between the project site and surrounding natural forms and development, particularly in areas that have been designated or eligible for State Scenic Highway designations.	
	MM 4.1-1c	The lead agency and/or project sponsor for subsequent projects under the CTP shall, to the extent feasible, use natural and native landscaping to enhance and complement the natural surroundings to minimize the contrast between the project and surrounding areas.	
	MM 4.1-1d	The lead agency and/or project sponsor for subsequent projects under the CTP shall, to the extent feasible, construct noise barriers of materials whose color and texture complements the surrounding landscape and development. Noise barriers shall be graffiti-resistant and landscaped with plants that screen the barrier, preferably with either native vegetation or landscaping.	
	MM 4.1-1e	The lead agency and/or project sponsor for subsequent projects under the CTP shall, to the extent feasible, limit view blockage by interchanges and SMART-related improvements. The edges of major cut and fill slopes shall be contoured to provide a more natural-looking finished profile.	
Impact 4.1-2 The construction and operation of 2009 CTP projects could temporarily damage scenic resources, including, but not limited to, trees, rock outcroppings, and historic buildings within a state scenic highway.	**None required.**		**Less than significant**
Impact 4.1-3 Implementation of the 2009 CTP may	As noted in Impact 4.1-1, potential impacts to the existing visual character of the county can be mitigated with implementation of mitigation measures MM 4.1-1a through 4.1-1e		**Less than significant**

Impact	Mitigation Measures		Significance After Mitigation
create significant contrasts or add an incongruous visual element by substantially degrading the existing visual character of the county.	by designing the improvements to complement and blend with the existing visual landscape characteristics of the subsequent project sites consistent with the intent of applicable local scenic policies, programs, and standards.		
Impact 4.1-4 The construction and operation of 2009 CTP projects may create new sources of light and/or glare that would adversely affect nighttime views in project areas.	**MM 4.1-4a** **MM 4.1-4b**	Roadway light fixtures for subsequent projects shall be installed and shielded in such a manner that light rays emitted from the fixture at angles above the horizontal plane are minimized. Construction lighting that is used for nighttime construction activities will include shields or other features to prohibit spillover lighting when used adjacent to residential areas.	**Less than significant**
Air Quality			
Impact 4.2-1 The proposed 2009 CTP includes multi-modal transportation projects and programs that would not conflict with or obstruct implementation of BAAQMD's Clean Air Plan. Rather, the plan would help implement applicable Transportation Control Measures (TCMs) from the CAP on a timely basis. In addition, the CTP is consistent with CAP assumptions for population and VMT growth over time and its objectives and policies implement other elements of the CAP. It does not include policies that would minimize or eliminate potential buffer zones around existing and proposed land uses that would emit odors or TACs.	**None required.**		**Beneficial**
Impact 4.2-2 The proposed 2009 CTP would help reduce ozone precursors of ROG and NOx by 2035 that are consistent with the BAAQMD's 2005 Ozone Strategy. The reductions in these two pollutants would not contribute to	**None required.**		**Beneficial**

Impact	Mitigation Measures		Significance After Mitigation
existing or projected ozone violations.			
Impact 4.2-3 While the proposed 2009 CTP would not directly cause increases in emissions from the transportation sector, motor vehicle emissions of PM_{10} and $PM_{2.5}$ would increase by 26 and 75 percent, respectively, over existing conditions by 2035. However, these emissions would not lead to any violation of air quality standards, contribute to an existing or projected air quality violation, or result in a cumulatively considerable net increase of emissions of PM_{10} and $PM_{2.5}$, as these emissions are factored into the BAAQMD's plan to attain federal and state particulate standards.	**None required.**		**Less than significant**
Impact 4.2-4 Construction of capital improvements in the 2009 CTP would produce short-term emissions of nonattainment pollutants or precursors in the San Francisco Bay Area Air Basin. These emissions could lead to temporary increases in ROG, NOx, PM_{10} and $PM_{2.5}$ emissions. This could lead to violations of air quality standards, contribute to an existing or projected air quality violation, or result in a cumulatively considerable net increase of emissions.	**MM 4.2-4**	Consistent with BAAQMD guidance, the following standard BAAQMD air quality Best Management Practices (BMPs) shall be implemented on the project site during the construction period to reduce emissions of PM_{10} and $PM_{2.5}$: • Water all active construction areas at least twice daily. • Cover all trucks hauling soil, sand, and other loose materials or require all trucks to maintain at least two feet of freeboard. • Pave, apply water three times daily, or apply (non-toxic) soil stabilizers on all unpaved access roads, parking areas, and staging areas at construction sites. • Sweep daily (preferably with water sweepers) all paved access roads, parking areas, and staging areas at construction sites. • Sweep streets daily (preferably with water sweepers) if visible soil material is carried onto adjacent public streets. • Hydroseed or apply (non-toxic) soil stabilizers to inactive construction areas.	**Less than significant**

Impact	Mitigation Measures	Significance After Mitigation
	• Enclose, cover, water twice daily, or apply (non-toxic) soil binders to exposed stockpiles (dirt, sand, etc.). • Install sandbags or other erosion control measures to prevent silt runoff to public roadways. • Replant vegetation in disturbed areas as quickly as possible. • Implement T-BACT (the Best Available Control Technologies for Toxics) for diesel construction equipment. • Idling times shall be minimized either by shutting equipment off when not in use or reducing the maximum idling time to 5 minutes (as required by the California airborne toxics control measure Title 13, Section 2485 of California Code of Regulations [CCR]). • All construction equipment shall be maintained and properly tuned in accordance with manufacturer's specifications. All equipment shall be checked by a certified mechanic and determined to be running in proper condition prior to operation.	
Traffic and Circulation		
Impact 4.3-1 Implementation of the 2009 CTP would not directly cause increases in traffic or vehicle miles traveled. However, the 2009 CTP would support growth in Sonoma County that would substantially increase daily vehicle miles traveled in 2035 by 2,976,144 over existing conditions. The traffic impacts associated with the anticipated growth within the county (through 2020) were identified as significant and unavoidable in the County's General Plan 2020 EIR.	**MM 4.3-1a** SCTA shall seek funding to go beyond the financially constrained portion of the 2009 CTP to achieve VMT reductions that could be obtained through pricing strategies and additional transit, ridesharing programs, nonmotorized investments, and public education programs. **MM 4.3-1b** SCTA shall encourage local governments to implement land use strategies, pricing strategies, and additional transit, ridesharing programs, public education, and nonmotorized investments.	**Significant and unavoidable**
Impact 4.3-2 Implementation of the 2009 CTP would not directly cause increases in	**MM 4.3-2a** SCTA shall seek funding to go beyond the financially constrained portion of the 2009 CTP to achieve VHT reductions that could be obtained through pricing strategies and additional transit,	**Significant and unavoidable**

Impact	Mitigation Measures	Significance After Mitigation
daily vehicle hours traveled. However, the 2009 CTP would support growth in Sonoma County that would substantially increase daily vehicle hours ~~miles~~ traveled in 2035 by 282,874 over existing conditions. The impacts associated with the anticipated growth within the county (through 2020) were identified as significant and unavoidable in the County's General Plan 2020 Draft EIR. This impact is considered significant and unavoidable.	ridesharing programs, nonmotorized investments, and public education programs. Projects such as transit and land use strategies are shown to have the greatest potential benefits. **MM 4.3-2b** SCTA shall encourage local governments to implement transportation system management improvements and specific transportation investments that reduce travel time on local roadways.	
Impact 4.3-3 Implementation of the 2009 CTP would not directly cause a reduction of average daily vehicle speeds. However, the 2009 CTP would support growth in Sonoma County that would substantially reduce average daily vehicle speeds in 2035 by 11 miles per hour over existing conditions. The traffic impacts associated with the anticipated growth within the county (through 2020) were identified as significant and unavoidable in the County's General Plan 2020 Draft EIR.	Implement Mitigation Measures 4.3-2a and 4.3-2b.	**Significant and unavoidable**
Impact 4.3-4 Implementation of the 2009 CTP would not directly increase PHD or~~of~~ PHT on the county's roadway system. However, the 2009 CTP would support growth in Sonoma County that would substantially increase daily PHD by 250,102 and PHT by 335,166 over existing conditions. The traffic impacts associated with	Implement Mitigation Measures 4.3-2a and 4.3-2b.	**Significant and unavoidable**

Impact	Mitigation Measures	Significance After Mitigation
the anticipated growth within the county (through 2020) were identified as significant and unavoidable in the County's General Plan 2020 Draft EIR. This impact is therefore considered **significant and unavoidable.**		
Impact 4.3-5 Implementation of the 2009 CTP includes projects and programs that address surface transportation issues, including ground access to airports. However, the 2009 CTP would not directly or indirectly impact regional air traffic patterns substantially.	**None required.**	**Less than significant**
Impact 4.3-6 Implementation of the 2009 CTP includes new or expanded projects that would result in improvements to the county's roadway infrastructure that would generally reduce existing safety hazards and limit any potential future hazards.	**None required.**	**Beneficial**
Impact 4.3-7 The 2009 CTP includes policies supporting smart growth that could indirectly impact parking capacity from future transit-oriented development that local governments determined require less off-street parking than required under conventional zoning codes.	**None required.**	**Less than significant**
Impact 4.3-8 The 2009 CTP includes projects and programs that support alternative modes of transportation, such as bicycle, pedestrian, and transit	**None required.**	**Beneficial**

Impact	Mitigation Measures		Significance After Mitigation
modes that are consistent with existing regional and local plans that support alternative transportation.			
Impact 4.3-9 The 2009 CTP includes transportation projects that would be consistent with transportation policies in local general plans or other applicable local transportation plans.	**None required.**		**Beneficial**
Biological Resources			
Impact 4.4-1 Implementation of the proposed 2009 CTP may result in the loss of populations or essential habitat for special-status plant and wildlife species.	**MM 4.4-1a**	<u>During the environmental review process for proposed CTP projects, project sponsors shall prepare a</u> biological resources assessment ~~shall be prepared~~ for areas identified to contain or possibly contain special-status plant and animal species. Surveys shall be conducted as part of the environmental review process to determine the presence and extent of sensitive habitats and/or species in the project vicinity. Surveys shall be conducted during the appropriate seasons for proper identification of species. The assessment shall consider the potential for significant impacts on special-status plant and animal species and shall identify feasible mitigation measures to mitigate such impacts, as set forth in mitigation measure MM 4.4-1b below. Formal protocol-level surveys may be required on a species-by-species basis to determine the local distribution of these species. Consultation with the USFWS and/or CDFG shall be conducted at an informal level for transportation projects that could adversely affect federal or state candidate, threatened, or endangered species to determine the need for further consultation or permitting actions.	**Less than significant**
	MM 4.4-1b	Project sponsors shall seek to preserve, to the extent feasible, wetlands, habitat corridors, sensitive natural communities, and other essential habitat areas that may be adversely affected by transportation projects where special-status plant and animal species are known to be present or potentially occurring. Where impacts cannot be avoided, projects shall include the implementation of site-specific or project-specific effective mitigation strategies developed by a qualified professional in consultation with state or federal resource agencies with jurisdiction (if applicable).	

Impact	Mitigation Measures	Significance After Mitigation
	Mitigation strategies include, but are not limited to, the following: • For special-status plant species: Preservation of existing populations from direct and indirect impacts, and where feasible seed and soil collection shall occur to ensure that the plant population is maintained. • For special-status animal species: Avoidance of the species and its habitat as well as the potential provision of habitat buffers, avoidance of the species during nesting or breeding seasons, replacement or restoration of habitat on- or off-site, relocation of the species to another suitable habitat area presently uninhabited by the species, or payment of mitigation credit fees. • Project designs shall be reconfigured, whenever feasible, to avoid sensitive wetland or biological resources and avoid disturbances to wetland and riparian corridors. Projects shall minimize ground disturbances and construction footprints near sensitive areas to the extent feasible. • ~~Individual projects shall minimize the use of in-water construction methods in areas that support sensitive fish species, especially when fish are present.~~ • Individual projects will avoid the use of in-water construction methods in all state of federally jurisdictional surface waters, where feasible. • A qualified biologist shall locate and fence off identified sensitive resources before construction activities begin and, where required, shall inspect areas to ensure that barrier fencing, stakes, and setback buffers are maintained during construction. • For work sites located adjacent to special-status plant or wildlife populations, a biological resource education program shall be provided for construction crews and contractors (primarily crew and construction foremen) before construction activities begin. The education program shall address each special-status species, their habitat, laws protecting these resources, the avoidance and minimization measures being applied to protect these resources, and pertinent contact information.	

Impact	Mitigation Measures		Significance After Mitigation
Impact 4.4-2 Implementation of the proposed 2009 CTP could result in the loss of populations or essential habitat for special-status avian species, including raptors.	**MM 4.4-2**	Should the location of a subsequent project under the 2009 CTP be within 300 feet of any trees, the following mitigation measure would be applicable. If site disturbance and construction activities are planned to occur during the nesting season (typically February 15 through August 1), the project sponsor shall retain a qualified biologist to conduct a focused survey for active nests of special-status birds prior to ground disturbance or tree removal. If active nests are found, trees/shrubs with nesting birds shall not be disturbed until abandoned by the birds or a qualified biologist deems disturbance potential to be minimal (in consultation with USFWS and/or CDFG, where appropriate). Other restrictions may include establishment of exclusion zones (no ingress of personnel or equipment around the nest) or alteration of the construction schedule. If construction activities or tree removal are proposed to occur during the non-breeding season (September through January), a survey is not required, no further studies are necessary, and no mitigation is required.	**Less than significant**
Impact 4.4-3 Implementation of the proposed 2009 CTP could result in the loss of populations or essential habitat for special-status bat species through tree removal or other construction activities.	**MM 4.4-3**	Should the location of a subsequent project under the 2009 CTP be within 300 feet of any trees or structures proposed for removal, the following mitigation measure would be applicable. To ensure that there will be no adverse impacts to roosting special-status bat species, the project sponsor shall retain a qualified biologist to conduct a survey prior to the removal of trees or structures (including bridges) within the project area that are deemed suitable roosting habitats by a qualified biologist. If no bat roosts are detected, then no further action is required if the trees or structures are removed prior to the next breeding season. If special-status bats are found roosting within the project area, then the following mitigation will reduce the potential disturbance: If a female or maternity colony of bats is found within the project area and the project can be constructed without the elimination or disturbance of the roosting colony (e.g., if the colony roosts in a large tree not planned for removal), a qualified biologist shall determine the physical and time-limited buffer zones that shall be employed to ensure the continued success of the colony. Such buffer zones may include a construction-free barrier around the roost and/or the timing of the construction activities outside of the maternity roosting season (generally after July 31 and before	**Less than significant**

Impact		Mitigation Measures	Significance After Mitigation
		March 1). If an active nursery roost is known to occur within the project area and the project cannot be conducted outside of the maternity roosting season, consultation shall be initiated with CDFG to determine appropriate exclusionary or removal methods. The bats shall be excluded from the roosting site after July 31 and before March 1 to prevent the formation of maternity colonies. Non-breeding bats shall be safely evicted, under the direction of a qualified biologist.	
Impact 4.4-4 Implementation of the proposed 2009 CTP may result in disturbance, degradation, and/or removal of riparian habitat or other sensitive natural communities.	**MM 4.4-4**	In accordance with CDFG guidelines and other resource agency guidance, project sponsors shall minimize impacts on sensitive natural communities, especially riparian habitats, when designing and permitting projects. Where applicable, subsequent projects under the 2009 CTP shall conform to the provisions of special area management or restoration plans (e.g., West Petaluma Area Plan), which outline specific measures to protect sensitive natural communities including riparian and wetland habitats.	**Less than significant**
Impact 4.4-5 Implementation of the proposed 2009 CTP may result in the loss of jurisdictional waters of the U.S., including wetlands.	**MM 4.4-5a**	Project designs of subsequent projects under the 2009 CTP shall be reconfigured, whenever possible, to avoid waters of the U.S., including wetlands, and avoid disturbances to wetland and riparian corridors. Projects shall minimize ground disturbances and construction footprints near such areas to the extent feasible.	**Less than significant**
	MM 4.4-5b	Where potential waters of the U.S. are present within CTP project sites, project sponsors shall retain a qualified biologist to perform a formal wetland delineation to be submitted to USACE for verification. If USACE determines that there are jurisdictional waters on the project area, the project sponsor shall ensure that the project will result in no net loss of waters of the U.S. by providing mitigation through impact avoidance, impact minimization, and/or compensatory mitigation for the impact, subject to approval from the appropriate resource agencies and in accordance with applicable regulations. Compensatory mitigation may consist of (a) obtaining credits from a mitigation bank; (b) making a payment to an in-lieu fee program that will conduct wetland, stream, or other aquatic resource restoration, creation, enhancement, or preservation activities; and/or (c) providing compensatory mitigation through an aquatic resource restoration, establishment, enhancement, and/or	

Impact	Mitigation Measures		Significance After Mitigation
		preservation activity.	
Impact 4.4-6 Implementation of the proposed 2009 CTP may interfere with the movement of native resident or migratory wildlife species.	**MM 4.4-6a**	Project sponsors of subsequent projects under the 2009 CTP shall, to the extent feasible, avoid open space areas and sensitive natural habitats, especially stream and riparian corridors, when designing and permitting projects. Where applicable, projects shall conform to the provisions of special area management or restoration plans (e.g. West Petaluma Area Plan), which outline specific measures to protect sensitive habitats. Where migratory corridors cannot be avoided (e.g., walls or fences are constructed that may obstruct wildlife movement), the incorporation of mitigation measures identified under Impacts 4.4-1, 4.4-4, and 4.4-5 would assist in mitigating impacts to migratory corridors.	**Less than significant**
	MM 4.4-6b	Project sponsors should include into project design, to the maximum extent feasible, mitigation measures and best practices aimed at minimizing or avoiding impacts to migratory patterns, including strategies from the U.S. Department of Transportation Federal Highway Administration's Critter Crossings program.	
Impact 4.4-7 Implementation of the proposed 2009 CTP would not conflict with the provisions of an adopted Habitat Conservation Plan, Natural Community Conservation Plan, or any adopted biological resources recovery or conservation plan of any federal or state agency.	**None required.**		**Less than significant**
Cultural Resources			
Impact 4.5-1 Implementation of the proposed 2009 CTP could result in a substantial adverse change in the significance of historical resources. Construction projects could also unearth human remains that would require cessation of activities until	**MM 4.5-1a**	During the environmental review process for proposed CTP projects, project sponsors shall determine if there is a potential for a significant impact to historic resources to occur. If it is determined there is a potential significant impact to these resources, project sponsors shall implement the laws and regulations of the responsible regulatory agency. Examples of such mitigation measures include the following: • A qualified historian shall review previous site investigations of	**Less than significant**

Impact	Mitigation Measures	Significance After Mitigation
further analysis, as required by state law, is conducted.	the project site (if available) to determine the historic significance of the project site. If it is determined there are potential resources on the project site, the qualified architectural historian or historian shall also determine whether structures greater than 50 years in age are within the area of potential to be affected by the project and to determine their eligibility for recognition under state, federal, or local historic preservation criteria. • If there are projects being developed adjacent to sites with an identified historic resource, a qualified historian shall be utilized to determine the extent of the potential degradation and recommend measures to reduce the impacts to the resource. The project sponsor shall implement the measures to protect the integrity of the resource or site. **MM 4.5-1b** The project sponsor's planning department shall be notified immediately if any prehistoric or historic resources are uncovered during construction of project facilities. All construction must stop in the vicinity of the find, and a qualified archaeologist shall be retained to evaluate the finds and recommend appropriate action.	
Impact 4.5-2 Implementation of the proposed 2009 CTP could result in a substantial adverse change in the significance of a cultural resource, defined as physical demolition, destruction, relocation, or alteration of the resource or its immediate surroundings such that its significance would be materially impaired. Construction projects could also unearth human remains that would require cessation of activities until further analysis, as required by state law, is conducted.	**MM 4.5-2a** During the environmental review process for proposed CTP projects, project sponsors in consultation with the appropriate culturally affiliated tribe(s) shall determine if there is a potential for a significant impact to cultural resources to occur. If it is determined there is a potential significant impact to these resources, project sponsors shall implement the laws and regulations of the responsible regulatory agency. Examples of such mitigation measures include the following: • A qualified archaeologist shall review previous site investigations of the project site (if available) to determine the historic significance of the project site. A qualified archaeologist shall perform a records review through the Northwest Information Center at Sonoma State University to determine the potential for, or existence of, cultural resources. A qualified archaeologist shall review the records search to determine the significance (as defined by CEQA and National Historic Preservation Act guidelines) of cultural resources identified within the area of potential effect. **MM 4.5-2b** If a potentially significant cultural resource is encountered during subsurface earthwork activities for the project, all construction	**Less than significant**

Impact	Mitigation Measures	Significance After Mitigation
	activities within a 100-foot radius of the find shall cease until a qualified archaeologist, in consultation with the appropriate culturally affiliated tribe(s) determines whether the resource is significant. The project sponsor shall include a standard inadvertent discovery clause, including a requirement for consultation with the appropriate culturally affiliated tribe(s), in every construction contract to inform contractors of this requirement. Potentially significant cultural resources consist of, but are not limited to, stone, bone, glass, ceramic, wood or shell artifacts, fossils, or features including hearths, structural remains, or historic dumpsites. If the resource is determined significant under CEQA, the qualified archaeologist shall prepare and implement a research design and archaeological data recovery plan that will capture those categories of data for which the site is significant. The archaeologist shall also perform appropriate technical analyses, prepare a comprehensive report and file it with the Northwest Information Center, and provide for the permanent curation of the recovered materials.	
	MM 4.5-2c The project sponsor shall implement the appropriate mitigation measures presented by a qualified archeologist, and developed in consultation with the appropriate affiliated tribes(s), for any discovery of significant resources, based on applicable state and federal regulations. All construction must stop in vicinity of the find, and a qualified archaeologist shall be retained to evaluate the finds and recommend appropriate action. The project sponsor shall implement the mitigation recommendations presented by a qualified archaeologist for any unanticipated discoveries of significant resources. Such measures may include avoidance, preservation in place, excavation, documentation, curation, data recovery, or other appropriate measures. The project proponent shall be required to implement any mitigation necessary for the protection of cultural resources.	
	MM 4.5-2d If human remains are discovered, all work must stop in the immediate vicinity of the find, the project sponsor's planning department shall be notified immediately, and the County Coroner must be notified according to Section 7050.5 of California's Health and Safety Code. If the remains are determined to be Native American, the coroner will notify the Native American Heritage Commission, and the procedures outlined in CEQA Section 15064.5(d) and (e) shall be followed.	

Impact	Mitigation Measures		Significance After Mitigation
Impact 4.5-3 Construction activities associated with implementation of the 2009 CTP could result in impacts to undiscovered paleontological resources.	**MM 4.5-3a**	Where earthwork activity is proposed to depths below 3 feet, the project sponsor shall perform a search of the University of California, Berkeley Museum of Paleontology collections database to proactively identify any evidence of paleontological resources in the proposed project area.	**Less than significant**
	MM 4.5-3b	If any paleontological resources (fossils) are discovered during a project's ground-disturbing activity, all work in the immediate vicinity must stop and the project sponsor's planning department shall be immediately notified. A qualified paleontologist shall be retained to evaluate the finds and recommend appropriate mitigation measures for the inadvertently discovered paleontological resources. Such measures may include avoidance, preservation in place, excavation, documentation, curation, data recovery, or other appropriate measures. The project sponsor shall be required to implement any mitigation necessary for the protection of paleontological resources.	
Geology and Soils			
Impact 4.6-1 The proposed Comprehensive Transportation Plan invests in new capital roadway and transit improvements that will increase the capacity of the county's transportation infrastructure to move people and goods. This would increase the risk of loss, injury, or death to travelers or structures due to earthquakes, landslides, ground failure, or liquefaction.	**MM 4.6-1**	Project sponsors shall address the following measures in project-level analyses for proposed transportation improvements. • Site-specific analyses shall consider a site's seismicity and soil response, and dynamic characteristics of the proposed structure, and shall comply with the appropriate California Building Code, Caltrans construction standards, and State of California design standards for construction in or near fault zones, as well as all standard design, grading, and construction best management practices in order to avoid or reduce geologic hazards. • The project sponsor shall ensure that geotechnical analyses are conducted in construction areas to determine soil types and faulting probability prior to preparation of the project design. These investigations shall identify areas of potential failure and recommend geotechnical measures with which the project shall comply to eliminate any problems. Identified geotechnical measures shall be incorporated into the project design. • For future projects located within Alquist-Priolo Earthquake	**Significant and unavoidable**

Impact	Mitigation Measures		Significance After Mitigation
		Fault Zones, recommendations shall be prepared and implemented in accordance with California Geological Survey Guidelines for Evaluating the Hazard of Earthquake Fault Rupture. • Project sponsors shall ensure that projects either avoid or stabilize landslide areas and unstable slopes. • For projects located within liquefaction or earthquake-induced landslide seismic hazard zones, recommendations shall be prepared and implemented in accordance with California Geological Survey Guidelines for Evaluating and Mitigating Seismic Hazards.	
Impact 4.6-2 Construction of capital improvements in the proposed 2009 CTP could require significant earthwork and road cuts, which could increase soil erosion and slope instability potential associated with soils.	**MM 4.6-2a**	The project sponsors shall ensure that project designs provide adequate slope drainage and appropriate landscaping to minimize the occurrence of slope instability and erosion. Design features shall include measures to reduce erosion caused by stormwater consistent with applicable agency water quality control requirements. Road cuts shall be designed to maximize the potential for revegetation.	**Less than significant**
	MM 4.6-2b	Implementing agencies shall ensure that projects avoid landslide areas and potentially unstable slopes wherever feasible.	
	MM 4.6-2c	The project implementing agencies shall ensure that site-specific geotechnical investigations conducted by a qualified geotechnical expert shall be required prior to preparation of project design. These investigations would identify areas of potential failure and identify remedial geotechnical measures to eliminate any geotechnical problems.	
Impact 4.6-3 Construction and operation of proposed capital roadway and transit improvements on expansive soils or on weak, unconsolidated soils could damage and weaken these soils over time.	**MM 4.6-3a**	Project sponsors shall ensure that projects avoid geologic units or soils that are unstable or contain expansive soils and/or soils prone to lateral spreading, subsidence, liquefaction, or collapse wherever feasible. When avoidance of such conditions is not feasible, mitigation measure MM 4.6-3b shall be implemented.	**Less than significant**
	MM 4.6-3b	Project sponsors shall ensure that geotechnical investigations are conducted by qualified professionals to identify the potential for differential settlement and expansive soils. Identified corrective measures, such as structural reinforcement and replacing soil with engineered fill, shall be incorporated into project designs.	
Impact 4.6-4	**None required.**		**Less than significant**

Impact	Mitigation Measures		Significance After Mitigation
Development of capital roadway and transit improvements could expose persons or structures to the risk of loss, injury, or death from seiches or tsunamis. However, given the location of proposed CTP projects and their proximity to the Pacific Ocean and San Pablo Bay, impacts are considered less than significant.			
Hazards and Hazardous Materials			
Impact 4.7-1 The 2009 CTP includes transportation projects that have the potential to create significant hazards to the public or the environment through the routine transport, use, or disposal of hazardous materials**.** The Plan, however, would also improve the condition of roadways, reducing the potential for roadway accidents that could result in transport-related hazardous material spills.	**None required.**		**Less than significant**
Impact 4.7-2 Implementation of the proposed 2009 CTP would not omit or create a hazard to the public or the environment by locating new or expanded roadways or transit alignments that transport hazardous materials within one-quarter mile of a school.	**None required.**		**Less than significant**
Impact 4.7-3 Construction of new or expanded transportation facilities can disturb contaminated properties, particularly those in brownfield areas near proposed U.S. 101 freeway	**MM 4.7-3**	Subsequent projects under the CTP shall consult all known databases of contaminated sites and undertake a Phase I Environmental Site Assessment or other appropriate hazard assessment in the process of planning, environmental clearance, and construction for projects included in the 2009 CTP. Prior to development on or near active cleanup sites, the project proponent shall coordinate with all appropriate agencies. If contamination is	**Less than significant**

Impact	Mitigation Measures		Significance After Mitigation
improvements.		found, the implementation agency shall coordinate remediation of contamination in accordance with applicable Sonoma County, Regional Water Quality Control Board, the Department of Toxic Substances Control, and state standards.	
Hydrology and Water Quality			
Impact 4.8-1 The construction and operation of transportation improvements in the 2009 CTP, particularly new and expanded roadways, could degrade existing water quality or violate water quality standards or waste discharge requirements. Urban runoff could include discharge of sediments, non-sediment solids, nutrients, and other pollutant sources.	**MM 4.8-1a**	Subsequent projects shall comply with Caltrans, County, and city grading and erosion control requirements and other associated requirements, as applicable. Project sponsors shall prepare and implement, as necessary, a Stormwater Pollution Prevention Plan (SWPPP), as required by the North Coast Regional Water Quality Control Board or the Bay Area Regional Water Quality Control Board. The SWPPP shall be consistent with the Manual of Standards for Erosion and Sedimentation Control by the Association of Bay Area Governments, the California Stormwater Quality Association, Stormwater Best Management Practice Handbook for Construction, policies, recommendations, and requirements of the local urban runoff program, and the recommendations of the RWQCB, as appropriate. Typical components of a SWPPP may include but are not limited to the following: • To the extent feasible, excavation and grading activities shall be performed between April 15 and October 15. If excavation does occur during the wet season, the project sponsor shall regulate storm runoff from the construction area through a stormwater management/erosion control plan. This may include on-site silt traps and basins with multiple discharge points to natural drainages and energy dissipaters. Loose material stockpiles shall be covered and runoff shall be diverted away from exposed soil. If work stops due to rain, a positive grading away from slopes shall be provided to carry the surface runoff to areas where runoff can be controlled, such as temporary silt basins. Post-grading, erosion protection shall be provided on cut and fill slopes, and revegetation shall be facilitated and initiated as soon after completion of grading as possible and before October 15. Revegetation shall emphasize ~~drought tolerant perennial~~ native vegetation. • Temporary erosion control measures, which may include hydroseeding or alternative methods such as straw, straw with tackifier, or erosion control blankets instead of seeding, shall be provided until perennial revegetation occurs. Hazardous	**Less than significant**

Impact	Mitigation Measures	Significance After Mitigation
	materials used on construction sites shall be stored in covered containers and protected from rain and runoff. Spill cleanup materials shall be readily available at all construction sites, and employees shall be trained in spill prevention and cleanup. • ~~BMPs such as those described above shall be in place and operational prior to major earthwork.~~ BMPs shall be in place and operational prior to any construction activities. Post-construction. The construction phase facilities shall be maintained regularly and be cleared of accumulated sediment as necessary. SWPPP(s) for projects adjacent to or within drainages shall also incorporate the following erosion control criteria: • Except when necessary for construction crossings or barriers, construction equipment shall not be operated in flowing water. • Stream diversion structures shall be designed to preclude accumulation of sediment. • Barriers shall be constructed to prevent the discharge of turbid water in excess of specified limits when work areas are adjacent to live streams. • Riparian vegetation shall be removed only when necessary. • Construction material shall not be deposited where it could be eroded and carried to the stream by runoff or stream flows. **MM 4.8-1b** If a proposed project is located within or adjacent to a water body that requires a Streambed Alteration Agreement, one shall be completed by the project sponsor prior to initiation of any ground-disturbing activities. **MM 4.8-1c** If a proposed project is located within or adjacent to a water body within the jurisdiction of the San Francisco Bay Conservation and Development Commission (BCDC), the project must be in compliance with both the McAteer-Petris Act and the BCDC San Francisco Bay Plan. **MM 4.8-1d** In compliance with the Clean Water Act, any project which could potentially discharge pollutants into any water supply from any point source shall require National Pollutant Discharge Elimination System (NPDES) permits.	

Impact	Mitigation Measures		Significance After Mitigation
	MM 4.8-1e	Where specific projects are located within or adjacent to a water body that is under the jurisdiction of the Regional Water Quality Control Board, the projects shall implement the following measures: • Include construction BMPs specifically targeted towards retaining sediment onsite, preventing erosion of streambanks and pollution from construction vehicles, and collecting and treating storm water runoff onsite. • Utilize staging areas for vehicles that are removed from riparian areas and all construction should occur during the dry season. If such measures cannot be taken, the individual project should be required to analyze alternatives and provide mitigation measures for adverse impacts. • Where feasible, avoid the removal of riparian vegetation. If not feasible, the individual project shall be required to demonstrate a plan for revegetation including a post-construction monitoring plan to determine the success of revegetation efforts. Monitoring and maintenance plans shall also be in place to ensure that runoff treatment mechanisms such as sediment basins or silt fences continue to function properly. Runoff from all areas of new impervious surfaces should be mitigated for potential impacts to receiving water quality and flow. • Where feasible, specific projects shall incorporate Low Impact Development techniques to implement Mitigation Measure 4.8-1e.	
Impact 4.8-2 The transportation improvements in the 2009 CTP would not substantially deplete groundwater supplies or interfere substantially with groundwater recharge.	**None required.**		**Less than significant**
Impact 4.8-3 The transportation improvements in the 2009 CTP could alter existing drainage patterns or substantially increase the rate or amount of surface runoff. This could contribute runoff water that exceeds the capacity of	**MM 4.8-3a**	In implementing subsequent projects, project sponsors shall comply with design guidelines established by the California Stormwater Best Management Practice Handbook for New Development and Redevelopment or other methods acceptable to Caltrans, the County, and/or cities, as applicable, to minimize the increase in volume and rate of stormwater runoff and amount of pollutants entering the storm drains. Existing pervious surfaces shall be	**Less than significant**

Impact	Mitigation Measures		Significance After Mitigation
existing or planned stormwater drainage systems and result in flooding.		preserved to the extent feasible to minimize increases in stormwater runoff and rates. Additional measures may include construction of detention basins or structures that will delay peak flows and reduce flow velocities, or expansion and restoration of wetlands and riparian buffer areas and use of swales that serve as open drain systems to manage surface water runoff.	
	MM 4.8-3b	Subsequent projects shall comply with Caltrans, County, or city stormwater quality control measures required under their applicable NPDES permit requirements for stormwater discharges, as applicable.	
	MM 4.8-3c	All bridges and culverts shall be designed so that water is adequately conveyed throughout project-specific sites. Adequate conveyance can be confirmed by the project applicant preparing and submitting a drainage plan to the appropriate permitting agency. The drainage plan shall depict the specifics of the project drainage system. The drainage plan shall demonstrate that the system components are adequately sized and configured to address peak runoff and protect against storm events as required by the applicable agency.	
Impact 4.8-4 The 2009 CTP will not place roadways or other structures within a 100-year flood hazard area that could impede or redirect flood flows.	**None required.**		**Less than significant**

Impact	Mitigation Measures	Significance After Mitigation
Land Use		
Impact 4.9-1 Implementation of the transportation improvements in the proposed 2009 CTP would generally be consistent with existing local land use plans and policies, given the bottom-up planning process used to develop SCTA's transportation priorities. As such, the CTP is not expected to cause any land use disruption or displacement and would generally bring together communities by encouraging policies and projects that better integrate land use and transportation planning.	Although this impact is less than significant, consistency with local land use plans and policies can be further assured through implementation of the following recommended mitigation measure: **MM 4.9-1** During the project design and environmental review phase, lead agencies for proposed CTP projects shall consult with the appropriate land use agency(ies) to ensure consistency with local land use policies, particularly for Caltrans projects. If any inconsistency is identified, the project shall be designed and engineered to assure consistency with local land use policies.	**Less than significant**
Impact 4.9-2 The proposed 2009 CTP does not include projects that are located within habitat conservation plans. As such, the CTP would not conflict with any applicable habitat conservation plan or natural community conservation plan.	**None required.**	**Less than significant**
Impact 4.9-3 Implementation of the proposed 2009 CTP could result in the conversion of Prime Farmland, Unique Farmland, or Farmland of Statewide Importance to transportation-related uses. Without proper mitigation, this could lead to conflicts with zoning for agricultural use or conflicts with Williamson Act contracts.	There are four proposed projects in the 2009 CTP that are located on or directly adjacent to areas designated as important agricultural resources. While the amount of agricultural lands that would potentially be impacted by these projects is unclear, any relative impact on the county's regionally significant agricultural lands is considered less than significant. Nevertheless, if particular projects would eliminate significant farmlands, the following measure is recommended to address these circumstances: **MM 4.9-3** Project sponsors shall perform project-specific mitigation measures prior to certification of environmental documentation that would minimize the conversion of farmland. Mitigation measures that may be considered include: • Placement of berms or walls and fencing for the reduction of conflicts between transportation and farming uses. • Corridor realignment to avoid farmland or direct impacts to	**Less than significant**

Impact	Mitigation Measures		Significance After Mitigation
		farmland. • Setbacks to avoid farmland encroachment. • Where conversion of farmlands of concern cannot be avoided, require (at minimum) long-term preservation of one acre of existing farmland of equal or higher quality for each acre of state-designated Prime Farmland, Farmland of Statewide Importance, and Unique Farmland that would be converted to non-agricultural uses. This protection may consist of the establishment of farmland easements or other similar mechanisms.	
Noise			
Impact 4.10-1 2009 CTP projects will generate short-term construction-generated noise that could result in a substantial temporary increase in ambient noise and groundborne vibration levels at nearby noise-sensitive land uses. This could result in the exposure of persons to or generate noise levels in excess of standards established in local general plans or noise ordinance or applicable standards of other agencies.	**MM 4.10-1**	Noise and groundborne vibration-reduction measures shall be identified and incorporated into the construction activities of subsequent projects under the CTP to reduce potentially significant impacts to nearby noise-sensitive land uses, to the extent feasible. Such measures may include, but are not necessarily limited to, the following: • Construct temporary sound barriers to shield noise-sensitive land uses. • Locate noise-generating stationary equipment (e.g., power generators, compressors) at the farthest practical distance from nearby noise-sensitive land uses. • Phase demolition, earth-moving, and ground-impacting operations so as not to occur in the same time period. • Use equipment noise-reduction devices (e.g., mufflers, intake silencers, and engine shrouds) in accordance with manufacturers' recommendations. • Substitute noise-generating equipment with quieter equipment or procedures. For instance, In comparison to impact piles, drilled piles or the use of a sonic or vibratory pile driver are quieter alternatives where geological conditions would permit their use. • Limit noise-generating construction activities to the least noise-sensitive daytime hours.	**Less than significant**

Impact	Mitigation Measures		Significance After Mitigation
Impact 4.10-2 Proposed roadway improvements in the CTP, particularly new, realigned, or expanded roadways, could cause a substantial increase in ambient noise in areas that would exceed standards established in local general plans or noise ordinances and increase local noise levels by three or more dBA over existing conditions.	**MM 4.10-2**	Project sponsors for proposed CTP projects shall analyze individual projects, in accordance with applicable CEQA and/or NEPA requirements, for potential noise and groundborne vibration impacts. Where significant impacts are identified, mitigation measures shall be implemented to reduce identified adverse noise impacts. Such measures may include, but are not necessarily limited to, the following: • Construction of acoustic barriers to shield nearby noise-sensitive land uses. The specific heights, lengths, and feasibility of acoustic barriers will be determined on a project-by-project basis and will involve Caltrans in the determination of feasibility for such barriers along state highways. • Site/project redesign and use of buffers to ensure that future development is compatible with transportation facilities. • Changes to transportation facility design. Examples may include changes in proposed roadway alignment or construction of roadways so that they are depressed below grade of nearby sensitive land uses to create an effective barrier between the roadway and sensitive receptors. • Improvement of the acoustical insulation of dwelling units where setbacks and sound barriers do not sufficiently reduce noise. • Use of low-noise pavements (e.g., rubberized asphalt).	**Significant and unavoidable**
Impact 4.10-3 The proposed SMART commuter rail service improvements would permanently increase ambient noise levels along the railroad right-of-way from periodic passing trains. However, noise impacts would not exceed FTA's Severe Noise Impact Criteria and local noise standards in general plans or noise ordinances.	**None required.**		**Less than significant**
Impact 4.10-4 Proposed rail service on the railroad right-of-way will require use of train horns that will produce substantial	**No mitigation is available.**		**Significant and unavoidable**

Impact	Mitigation Measures		Significance After Mitigation
increases in ambient noise that would exceed applicable noise exposure standard of 60 dBA Ldn.			
Impact 4.10-5 The proposed CTP will create permanent increases in groundborne vibration from commuter rail operations that would expose persons to minimal groundborne vibration or groundborne noise levels that are less than FTA's vibration impact criterion of 0.01 inches per second root-mean-square (RMS) vibration velocity. While the vibration velocity impacts would be perceptible to humans, they would not be considered bothersome.	**None required.**		**Less than significant**
Impact 4.10-6 The proposed 2009 CTP would not include projects located within an airport land use plan or private airstrip that would expose people residing or working in the project area to increased noise levels. Further, while proposed projects would be located in the vicinity of existing airports, they would not expose people to substantially increased noise levels.	**None required.**		**Less than significant**
Population and Housing			
Impact 4.11-1 Implementation of the transportation improvements proposed in the 2009 CTP could potentially result in the displacement of existing residences or businesses and result in the need to construct additional housing units	**MM 4.11-1**	Prior to the approval of any CTP project that results in displacement of population, housing, or jobs, the project sponsor shall evaluate alternate route alignments and transportation facilities that minimize the displacement of homes and businesses to the maximum extent feasible. If the displacement of residences is warranted, the project sponsor shall coordinate with the Sonoma County Community Development Commission and implement a relocation program for persons that would be displaced by the proposed project, in	**Less than significant**

Impact	Mitigation Measures	Significance After Mitigation
in the county over the planning horizon.	compliance with the California Relocation Assistance Law.	
Impact 4.11-2 The transportation projects included in the Comprehensive Transportation Plan will not induce substantial population growth in an area. The CTP will not directly result in new development of housing or employment centers or extend roads or other infrastructure that would expose substantial new areas to unplanned growth.	**None required.**	**Less than significant**
Public Services		
Impact 4.12-1 Implementation of the proposed 2009 CTP could pose demands on future public services, such as police and fire/emergency personnel. However, these demands are expected to be minimal and unlikely to require the construction of additional public facilities in the county.	**None required.**	**Less than significant**
Impact 4.12-2 Implementation of the proposed 2009 CTP would result in new SMART commuter rail service and freight service that could impact emergency response times.	**None required.**	**Less than significant**
Impact 4.12-3 ~~Construction of capital improvements in the proposed CTP will produce solid waste that will not impact the existing Central Landfill operated by Sonoma County.~~ Construction debris would need to be transported to	**MM 4.12-3a** If a CTP project requires solid waste collection, the lead agency will ensure that the existing solid waste disposal facility(ies) can accommodate the demand for disposal. **MM 4.12-3b** The construction site contractor for a CTP project shall coordinate with Sonoma County's Recycling Coordinator to ensure that source reduction techniques and recycling measures are incorporated into	**Less than significant**

Impact	Mitigation Measures		Significance After Mitigation
other facilities outside of Sonoma County.		project construction.	
	MM 4.12-3c	Lead agencies for CTP projects shall integrate green building measures into project design, such as those identified in the U.S. Green Building Council's Leadership in Energy and Environmental Design, Energy Star Homes, GreenPoint Rated Homes, and the California Green Builder Program. These measures would include the following: • Reuse and minimization of construction and demolition (C&D) debris and diversion of C&D waste from landfills to recycling facilities. • The inclusion of a waste management plan that promotes maximum C&D diversion. • Source reduction through (1) use of materials that are more durable and easier to repair and maintain, (2) design to generate less scrap material through dimensional planning, (3) increased recycled content, (4) use of reclaimed materials, and (5) use of structural materials in a dual role as finish material (e.g., stained concrete flooring, unfinished ceilings). • Reuse of existing structure and shell in renovation projects. • Design for deconstruction without compromising safety. • Design for flexibility through the use of moveable walls, raised floors, modular furniture, moveable task lighting, and other reusable building components. • Development of indoor recycling program and space.	
Energy			
Impact 4.13-1 Implementation of the 2009 CTP would not directly cause increases in energy consumption from the transportation sector. ~~However, in addressing current and projected mobility challenges,~~ Though the 2009 CTP would accommodate planned growth in Sonoma County, projected ~~that will substantially increase~~ consumption of	**MM 4.13-1a**	Project sponsors shall promote green building standards in new or expanded transportation-related facilities (e.g., transit maintenance facilities) that can reduce energy use, rely on renewable energy resources, and reduce waste generation and water usage.	~~**Significant and unavoidable.**~~ **Less than significant.**
	MM 4.13-1b	Project sponsors shall promote use of low-energy technologies in roadway and transit facilities (e.g., use light emitting diodes in street lights, rail switching facilities).	
	MM 4.13-1c	As transit operators invest in new or expanded bus and rail service, they shall consider investments in alternative fuel buses and rolling stock (e.g., hybrid electric drivetrains) that consume less	

Impact		Mitigation Measures	Significance After Mitigation
nonrenewable petroleum-based products like gasoline and diesel fuel are projected to decrease over existing conditions by 2035. By 2035, motor vehicles would consume 68,728 ~~159,000~~ fewer ~~more~~ gallons of gasoline and 11,286 ~~5,000~~ more gallons of diesel fuel per day than under existing conditions. This represents a 12 ~~20~~ percent decrease in gasoline consumption and a 16 ~~7~~ percent increase in diesel fuel. In addition, proposed commuter rail service and freight service on the SMART corridor will consume ~~916,000 gallons of diesel fuel daily~~ 30 billion BTUs of energy annually starting in 2014; however, any increases in diesel fuel for locomotives is expected to be more than offset by reductions in vehicle use from SMART riders. The CTP's cumulative ~~is~~ impact on energy consumption is **less than significant** ~~and unavoidable~~**.**		nonrenewable fossil fuels.	
Impact 4.13-2 Construction of capital roadway and transit improvements in the 2009 CTP will involve use of off-road vehicles and equipment that will consume gasoline, diesel, electricity, natural gas, and other nonrenewable energy sources. These increases in energy consumption will generally be consistent with local general plan policies in conservation elements and other policy plans and are not expected to be substantial.	**MM 4.13-2**	Project sponsors of capital projects shall evaluate the energy demands of construction activities and incorporate best available control technology and best management practices to the extent practicable. This includes the following types of measures that can reduce energy consumption during project construction: • Reduce vehicle trips for construction materials to and from construction sites; • Limit idling of construction equipment engines to less than 15 minutes; • Require that all construction engines be properly tuned; • Encourage ridesharing by construction personnel traveling to and from construction sites; • Plan construction actives to minimize the use of on-site	**Less than significant**

Impact	Mitigation Measures	Significance After Mitigation
	construction equipment; and • Require off-road vehicles and equipment at construction sites to operate on alternative fuels.	
Cumulative Impacts		
Impact 5.0-1 Implementation of the 2009 CTP would help decrease emissions of carbon dioxide equivalents (CO2e) from motor vehicles in 2035 by almost 550,000 pounds per day over existing (2005) conditions. While any emissions of GHG from the transportation sector contribute to the significant issues of global climate change, the CTP's contribution to a net reduction in GHG emissions is considered to be beneficial.	**MM 5.0-1a** SCTA shall consider working in partnership with the Bay Area Air Quality Management District to conduct demonstration projects in Sonoma County that help reduce GHG emissions. This would help implement Bay Area Ozone Strategy TCM-17. **MM 5.0-1b** SCTA shall work in partnership with appropriate stakeholders (e.g., Bay Area Air Quality Management District, Sonoma County Alliance, Leadership Institute for the Ecology and the Economy) to develop public information campaigns to educate residents, merchants, and the traveling public about transportation strategies that can help reduce GHG emissions. **MM 5.0-1c** SCTA shall encourage project sponsors to design transportation-related improvements such as transit buildings and facilities to be certified by the Leadership in Energy and Environmental Design program (LEED). **MM 5.0-1d** SCTA shall work with local governments to limit idling time for commercial vehicles, including delivery and construction vehicles. **MM 5.0-1e** SCTA shall work with project sponsors to develop standards for construction management, including use of recycled materials or low-carbon products. **MM 5.0-1f** SCTA shall work with MTC, BCDC, and other partners to address vulnerability of the county's transportation infrastructure and appropriate adaptation strategies to protect those transportation resources that are likely to be impacted by sea level rise and flooding associated with global climate change. Examples could include, but not be limited to: • Engineering designs for new transportation projects shall demonstrate that they have factored in sea level rise and potential increases in storm surge inundation, and are budgeting for and already incorporating mitigation measures to adapt to projected sea level rise and storm surge. These mitigation measures should consider the effects on Bay and coastal zone resources and avoid or reduce risk to the infrastructure and the region. • For transportation projects that increase the capacity of existing infrastructure, project sponsors shall demonstrate they have investigated the vulnerability of their existing facilities to sea level rise and potential increases in storm surge inundation, and are budgeting for and already incorporating mitigation measures to adapt to projected sea level rise and storm surge. These mitigation measures should consider the effects on Bay	**Beneficial**

Impact	Mitigation Measures	Significance After Mitigation
	and coastal zone resources and avoid or reduce risk to the infrastructure and the region. **MM 5.0-1g** Where applicable, project sponsors for subsequent projects under the 2009 CTP shall include mitigation measures to reduce impacts related to significant storm events, sea level rise, and flooding resulting from global climate change.	
Impact 5.0-2 Implementation of the 2009 CTP would result in construction of capital improvements that would emit carbon dioxide and other greenhouse gas emissions. While the continuation of construction activities over time will contribute GHG emissions to existing climate change, construction-related emissions would be expected to decrease per capita over time as low-carbon fuel standards and other climate change measures consistent with AB 32 and other State mandates are implemented. In addition, these impacts would be short-term in duration and as such, this impact is considered to be less than significant.	**MM 5.0-2a** SCTA shall work with the BAAQMD and other appropriate stakeholders to develop guidance and/or requirements to use low-carbon emitting techniques or equipment in the construction process for capital improvements included in the 2009 CTP.	Less than significant
Impact 5.0-3 Implementation of the 2009 CTP would help decrease emissions of carbon dioxide equivalents (CO2e) in 2035 by almost 550,000 pounds per day over existing (2005) conditions. This would be a 21.6 percent reduction in GHG emissions by 2035, which is generally consistent with AB 32's mandate to reduce GHG emissions to 1990 levels by 2020 (equivalent to an approximately 15 percent reduction in GHG from today's levels) as well as local efforts in Sonoma County. This impact is	**MM 5.0-3** SCTA shall work with appropriate stakeholders provide funding for future transportation plans and projects are consistent with AB 32 implementation standards and guidelines once they are developed.	Less than significant

Impact	Mitigation Measures	Significance After Mitigation
considered to be less than significant.		

3.0 Comments and Responses to Comments on the Draft EIR

3.1 INTRODUCTION

This section of the Final EIR includes copies of comments (letters, e-mails, and hearing transcripts) received during the public comment period on the Draft EIR, along with written responses to those comments. All submittals have been assigned a letter or number code as shown in the list of commenters provided in Section 3.2, below. Individual commenters seeking responses to their comments should use the list provided to identify the alphabetical or numerical code assigned to their comments and then proceed to that place in the document. The California Environmental Quality Act (CEQA) requires that responses be provided to substantive comments on the environmental analysis

No new significant environmental impacts or issues, beyond those already covered in the Draft EIR (DEIR) for the 2009 Comprehensive Transportation Plan (CTP), were raised during the comment period, and the Sonoma County Transportation Authority, acting as lead agency, directed the preparation of responses to the Draft EIR comments presented herein. Responses to comments received during the comment period do not involve any new significant impacts or "significant new information" that would require recirculation of the Draft EIR pursuant to CEQA Guidelines Section 15088.5.

3.2 LIST OF COMMENTERS

The following individuals and representatives of organizations and agencies submitted written comments on the Draft EIR.

Letter	Individual or Signatory	Affiliation	Date
A	Lisa Carboni	Department of Transportation	June 4, 2009
B	John Short	California Regional Water Quality Control Board	June 1, 2009
C	Terry Roberts	Governor's Office of Planning and Research	June 8, 2009
D	Alex Lee	Department of Toxic Substances Control	May 27, 2009
E	Brenda L. Tomaras	Lytton Rancheria of California	June 19, 2009
F	Nancy Adams	City of Santa Rosa Public Works Department	June 23, 2009
G	Joanne Parker	Santa Rosa City Bus	June 23, 2009
H	Michael G. Rea	West County Transportation	May 18, 2009
I	Peter Chamberlin	Town of Windsor	June 17, 2009
J	Vincent Marengo	City of Petaluma	June 18, 2009
1	Steve Birdlebough	Sierra Club	June 22, 2009
2	Ann Hancock, Christine Culver, Willard Richards	Climate Protection Campaign , Bicycle Coalition Sonoma County Transportation and Land Use Coalition	June 22, 2009
3	David Schonbrunn	Transportation Solutions Defense and Education Fund	June 20, 2009
4	Grace C. Schulman	EarthKeeping Ministry	June 23, 2009
5	Jenny Bard, Shan Magnuson	American Lung Association, Sonoma County Asthma Coalition	June 15, 2009

Letter	Individual or Signatory	Affiliation	Date
Public Hearing	**Individual or Signatory**	**Affiliation**	**Date**
6	Various	May 13 Public Meeting, 3:00 to 4:30	May 13, 2009
7	Various	May 13 Public Meeting, 5:30 to 7:00	May 13, 2009
8	Robert B. Tanner	Citizen	May 13, 2009
9	Willard Richards	Citizen	June 8, 2009

3.3 APPROACH AND FORMAT TO COMMENTS AND RESPONSES

State CEQA Guidelines 15088 requires that lead agencies evaluate all comments on environmental issues received on the Draft EIR and prepare written responses. The written response must address the significant environmental issue raised and must provide a detailed response, especially when specific comments or suggestions (e.g., additional mitigation measures) are not accepted. In addition, the written response must be a good faith and reasoned analysis. However, lead agencies need only to respond to significant environmental issues associated with the project and do not need to provide all the information requested by commenters, as long as a good faith effort at full disclosure is made in the EIR (State CEQA Guidelines 15204).

State CEQA Guidelines 15204 recommends that commenters focus on the sufficiency of the Draft EIR in identifying and analyzing the possible impacts on the environment and ways in which the significant effects of the project might be avoided or mitigated. State CEQA Guidelines 15204 also notes that commenters should provide an explanation and evidence supporting their comments. Pursuant to State CEQA Guidelines 15064, suggested physical effects on the environment shall not be considered significant in the absence of substantial evidence.

State CEQA Guidelines 15088 also recommends that where response to comments results in revisions to the Draft EIR, those revisions be noted as a revision to the Draft EIR or in a separate section of the Final EIR.

Several comment letters included similar comments on issues associated with the project and the Draft EIR. In order to streamline the Final EIR, master responses have been prepared for these similar comments and address the following issue areas:

- DEIR Process and Review Period
- Jurisdiction and role of SCTA
- Commitment of Funds
- Program EIR / Level of Detail
- Climate Change and Greenhouse Gas Emission Impacts
- Adequacy of Alternatives Analysis

Following the master responses, written comments on the Draft EIR are reproduced, along with responses to those comments. To assist in referencing comments and responses, the following coding system is used:

Public agency comment letters are coded by letters and each issue raised in the comment letter is assigned a number (e.g., Comment Letter A, comment 1: A-1).

Individual and interest group comment letters are coded by numbers and each issue raised in the comment letter is assigned a number (e.g., Comment Letter 1, comment 1: 1-1).

Where changes to the Draft EIR text result from responding to comments, those changes are included in the response and demarcated with revision marks (underline for new text, ~~strike-out~~ for deleted text). Comment-initiated text revisions to the Draft EIR and minor staff-initiated changes are also provided and are demarcated with revision marks in Section 4.0, Minor Revisions to the Draft EIR, of the Final EIR.

3.4 MASTER RESPONSES

3.4.1 DEIR PROCESS AND REVIEW PERIOD

CEQA requires a public review period of at least 45 days for a DEIR that is submitted to the State Clearinghouse for review by state agencies (Pub. Res. Code, Section 21091). The CEQA Guidelines clarify that the public review period for a Draft EIR should not be longer than 60 days “except for unusual circumstances” (State CEQA Guidelines Section 15105(a)). In recognition of the size of the Draft EIR (658 pages) and the expressed desire of a number of public interest groups to review the DEIR in detail, the review period was extended for an additional 21 days to June 23, 2009, for a total review period of 66 days.

3.4.2 JURISDICTION AND ROLE OF SCTA

A number of comment letters question why the proposed 2009 CTP includes policies and that encourage or support, rather than compel, certain actions. In many instances, the comments urge the SCTA to adopt actions and/or mitigation measures in the Draft EIR that will accomplish the intended purpose of a particular policy or environmental benefit (e.g., greenhouse gas emission reductions) that is not within the scope of the SCTA’s authority. The proposed 2009 CTP contains goals, objectives, and policies that establish future SCTA policy regarding many different issues and problems related to transportation planning. These goals, objectives, and policies will guide future SCTA, County and city decision makers regarding transportation projects and programs and land use matters. However, the SCTA does not control or have jurisdiction over many of the decisions that affect and are affected by its future planning. For example, state agencies make decisions about future transportation funding for transit. Local governments (i.e., Sonoma County and the associated cities) control land use decisions and parking mechanisms through their general plans, zoning and development requirements. The federal and state governments can address fuel standards and provide incentives for technological improvements. As a result of these and other jurisdictional factors, many of the proposed 2009 CTP goals, objectives, and policies reflect these limitations on the SCTA’s authority and provide guidance for other agencies in making their decisions. Where the SCTA does not have the decision making authority to require or mandate a policy or mitigation measure, terms such as “encourage”, “support”, or “request” are utilized in order to properly reflect the scope of the SCTA’s jurisdictional authority and the SCTA’s intent that the policy be implemented by the appropriate jurisdiction.

The Draft EIR analyzes the 2009 CTP objectives, policies and strategic projects and proposes mitigation measures to reduce potentially significant impacts to below a level of significance. In certain instances the SCTA is limited within to its jurisdictional authority and may not be able to act upon or implement suggested actions and measures outside of its scope. The Draft EIR is required to recommend mitigation measures to address physical environmental impacts that can be feasibly implemented. This is consistent with CEQA's definition of "feasible":

> *"Feasible" means capable of being accomplished in a successful manner within a reasonable period of time, taking into account economic, environmental, legal, social, and technological factors. (State CEQA Guidelines Section 15364)*

The SCTA describes Goals, Objectives and Policies in the proposed 2009 CTP that were developed through an extensive public outreach process described in the Public Outreach Report (Appendix B) of the proposed 2009 CTP. In addition, performance measures, or benchmarks were used to assess the modeling scenarios. Development of the performance targets is described in Appendix C. Research & Technical Documents v.i. Sonoma County Travel Model Update & Analysis of the proposed 2009 CTP.

SCTA approval of the objectives for the proposed 2009 CTP does not constitute a legal mandate, nor do they constitute thresholds of significance under CEQA. CEQA does not require thresholds of significance to be the same as the proposed plan's performance objectives.

This said, SCTA takes the Goals, Objectives and Policies of the proposed 2009 CTP very seriously. The Goals are as follows.

- Maintain the System
- Relieve Congestion
- Reduce Emissions
- Plan for Safety & Health
- Specifically, the proposed 2009 CTP strives to
- Improve Countywide PCI to 80 by 2035, with a minimum road PCI of 70 by 2035.
- Reduce person hours of delay 20% below today's levels (2005) by 2035.
- Reduce GHG emissions to 25% below 1990 levels by 2015, and 40% below 1990 levels by 2035.
- Increase safety by minimizing traffic related injuries and fatalities and emphasize health aspects of transportation planning strategies.

These are ambitious goals, which SCTA endeavors to meet through the improvements named in the proposed 2009 CTP. The total cost of these projects is many times greater the funding available, though SCTA includes projects and programs that may be eligible for any, as yet unidentified, funding that may become available in the future. In addition, though the SCTA will promote these goals by whatever means it can, some of the solutions are beyond SCTA's authority (e.g. fuel standards, roadway pricing). In these cases SCTA will fulfill its role by vigorously advocating to the proper authorities.

3.4.3 COMMITMENT OF FUNDS

Commenters have suggested shifting funds between projects to better support currently unfunded projects that could further reduce the plan's environmental impacts, for example, by lowering VMT. Such an option is generally difficult, if not impossible, as regional, state and federal requirements often specify certain funds must be spent on certain types of projects.

For projects that include voter-approved transportation funds (Measure M, Proposition 1B, etc.) the ability to shift funds to other projects is extremely limited, as the expenditure plans for the ballot measures approved by the voters committed the funds to certain projects or classes of projects. A substantial change in the way funds are allocated among projects identified in the expenditure plan would thwart the will of the voters.

Passed by the voters in November 2004, the Traffic Relief Act for Sonoma County (Measure M) funds the HOV lane on Hwy 101, specific road and bicycle projects, maintenance, bus transit and the Sonoma Marin Rail Transit (SMART). The Act provides for a ¼ cent sales tax to fund the specific programs and projects detailed in the Expenditure Plan. Measure M received more than the required two-thirds vote.

The Measure M expenditure plan, once adopted by the voters, cannot be modified by the SCTA except to account for unexpected revenues or to take into consideration unforeseen circumstances (see Pub. Util. Code, § 180207). Similarly, the Proposition 1B Corridor Mobility Improvement Account (CMIA) funds specific types of projects, as determined by the voters and the California Transportation Commission. CMIA funding was awarded to eligible congestion reducing projects across the State, including construction of the HOV lane on Highway 101 in Sonoma County. SCTA does not have the authority to reassign those funds to another project, and if the project does not progress, funding will be reassigned by the state to another similar project elsewhere in California.

In addition to fund source limitations, the list of projects included in Measure M and the proposed 2009 CTP reflects local priorities largely in place since the 2001 Countywide Transportation Plan was developed in concert with the local governments of Sonoma County and with extensive public input. The SCTA accepts local priorities as foremost in planning and programming for all modes of transportation.

Many transportation projects require extensive planning and coordination of a variety of fund sources. Abrupt change of priorities and abandonment of projects would result in the loss of the investment and sunk costs and delays in delivery increase costs.

3.4.4 PROGRAM EIR / LEVEL OF DETAIL

Many comment letters question the level of detail and scope of analysis of the DEIR. Others request that the DEIR add more detailed analysis of the impacts of specific projects. As stated in the Introduction Section of the DEIR (Section 2.0, Introduction and Study Approach), the DEIR is a Program EIR under Section 15168 of the CEQA Guidelines and evaluates the environmental impacts of the proposed project on a general level rather than a project-specific level (see DEIR pages 2.0-1 through -3).

CEQA and the State CEQA Guidelines set out the different circumstances in which Program EIRs and Project EIRs are appropriate. (See Pub. Res. Code, Sections 21068.5, 21093.) Under Section 15168 of the State CEQA Guidelines, a Program EIR is an EIR which may be prepared on a series of actions that can be characterized as one large project and are related ... in connection with issuance of rules, regulations, plans, or other general criteria to govern the conduct of a continuing program. The State CEQA Guidelines list some of the advantages of a Program EIR, including that it allows the Lead Agency to “consider broad policy alternatives and programwide mitigation measures at an early time when the agency has greater flexibility to deal with basic problems or cumulative impacts. . . .” (CEQA Guidelines, Section 15168[b][4])

The most common type of EIR is a Project EIR, which examines the environmental impacts of a site-specific development project. A program level analysis for a transportation plan, on the other hand, considers the future land uses and transportation projects and programs that may occur over the lifetime of the plan. The program level analysis assesses the cumulative and associated long range impacts of those projects and programs. One of the primary purposes of a Program EIR is to ensure consideration of cumulative impacts that might be overlooked in a case-by-case analysis (see CEQA Guidelines, Section 15168[b]). Thus, the Program EIR provides a framework within which future and more detailed planning for the future specific projects may be reviewed, and identifies areas that may require additional site-specific environmental analysis at subsequent stages of project implementation. State CEQA Guidelines Section 15146 acknowledges that an EIR on a construction project will necessarily be more detailed in the specific effects of the project than will be an EIR on the adoption of a plan because the effects of the construction can be predicted with greater accuracy.

When a Program EIR has been prepared and certified and a subsequent activity in the program or plan is proposed for development, the activity is examined to determine whether an additional environmental document must be prepared. (CEQA Guidelines, § 15168(c).) If an agency finds that no new effects could occur or no new mitigation measures would be required, the agency may approve the activity as being within the scope of the Program EIR, and no new environmental document would be required. (CEQA Guidelines, § 15168(c)(2).) The Program EIR can be used to simplify the subsequent environmental review for later activities in the program, for example by incorporating relevant analysis from the Program EIR by reference and by focusing the subsequent document on effects which had not been considered before. (CEQA Guidelines, § 15168(d).)

The proposed 2009 CTP EIR may serve as a "first tier" CEQA document (Pub. Res. Code, Section 21093; State CEQA Guidelines Section 15152). First tier documents are general in scope and typically discuss broad environmental issues that affect a large geographic area, such as an entire county. Mitigation measures and alternatives are also correspondingly more general in nature than typical mitigation measures and alternatives for a specific development project. Subsequent environmental reviews are narrower in scope and address site specific details. First tier documents are appropriate for long range planning documents, while project level reviews typically address specific project impacts. In preparing a first tier EIR, such as for a transportation plan, the lead agency must still identify the reasonably foreseeable significant environmental impacts of the proposed plan and may not defer analysis to a later tier document (State CEQA Guidelines Section 15152[b]). However, the level of detail in a first tier EIR need not be greater than the level of detail in the plan being analyzed. (Ibid.)

Cumulative impacts are described in Section 5.0 (Cumulative Impacts) of the DEIR. As noted in that section, with respect to the cumulative impacts of transportation projects and programs that could occur under the proposed 2009 CTP, the geographic area of concern is primarily Sonoma County, although the DEIR considers regional effects of counties adjoining Sonoma County (see DEIR page 5.0-2). Consistent with CEQA, the discussion of cumulative impacts is guided by standards of practicality and reasonableness.

3.4.5 CLIMATE CHANGE AND GREENHOUSE GAS EMISSION IMPACTS

Several comment letters expressed concerns about the climate change and greenhouse gas emission impacts associated with implementation of the CTP, specifically:

- Conflict between proposed CTP Policy 3 and the Sonoma County Community Climate Action Plan and the greenhouse gas emission estimates and analysis conclusions for year 2035 identified in the Draft EIR.
- Need to better address increases in vehicle miles traveled and associated increases in energy use.
- Need for the Draft EIR and the proposed CTP to provide additional mitigation measures/provisions to further mitigate increases in greenhouse gas emissions consistent with the Sonoma County Community Climate Action Plan and other recommended measures from comment letters.

The discussion bellows responds to these issue points regarding climate change and greenhouse gas emissions.

It is important to recognize that the Draft EIR identifies the proposed 2009 CTP would result in reduced greenhouse gas emissions than what occurred under year 2005 conditions (see Draft EIR pages 5.0-21 through -24). An improved circumstance in the existing environment is not considered a significant environmental impact under CEQA. Specifically, State CEQA Guidelines Section 15126.2 identify that significant environmental effects are determined by changes caused by a project on the existing physical conditions of the environment. In this circumstance, greenhouse gas emissions will be less with implementation of the 2009 CTP in year 2035 than they were in 2005. Thus, the greenhouse gas beneficial impact determination in the Draft EIR is accurate and consistent with the requirements and intent of CEQA.

Conflicts with Proposed CTP Policy 3 and Sonoma County Community Climate Action Plan

Comment letters received by SCTA expressed concern that information in the Draft EIR demonstrates that the proposed CTP would not meet CTP Policy 3 that is based on the Sonoma County Community Climate Action Plan's (SCCCAP) target of reducing County emissions 25% below 1990 emission levels (1.4 million ton reduction). Proposed CTP Policy 3 specifically states:

> *Goal: Meet the targets to reduce GHG emissions 25% below 1990 levels by 2015, and 40% below 1990 levels by 2035 by working with government agencies and the public.*

See Chapter 4 – Vision for the Future in the proposed 2009 CTP for more information about the Goals, Objectives and Policies.

While the proposed 2009 CTP has identified its desired intent of meeting this greenhouse gas (GHG) emission reduction target through a variety of measures, including transit, roadway improvements, land use improvement (smart growth and supportive transit), transportation technology improvements and transportation pricing policies, current funding and SCTA authority limitations inhibit the CTP's ability to fully implement these strategic projects (see CTP pages 95 through 99) and thus meet its benchmarks (including GHG emission reductions) (see CTP page 50). The environmental impact analysis in the Draft EIR is conservatively based on projects and improvements that are feasible for SCTA to implement and have known existing and planned funding sources (e.g., Measure M and funding from the Metropolitan Transportation Commission) (see CTP page 35 and Draft EIR pages 3.0-10 through -13). The reader is referred to the discussion below under "Need for the Draft EIR to Include Additional Mitigation Measures to Further Mitigate Greenhouse Gas Emissions" regarding the infeasibility of SCTA to fully implement these measures and other measures suggested by the commenters.

It should be noted that Section 6.0 (Alternatives) of the Draft EIR does provide an analysis that shows VMT reductions that could further reduce GHG emissions (as compared to the proposed CTP) associated with a 7% reduction in VMT under Alternative 3, 11% reduction in VMT under Alternative 4, and 18% reduction in VMT under Alternative 5. Each of these alternatives includes aspects of the CTP strategic projects such as smart growth and transit expansion, congestion pricing, and a combination of both (see Section 4.0, Minor Revisions to DEIR Appendix F). Alternative 5 is the only Alternative that meets the GHG reduction emissions goals, however there are programs contained within the Alternative 5 that are outside of the jurisdiction of the SCTA and are financially unfeasible and are not able to be implemented as part of the 2009 CTP.

While the Draft EIR acknowledges that the CTP would not fully meet the GHG emission reduction targets set forth in CTP Policy 3 or the SCCCAP target, the proposed CTP would improve county-wide mobile GHG emissions by approximately 22% from existing conditions (2005) through improved VMT under year 2035 conditions (with the 2009 CTP) as well as through expected improvements in fuel economy from implementation of AB 1493. In addition, the CTP includes SCCCAP solutions as both CTP objectives (see CTP pages 43 through 49) as well as strategic projects (see CTP pages 95 through 99). Thus, the CTP does not conflict with the SCCCAP. It should be noted that in the SCCCAP itself notes that, some of its transportation and land use solutions are expected to have varied levels of feasibility to implement and would require other agencies beyond SCTA to implement to meet the target (see SCCCAP pages 41 through 44). Given that the proposed CTP would improve on existing mobile GHG emissions as well as anticipated GHG emissions under year 2035 no CTP update conditions, no significant climate change impact was identified in the Draft EIR.

The proposed CTP would also be generally consistent with the land use and transportation and programs to reduce VMT recommendations identified in the California Governor's Office of Planning and Research technical advisory entitled "CEQA and Climate Change: Addressing Climate Change Through California Environmental Quality Act (CEQA) Review" (June 2008). While not a general plan, the proposed CTP is also generally consistent with the recommended transportation, VMT reduction, transit improvement and pedestrian and bicycle policies identified in the California Air Pollution Control Officer Association's "Model Policies for Greenhouse Gases in General Plans" (June 2009).

Need to Better Address Vehicle Miles Traveled and Energy Use Increases

Comment letters identify the following issues associated with the Draft EIR analysis of energy use and GHG emission estimates for year 2035:

- Inconsistency with the analyses and conclusions associated with increases in VMT, energy consumption, and GHG emissions provided in Draft EIR pages 4.13-10 through -15 and 5.0-20 through -25. Specifically, that VMT is expected to increase and fuel economy is expected to increase yet the Draft EIR identifies an increase in fuel consumption

- The Draft EIR identifies that the proposed CTP would not meet CTP Objective 3A that calls for the reduction of VMT by 10% below year 2005 levels by 2035.

The Draft EIR's analysis of future energy consumption for year 2035 under the proposed CTP and Draft EIR alternatives has been revised and corrections to this analysis is provided in Section 4.0, (Minor Revisions to the Draft EIR). Specifically, the analysis now includes consideration of the federal CAFE and State fuel economy standards under AB 1491 (Pavley). There is a 22%

reduction in fuel consumption for light duty autos and trucks, as they are the vehicle classes that are subject to federal CAFE and State fuel economy standards under AB 1491. However, the 26% increase in VMT results in concomitant increases in fuel consumption in the other vehicle classes that are not affected by AB 1491. Overall, the vehicle fleet's fuel consumption of gasoline and diesel fuels is projected to be reduced by 9% under the 2035 CTP scenario when compared to existing conditions (2005). Draft EIR Table 4.13-2, Table 4.13-3 and the analysis in the Executive Summary, Energy section, and Cumulative Impacts sections of the Draft EIR have been revised accordingly (see Section 4.0, Minor Revisions to the Draft EIR). This updated analysis has resulted in a change in the significance determination of Draft EIR Impact 4.13-1 from significant and unavoidable to less than significant.

The Draft EIR's analysis of future VMT is based on output from the Sonoma County Travel model which uses regional population and employment forecasts for Sonoma County and the Bay Area region. The Association of Bay Area Governments (ABAG) is responsible for making long-term forecasts of population, housing, and employment, and updates forecasts every 2 years. ABAG forecasts present a realistic assessment of growth in the region, while recognizing trends in markets and demographics, and accounting for local general plans and planning documents. The advent of legislation that seeks to address and reduce Greenhouse Gas emissions, such as SB 375, will impact future county and regional population and employment forecasts. SB 375 directs the California Air Resources Board to set regional targets for reducing GHG emissions and requires Metropolitan Planning Organizations (MPOs – the Metropolitan Transportation Commissions is the MPO for the nine county Bay Area region) to develop Sustainable Communities Strategies (SCS) (or a feasible alternative planning strategy) to meet those targets. Decisions relating to the allocation of transportation funding must be consistent with the region's SCS. An SCS is essentially an outline for regional transportation infrastructure and development that will reduce GHG emissions from cars and light trucks. Future county and regional forecasts will most likely shift future population and employment growth to more urbanized parts of the region at higher densities and clustered around transit and in walkable communities. SCS forecasts for Sonoma County will likely be similar to the land use scenario analyzed as part of 2009 CTP EIR Scenario 3 (Smart Growth Scenario). As described in the 2009 CTP by 2035, the population of Sonoma County that is 65 or older will go from 13.4% to 27.6% of the total population. Due to these changes, SCS land use allocations will also likely show lower population and growth rates for Sonoma County, which will subsequently lead to lower future VMT and GHG growth and make it easier for SCTA to meet VMT and GHG reduction goals. SCTA is active in monitoring the initial stages of SB 375 implementation and is engaged at the regional level in the development of the SCS.

The analysis of the CTP is based on ABAG's Projections 2007 (initial Projections 2005 estimates were updated using Projections 2007 once available), which were the published regional forecasts for the region during the development of the CTP and testing of scenarios. Population and Job growth numbers and associated VMT data for Sonoma County are shown below:

	Population	Jobs	VMT
2005	478,800	220,460	11,441,811
2035	568,900	344,290	14,417,956
% change	18.8%	56.2%	26%

The reader will note that growth in VMT is greater than projected population growth for Sonoma County. VMT is a function of population, employment, and the location of travel destinations. High projected job growth and the expected expansion of Santa Rosa Junior College and Sonoma State University enrollments by 2035 contribute to increased travel in the county and lead to a VMT growth that outpaces the projected population increase for Sonoma County. As discussed above, the Sonoma County population is also projected to continue to age which could also increase the need for out of county in-commuting to fulfill employment needs. Thus, the increase in VMT reflects increased commuting and school trips within the county and higher in-commutes (and higher education school trips) from surrounding counties.

The Draft EIR analysis acknowledges that although the proposed 2009 CTP has an objective goal to reduce VMT per capita by 10% below 2005 levels by 2035, VMT is anticipated to increase by approximately 26% over existing conditions. As identified above, the 2009 CTP proposes to meet the VMT reduction target through transit, roadway improvements, land use improvements (smart growth and supportive transit), transportation technology improvements and transportation pricing policies. However, current funding and SCTA authority limitations inhibit the CTP's ability to fully implement these strategic projects (see CTP pages 95 through 99) to meet this VMT reduction (see CTP page 50). Thus, the environmental impact analysis in the Draft EIR is conservatively based on projects and improvements that are feasible for SCTA to implement and have known existing and planned funding sources (see CTP page 35 and Draft EIR pages 3.0-10 through -13).

VMT increases identified in Draft EIR Table 4.3-15 (see Draft EIR page 4.3-29) for year 2035 are based on continued growth and land uses in the County and its cities associated with their general plans (growth as projected by ABAG in Projections 2007) that will continue to generate traffic and impact VMT that SCTA has no authority to regulate, though the proposed CTP does include recommended land use measures under its strategic projects list that encourage and promote clustered and infill development (see CTP pages 96 and 97). Future land use forecasts (Sustainable Communities Strategy) based on SB 375 requirements will also provide a future land use scenario that will make it more likely that VMT and GHG reduction targets will be met. The purpose of the CTP is provide long range planning that seeks to improve mobility via Sonoma County's streets, highways, transit system and bicycle/pedestrian facilities, as well as to reduce transportation-related impacts. As demonstrated in Draft EIR Table 4.3-15, the proposed CTP would result in an improvement in VMT as compared to no project under year 2035 conditions.

Need for the Draft EIR to Include Additional Mitigation Measures to Further Mitigate Greenhouse Gas Emissions

Comment letters suggest additional mitigation measures to address climate change. As explained in the Draft EIR, implementation of the CTP would not result in a significant climate change or greenhouse gas emission impact and therefore mitigation is not required (see Draft EIR pages 5.0-20 through -26). Nevertheless, the Draft EIR recommends additional mitigation measures (MM 5.0-1a through g, MM 5.0-2a, and MM 5.0-3) that would further reduce potential impacts of climate change, beyond what is required under CEQA.

Mitigation measures (MM 5.0-1a through g, MM 5.0-2a, and MM 5.0-3) are presented below:

MM 5.0-1a SCTA shall consider working in partnership with the Bay Area Air Quality Management District to conduct demonstration projects in Sonoma County that help reduce GHG emissions. This would help implement Bay Area Ozone Strategy TCM-17.

MM 5.0-1b SCTA shall work in partnership with appropriate stakeholders (e.g., Bay Area Air Quality Management District, Sonoma County Alliance, Leadership Institute for the Ecology and the Economy) to develop public information campaigns to educate residents, merchants, and the traveling public about transportation strategies that can help reduce GHG emissions.

MM 5.0-1c SCTA shall encourage project sponsors to design transportation-related improvements such as transit buildings and facilities to be certified by the Leadership in Energy and Environmental Design program (LEED).

MM 5.0-1d SCTA shall work with local governments to limit idling time for commercial vehicles, including delivery and construction vehicles.

MM 5.0-1e SCTA shall work with project sponsors to develop standards for construction management, including use of recycled materials or low-carbon products.

MM 5.0-1f SCTA shall work with MTC, BCDC, and other partners to address vulnerability of the county's transportation infrastructure and appropriate adaptation strategies to protect those transportation resources that are likely to be impacted by sea level rise and flooding associated with global climate change. Examples could include, but not be limited to:

- Engineering designs for new transportation projects shall demonstrate that they have factored in sea level rise and potential increases in storm surge inundation, and are budgeting for and already incorporating mitigation measures to adapt to projected sea level rise and storm surge. These mitigation measures should consider the effects on Bay and coastal zone resources and avoid or reduce risk to the infrastructure and the region.

- For transportation projects that increase the capacity of existing infrastructure, project sponsors shall demonstrate they have investigated the vulnerability of their existing facilities to sea level rise and potential increases in storm surge inundation, and are budgeting for and already incorporating mitigation measures to adapt to projected sea level rise and storm surge. These mitigation measures should consider the effects on Bay and coastal zone resources and avoid or reduce risk to the infrastructure and the region.

MM 5.0-1g Where applicable, project sponsors for subsequent projects under the 2009 CTP shall include mitigation measures to reduce impacts related to significant storm events, sea level rise, and flooding resulting from global climate change.

MM 5.0-2a SCTA shall work with the BAAQMD and other appropriate stakeholders to develop guidance and/or requirements to use low-carbon emitting techniques or equipment in the construction process for capital improvements included in the 2009 CTP.

MM 5.0-3 SCTA shall work with appropriate stakeholders to provide funding for ~~ensure that~~ future transportation plans and projects are consistent with AB 32 implementation standards and guidelines once they are developed.

The following is a summary of additional mitigation measures suggested by commenters to be considered in the EIR. Below each suggested mitigation measure is an analysis of the measure.

- *Make the full costs of automobile use transparent to drivers (education and transportation pricing such as paid parking, mileage-based insurance, HOT lanes, and additional gas taxes).*

  As previously identified above, the proposed CTP includes Objective 2D and pricing strategies and actions in its strategic projects list that includes HOT lanes, charging for parking at activity centers, congestion pricing, and support for increases in gas tax or user fees (see CTP page 97 and 98). However, all of those projects with the exception of charging parking at activity centers, would require the passage of special legislation by the State and are not under the authority of SCTA to implement. Implementation of Draft EIR mitigation measure MM 5.0-1b requires SCTA to coordinate with other stakeholders in public information campaigns to educate the public about transportation strategies that can help reduce GHG emissions. Thus, the CTP and Draft EIR already include this mitigation approach to the extent feasible at this time.

- *Expansion of hybrid, electric and other alternative fuel vehicle use.*

  The proposed CTP includes programs and policies that address the comment via Objective 3E, which supports development and deployment of new technologies to reduce transportation emissions and “Traffic Flow Improvement” strategies/actions in its strategic projects list. These strategies/actions include increase in fuel efficiencies, improved fuels/biofuels, and acceleration of school bus replacement (see CTP page 98 and 99). SCTA is committed to supporting these important strategies; however, as identified in the CTP, much of the implementation of these strategies and actions depends on action by the state and federal government (e.g., fuel efficiency legislation and the private sector and the availability of future funding. Thus, the CTP already includes this mitigation approach to the extent feasible.

- *Further expansion of public transportation and improve its convenience associated with land uses and other forms of transportation.*

  The proposed CTP includes projects and policies that address the comment via transit improvements associated with Sonoma-Marin Area Rail Transit (SMART) passenger rail project (30-minute headways during peak periods and 60-minute headways off-peak), increased frequencies on Santa Rosa CityBus, Mendocino Avenue/Santa Rosa Avenue Rapid Bus, and Montgomery/Sonoma/West Santa Rosa Rapid Bus. CTP also includes pedestrian and bicycle improvements as well as traffic safety and safe routes for school projects. The CTP also includes “Land Use Measures” strategies and actions in its strategic projects list that includes clustering development near transit hubs and development of transportation investment criteria that support the 4-d Development Strategy (density, diversity, design, destinations).

- *Changes in land use patterns and other features to make it easier to live without a car.*

  As identified above, the proposed CTP includes transit, pedestrian and bicycle improvements. In addition, the CTP includes land use strategies and actions in its strategic projects list associated with clustered and mixed-use development. Although SCTA does not have land use authority to implement clustered development, the projects and policies in the CTP support other jurisdictions in making transit-oriented development a priority.

- *Improvement of pedestrian and bicycle facilities and safety.*

  As identified above, the proposed CTP already includes pedestrian and bicycle improvements as well as traffic safety and safe routes for school projects.

- *Implementation of traffic calming measures.*

  The CTP includes Policy 4 and objectives 4A and 4B that address traffic safety and public health, and pedestrian and bicycle improvements as well as traffic safety and safe routes for school projects. The CTP also includes "Traffic Flow Improvement" strategies and actions in its strategic projects list that includes traffic circles and other traffic calming measures (see CTP page 98). Many jurisdictions have implemented traffic calming measures to meet their particular local needs and the CTP supports continuation of these efforts.

3.4.6 ADEQUACY OF ALTERNATIVES ANALYSIS

Some comment letters expressed concerns associated with the alternatives analysis and suggested additional alternatives to be evaluated. Specific comments included:

- Inadequate analysis of the No Project Alternative in the Draft EIR.
- Need for the Draft EIR to consider additional alternatives including:
  - A variation of Alternative 3 that transfers funding from capacity improvements of the Marin-Sonoma Narrows to SMART and other transit and the market-based pricing concepts of Alternative 4 to reduce travel demand (referred to hereafter as "Alternative 6"); and,
  - An alternative that would involve a 20% reduction in vehicle miles traveled (referred to hereafter as "Alternative 7");

CEQA Requirements for a Range of Reasonable Alternatives in an EIR

State CEQA Guidelines Section 15126.6(a) states that an environmental impact report (EIR) shall describe and analyze a range of reasonable alternatives to a project. The range of alternatives required in an EIR is governed by a "rule of reason" that requires the EIR to set forth only those alternatives necessary to permit a reasoned choice (State CEQA Guidelines Section 15126.6[f]). Alternatives to be considered are limited to ones that would avoid or substantially lessen any of the significant effects of the project and at the same time feasibly attain most of the basic objectives of the project.

When addressing feasibility, the State CEQA Guidelines Section 15126.6(f)(1)states that among the factors that may be taken into account when addressing the feasibility of alternatives are economic viability, availability of infrastructure, jurisdictional boundaries, and regulatory limitations. In addition to these provisions, State CEQA Guidelines Section 15364 defines feasible as:

> *capable of being accomplished in a successful manner within a reasonable period of time, taking into account economic, environmental, legal, social, and technological factors.* (See also *Citizens of Goleta Valley, et al. v. Board of Supervisors of the County of Santa Barbara, et al.*)

An EIR need not consider every conceivable alternative to a project, nor is it required to consider alternatives that are infeasible. (See *Sequoyah Hills Homeowners Association v. City of Oakland* (1994) 23 Cal.App.4th 704)

Development of Range of Alternatives

The alternatives evaluated in the Draft EIR are based on the scenarios evaluated in the proposed CTP (see CTP Appendix C, vi. Sonoma County Travel Model Update & Analysis). These scenarios were developed to consider a range of actions associated with the prioritization of transportation projects and policies to determine what types of projects and policies would provide SCTA the greatest ability to feasibly meeting its goals and objectives, which includes improvement of environmental conditions. The following alternatives were evaluated in the DEIR. A detailed description of these alternatives is provided in Section 6.0 (Project Alternatives), while an updated list of projects under each alternative is provided in Section 4.0 of this document in the edits to DEIR Appendix G.

1. No Project/No Action
2. CTP Vision Scenario, Financially Unconstrained Capital Improvement Scenario
3. VMT Reduction – Transit Expansion/Smart Growth Focused Scenario
4. VMT Reduction – Pricing Policy Focused Scenario
5. Comprehensive – “Do Everything” Scenario

These alternatives were identified as potentially meeting the basic objectives of the proposed CTP, which are included in Chapter 3.0, Overview of the 2009 Comprehensive Transportation Plan, of the Draft EIR.

Inadequate Analysis of No Project Alternative

Commenters suggest that the No Project Alternative was incorrectly defined and should have been defined as the existing transportation network as it would function with 2035 population and land use. However, this is contrary to State CEQA Guidelines Section 15126.6(e)(3)(A) which specifically identifies that in the case of the revision of an existing land use or regulatory plan, policy or ongoing operation, the "no project" alternative will be the continuation of the existing plan, policy or operation into the future. The No Project Alternative includes projects included in the 2004 CTP that are fully funded (see Draft EIR page 6.0-2). As discussed in Section 6.0 of the DEIR, if the 2009 CTP is not approved, SCTA would continue to rely on the existing CTP until such time as a revised CTP were adopted. The existing 2004 CTP contains most of the same proposed large projects that are included in the current Draft CTP. The specific projects included in the No Project Alternative are:

- U.S. 101: Wilfred - Rohnert Park Expressway to Santa Rosa Avenue – Add one HOV lane in each direction; add a two-lane connector road between Wilfred Avenue and Santa Rosa Avenue; add auxiliary lanes between Rohnert Park Expressway overcrossing and

Wilfred Avenue/Golf Course Drive interchange; add auxiliary lane between Wilfred Avenue and Santa Rosa Avenue overcrossing; and realign surrounding roadways.

- U.S. 101: North - Windsor River Road to Steele Lane (Phase A) – Add one HOV lane in each direction.
- U.S. 101: Central - Rohnert Park Expressway to Old Redwood Highway (Phase A) – Add one HOV lane in each direction between Pepper Road and Rohnert Park Expressway; add northbound climbing lane from one mile north of Old Redwood Highway to West Sierra Avenue; add auxiliary lanes between Pepper Road and Rohnert Park Expressway.
- U.S. 101: Marin-Sonoma Narrows (Phase 1) – Upgrade Petaluma Boulevard South interchange and frontage roads; close expressway access.

Consideration of a no project alternative based on no changes to the existing transportation network with year 2035 population and land use, as urged by some commenters, would fail to consider approved, planned and funded transportation improvements (i.e., reasonably foreseeable projects) expected to be complete by the year 2035 (e.g., Phase 1 of the Marin Sonoma Narrows Project). The Draft EIR No Project Alternative includes these expected transportation improvements, consistent with CEQA Guidelines section 151526.6.

The commenters appear to confuse the definition of environmental baseline under CEQA (State CEQA Guidelines Section 15125[a]) and the requirements of the no project alternatives analysis (State CEQA Guidelines Section 15126.6[e]). Section 15125[a] of the State CEQA Guidelines requires that an environmental impact report [EIR] include a description of the physical environmental conditions in the vicinity of a project as they exist at the time the Notice of Preparation (NOP) is published and the environmental analysis is begun. The State CEQA Guidelines also specify that this description of the physical environmental conditions is to normally serve as the baseline physical conditions by which a lead agency determines whether impacts of a project are considered significant, as was done in the DEIR. This differs from the evaluation of the no project alternative under Section 15126.6 of the State CEQA Guidelines, which assumes that "other projects initiated under the existing plan will continue while the new plan is developed." (State CEQA Guidelines, § 15126.6(e)(3)(A).) The impacts that would occur under the existing plan, including projects that "would be reasonably expected to occur in the foreseeable future if the project were not approved," are then compared to the projected impacts of the proposed plan. (State CEQA Guidelines, § 15126.6(e)(2), (3).)

As previously identified above, the definition of a no project alternative under Section 15126.6(e) substantially differs from environmental baseline conditions as it requires the consideration of the subsequent activities that would reasonably occur if the CTP update project were not approved. In the case of the Draft 2009 CTP, SCTA would continue to operate under the 2004 CTP and transportation projects that are planned and funded would move forward as noted above.

Consideration of Alternatives Suggested

Suggested Alternative 6, proposed by TRANSDEF, is a variation of Alternative 3 that would transfer funding from capacity improvements of the Highway 101 Marin-Sonoma Narrows Project to SMART and other transit to maximize transit availability, and include the market-based pricing concepts of Alternative 4 to reduce travel demand. As described, this alternative is substantially a combination of Alternatives 3 and 4 already analyzed in the DEIR, with the difference that it would shift funding from highway widening to transit. This alternative would not be feasible given that programmed funding for the Marin-Sonoma Narrows Project has been allocated by the California Transportation Commission from the Corridor Mobility Improvement Account for highway improvements, and if it were deprogrammed from the Highway 101 project, it would return to the state; it would not be available to program to rail improvements. Changes to the Measure M funding allocated to the Marin-Sonoma Narrows Project would require voter approval to amend Measure M.

Suggested Alternative 7, proposed by the Climate Action Campaign, Bicycle Coalition and Sonoma County Transportation and Land Use Coalition, proposes a 20% reduction in vehicle miles traveled. However, the comment does not specify additional transportation improvements or policies, beyond those identified in the 2009 CTP and the DEIR, that could be implemented to ensure a 20% reduction in VMT. Thus, it impossible to determine how such an alternative could be feasibly implemented by SCTA. For purposes of comparison, it should be noted that the Draft EIR includes Alternative 5 (Comprehensive/"Do Everything" Alternative), which would achieve a 20% reduction in VMT compared to no project conditions in year 2035.

STATE OF CALIFORNIA—BUSINESS, TRANSPORTATION AND HOUSING AGENCY RECEIVED ARNOLD SCHWARZENEGGER, Governor

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June 2, 2009

Letter A

SON-GEN-0.0
SON000155
SCH#2008082011

Ms. Seana Gause
Sonoma County Transportation Authority
490 Mendocino Avenue, Suite 206
Santa Rosa, CA 95401

Dear Ms. Gause:

Sonoma County Transportation Authority (SCTA) Comprehensive Transportation Plan (CTP) Draft Environmental Impact Report (DEIR)

Thank you for continuing to include the California Department of Transportation (Department) in the environmental review for the above-referenced project. The Department has reviewed this document and we provide the following comments:

Impact 4.3-1 notes that this CTP supports growth from Vehicle Miles of Travel (VMT), and that the im[ ] "significant and unavoidable." However, the mitigation measures noted for this impact are mat SCTA will seek additional funding for pricing projects and Transportation Demand Management (TDM) programs to reduce VMT, as well as encourage local governments to implement VMT reduction strategies. It appears that although the SCTA acknowledges the need for pricing and TDM strategies to reduce VMT, there is not enough commitment to these strategies to make a differ nce. It should be noted that the Metropolitan Transportation Commission's (MTC) T2035 commits to much more than this in their document. **A-1**

It should also be noted that on Page 4.3-14, Table 4.3-9 uses data from 2002. The MTC/Department State of the System Report 2007 provides much more current data and is available on the MTC website. **A-2**

If you have any questions or need further information, call Alice Jackson at (510) 286-5988.

Sincerely,

[redacted]

for CARBONI
t Branch Chief

"Caltrans improves mobility across California

3.5 INDIVIDUAL RESPONSES

Letter A — Lisa Carboni, California Department of Transportation

Response A-1: The 2009 CTP identifies two goals to address reductions in both VMT and GHG. Of the four goals the second is to relieve traffic congestion, which directly addresses a reduction in VMTs, which in turn reduces GHGs. The SCTA has also listed the reduction of greenhouse gas emissions among the four goals of the CTP (p. 46.) Moreover, the 2009 CTP identifies a strategic list of GHG reduction projects which includes strategies and actions, implementing parties implementation needs, time frames and examples of implementation for these impacts.

The mitigation measures proposed in the Draft EIR are limited by the current funding and SCTA authority limitations (e.g., SCTA does have land use authority to require land use strategies that would reduce VMT) which inhibit the CTP's ability to fully implement these strategic projects (see CTP pages 95 through 99) to meet this VMT reduction (see CTP page 50). VMT increases identified Draft EIR Table 4.3-15 (see Draft EIR page 4.3-29) for year 2035 are based on continued growth and land uses in the County and its cities associated with their general plans that will continue to generate traffic and impact VMT that SCTA has no authority to regulate. However, it is important to note that the proposed CTP would result in reduced VMT under year 2035 conditions as compared to the no project scenario.

Response A-2: The following textual revisions are made to the Draft EIR to include the Weekday Congestion Locations on U.S. 202, Ranked by Delay (2007).

- Draft EIR page 4.1-13, Table 4.3-9 is removed and the following Table will replace Table 4.3-9:

~~TABLE 4.3-9~~
~~WEEKDAY CONGESTION LOCATIONS ON U.S. 101, RANKED BY DELAY (2002)~~

~~Rank in County~~	~~U.S. 101 Segment~~	~~Direction~~	~~Time Period~~	~~Delay (Vehicle Hours)~~
~~1~~	~~Santa Rosa Ave. & N. Todd Rd. to Steele Ln.~~	~~Northbound~~	~~2:30 PM – 6:45 PM~~	~~1,420~~
~~2~~	~~Hopper Ave. to Route 12~~	~~Southbound~~	~~2:35 PM – 6:25 PM~~	~~860~~
~~3~~	~~Golf Ave. to Baker Rd.~~	~~Northbound~~	~~7:10 AM – 9:15 AM~~	~~630~~
~~4~~	~~Redwood Hwy to Kastania Rd.~~	~~Southbound~~	~~5:45 AM – 8:05 AM~~	~~570~~
~~5~~	~~At Steele Ln.~~	~~Southbound~~	~~7:15 AM – 8:55 AM~~	~~210~~
~~6~~	~~Airport Blvd. to River Rd.~~	~~Southbound~~	~~7:15 AM – 8:50 AM~~	~~200~~
~~7~~	~~At Route 12~~	~~Southbound~~	~~6:25 AM – 9:20 AM~~	~~160~~
~~8~~	~~At Redwood Hwy~~	~~Northbound~~	~~3:50 PM – 6:10 PM~~	~~120~~
~~9~~	~~E. Washington Ave.~~	~~Northbound~~	~~4:25 PM – 6:25 PM~~	~~100~~

~~*Source: Caltrans, District 4 Office of Highway Operations. Information Memorandum, Year 2002 Bay Area Freeway Congestion Data, Tables 4A and 4B (accessed September 12, 2008)*~~

TABLE 4.3-9
WEEKDAY CONGESTION LOCATIONS ON U.S. 101, RANKED BY DELAY

Rank in County	U.S. 101 Segment	Direction	Time Period	Delay (Vehicle Hours)
1	East Washington St. to Kastania Rd.	Southbound	5:25 AM – 7:15 AM	1,880
2	Baker Ave. to College Ave.	Northbound	2:05 PM – 6:30 PM	1,220
3	Mendocino Ave. to 5th St.	Southbound	2:40 PM – 6:20 PM	1,180
4	Route 12 to College Ave.	Northbound	7:00 AM – 9:15 PM	590
5	At East Washington St.	Northbound	2:50 PM – 6:30 PM	290
6	Shilo Rd. to south of Mendocino Ave.	Southbound	7:30 AM – 9:00 AM	270
7	Route 116 to Wilfred Ave.	Northbound	2:30 PM – 4:50 PM	260
8	Steele Ln. to College Ave.	Southbound	7:20 AM – 9:30 AM	180
9	At Old Redwood Hwy	Northbound	3:10 PM – 5:00 PM	50

Source: MTC, Congested Freeway Locations – Morning and Evening Commutes, 2008. http://www.mtc.ca.gov/news/press_releases/congestion/2008/am_pm_peak_period_congestion.pdf. (accessed July 20, 2009).

Letter B

California Regional Water Quality Control Board
North Coast Region
Bob Anderson, Chairman

Linda S. Adams
Secretary for Environmental Protection

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Arnold Schwarzenegger
Governor

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JUN 02 2009
SONOMA COUNTY TRANSPORTATION AUTHORITY

June 1, 2009

Ms. Seana Gause
Sonoma County Transportation Authority
490 Mendocino Ave., Ste. 206
Santa Rosa, CA 95401

Dear Ms. Gause:

Subject: Comments on the Draft Environmental Impact Report for the 2009 Comprehensive Transportation Plan Update, Sonoma County SCH No. 2008082011

Thank you for the opportunity to comment on the Draft Environmental Impact Report for the 2009 Comprehensive Transportation Plan Update. We appreciate the chance to respond and express concerns early in the environmental review process relating to our own statutory responsibility. The North Coast Regional Water Quality Control Board (RWQCB) is a responsible agency for this project, as defined by the California Environmental Quality Act (CEQA) having jurisdiction over the quality of ground and surface waters (including wetlands) and the protection of the beneficial uses of such waters.

The 2009 Comprehensive Transportation Plan Update (CTP) is a long-range county-wide plan for transportation infrastructure maintenance, expansion and improvement over the next 25 years. The CTP includes highway improvements, local road improvements, transit improvements, non-motorized transportation improvements, local street maintenance, safe routes for schools, and regional operations programs.

We have reviewed the document prepared for the Comprehensive Transportation Plan Update and offer the following comments:

General Comments

Sonoma County contains a large portion of the Gualala River, as well as much of the Russian River and its tributaries, including the Laguna de Santa Rosa. The Gualala River is listed on the RWQCB's list as impaired due to water temperature. Potential sources for changes in water temperature include removal of riparian vegetation, **B-1**

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Ms. Gause -2- June 1, 2009

streambank modification and destabilization, channel erosion, erosion and siltation, and nonpoint source. B-1

The Russian River in its entirety is listed as impaired due to sedimentation and siltation. Potential sources include construction, land development, highway/road/bridge construction, hydromodification, channelization, habitat modification, removal of riparian vegetation, streambank modification and destabilization, drainage and filling of wetlands, channel erosion, urban runoff, surface runoff, and disturbed sites. The Russian River is also listed as impaired due to water temperature, with potential sources including flow regulation and modification, upstream impoundment, and hydromodification in addition to those listed for the Gualala River's high temperatures. B-2

In addition to sedimentation/siltation and high water temperature, specific tributaries of the Russian River are listed as impaired in various conditions. The Laguna de Santa Rosa is listed as impaired due to low dissolved oxygen, mercury, nitrogen and phosphorus. Santa Rosa Creek and the Guerneville HSA are listed as impaired due to pathogens. Lake Sonoma is listed as impaired due to mercury. B-3

The Russian River and Gualala River both support fisheries. The Russian River provides habitat for steelhead trout and coho salmon, both federally listed threatened species. Recent data suggests that rising water temperatures are a source of impairment to cold water fisheries. B-4

Wetlands and waters of the state

The DEIR should include the definition of "waters of the state" in addition to that of "waters of the United States" when discussing impacts that may require mitigation (for example, the description of potential impact 4.4-5. The RWQCB's Water Quality Control Plan for the North Coast Basin (Basin Plan) and the California Water Code define waters of the state as follows: "'Waters of the state' means any surface water or groundwater, including saline waters, within the boundaries of the state (Water Code §13050 (e)." This definition is broader than that of "waters of the United States" and consequently should always be acknowledged and considered when determining impacts upon water resources. Specifically, Impact 4.4-5 states that "implementation of the proposed 2009 CTP may result in the loss of jurisdictional waters of the U.S., including wetlands." This should be changed to read "...jurisdictional waters of the state and waters of the U.S., including wetlands." In addition, Mitigation Measure 4.4-5 should note the jurisdictional authority of the Regional Water Board, as the Regional Water Board has jurisdiction over surface waters, groundwater and wetlands. B-5

Hazardous Materials/Cleanups sites

The California Environmental Protection Agency's Cortese List notes the presence of six sites that are undergoing or underwent cleanups for hazardous substances. Five are active and the remaining one is a Federal Superfund site that is certified with land use restrictions. There are four state response sites, a military evaluation and the B-6

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aforementioned Federal Superfund. In addition, the RWQCB's Geotracker database estimates 2,338 Leaking Underground Storage Tanks (LUST) or cleanup program sites in the Sonoma County area.

Development on active cleanup sites can proceed concurrently with cleanup activities, as long as development activities do not hinder investigation and remedial activities. Proposed development needs to be compatible with ultimate cleanup actions. Mitigation Measure 4.7-3 states that "the implementing agency shall coordinate remediation of contamination in accordance with applicable Sonoma County, Regional Water Quality Control Board, and state standards." While we appreciate the effort to comply with local, regional and state standards, contact with all involved agencies and the developer is essential through the development process. Mitigation measures should include requirements to contact and coordinate with all appropriate agencies prior to development on or near active cleanup sites. **B-6**

Specific Comments

Surface waters

Instream construction

Mitigation Measure 4-3 states that "individual projects shall minimize the use of in-water construction methods in areas that support sensitive fish species, especially when fish are present." This is not sufficient, nor is it enforceable. Given the current conditions of the Russian River and the Gualala River, in-water construction should never occur in areas that support sensitive fish species. Mitigation Measure 4-3 should be modified to read "individual projects will avoid the use of in-water construction methods in all state or federally jurisdictional surface waters." Please note that in-water construction methods will likely require a Streambed Alteration Agreement from the California Department of Fish and Game as well as permits from the Regional Water Board. **B-7**

Construction and post-construction impacts

As previously mentioned, the Gualala River and Russian River are both listed on the 303(d) list as impaired due to water temperature, and the Russian River is listed as impaired due to sedimentation and siltation. Potential sources of increased water temperature and sedimentation include highway/bridge/road construction, land development, removal of riparian vegetation, and streambank modification, all of which are associated with the type of projects involved in the CTP. The CTP mentions some Best Management Practices (BMPs) to be utilized during construction, and these are valuable and appreciated. However, the CTP needs to be far more thorough in its requirements for individual projects' BMPs. **B-8**

Mitigation Measure 4.8-1a states "BMPs such as those described above shall be in place and operational prior to major earthwork." This statement should be changed to read "BMPs shall be in place and operation prior to *any* construction activities." Each **B-9**

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project should be required to have extensive construction and post-construction BMPs in place prior to beginning any work within the vicinity of waters of the state. The CTP should articulate a set of construction BMPs that are standard for all projects conducted under the CTP, as well as a set of issues that each project should address individually. B-9

All projects should include construction BMPs specifically targeted towards retaining sediment onsite, preventing erosion of streambanks and pollution from construction vehicles, and collecting and treating storm water runoff onsite. All projects should utilize staging areas for vehicles that are removed from riparian areas and all construction should occur during the dry season. If such measures cannot be taken, the individual project should be required to analyze alternatives and provide mitigation measures for adverse impacts. All projects should be required to avoid entirely the removal of riparian vegetation (as previously mentioned, removal of riparian vegetation is a contributing factor to both water temperature and sedimentation). If this is not possible, the individual project should be required to demonstrate a plan for revegetation including a post-construction monitoring plan to determine the success of revegetation efforts. Monitoring and maintenance plans should also be in place to ensure that runoff treatment mechanisms such as sediment basins or silt fences continue to function properly. Runoff from all areas of new impervious surfaces should be mitigated for potential impacts to receiving water quality and flow. We strongly recommend use of Low Impact Development techniques to accomplish this mitigation. B-10

On an individual level, each project should clearly address the issues of sedimentation and water temperature in terms of potential impacts of construction activities. B-11

Mitigation Measure 4.8-1a states that "revegetation shall emphasize drought-tolerant perennial vegetation." This statement should be changed to "revegetation shall emphasize native vegetation." The Regional Water Board strongly encourages the use of native vegetation in landscaping, as the use of native species reduces need for pesticides, herbicides and other toxic chemicals, which have the potential for discharge to waters of the state. In addition, there should be no herbicide or pesticide application, intentional or incidental, to waters of the state. Native species vegetation can also conserve water and reduce energy needs. B-12

Mitigation

Mitigation Measures 4.8-1b and 4.8-1d state that individual projects will pursue the appropriate permits should they attempt to discharge point source pollutants or disturb streambed areas. While we appreciate the efforts to comply with State and local regulations, obtaining a permit is not an adequate mitigation measure. A permit will provide a means to reduce potentially significant impacts to waters of the state but only to the extent that appropriate mitigation measures are implemented in order to reduce those impacts. B-13

Ms. Gause -5- June 1, 2009

According to CEQA §15370, Mitigation includes:

(a) Avoiding the impact altogether by not taking a certain action or parts of an action.
(b) Minimizing impacts by limiting the degree or magnitude of the action and its implementation.
(c) Rectifying the impact by repairing, rehabilitating, or restoring the impacted environment.
(d) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action.
(e) Compensating for the impact by replacing or providing substitute resources or environments.

B-13

Compensatory Mitigation

In cases of project areas containing waters of the U.S., Mitigation Measure 4.4-5b states that "the project sponsor shall ensure that the project will result in no net loss of waters of the U.S. by providing mitigation through impact avoidance, impact minimization, and/or compensatory mitigation for the impact." The Regional Water Board encourages impact avoidance and minimization before the use of compensatory mitigation. Should compensatory mitigation be the only option for mitigating a project's impacts, please note that Regional Water Board staff may require a mitigation ratio greater than 1:1 as a condition of project approval, and/or require that the quality of the impacted waters or mitigation for disturbed/filled waters be higher. Compensatory mitigation must cover acreage, function and value, and it must be in-kind. Areas of compensatory mitigation also need to be protected in perpetuity by legal devices such as conservation easements, deed restrictions, etc., and have appropriate monitoring and maintenance programs in place. Compensatory mitigation should be as close to the area of impact as possible and within the same watershed.

B-14

For unavoidable impacts to waters of the State, submittal of applications for 401 Water Quality Certification and/or Waste Discharge Requirements (Dredge/Fill) permits from the Regional Water Board will be necessary. United States Army Corps of Engineers Clean Water Act Section 404 permits and Department of Fish and Game stream alteration agreements may also be necessary. This information must be included in the EIR as a resource for future development.

B-15

Storm water

As noted in the DEIR, the CTP could alter existing drainage patterns or substantially increase the rate or amount of surface runoff, possibly to an extent that exceeds the capacity of existing or planned storm water drainage systems. Each project will need to address storm water impacts both during and after construction. Post-construction storm water runoff pollutant and flow levels should be mitigated in order to match the pre-construction storm water levels.

B-16

California Environmental Protection Agency

Recycled Paper

Ms. Gause -6- June 1, 2009

Storm water BMPs should be in place during construction activities (please see the section on Construction and post-construction impacts) and each project should have a plan in place to treat storm water run off. The Regional Water Board strongly encourages the use of biofiltration techniques and Low-Impact Development. **B-17**

Low Impact Development

The Regional Water Board has been directed by the State Water Board, in a resolution adopted on May 6, 2008, to incorporate Low Impact Development (LID) in regulatory actions (http://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2008/rs2008_0030.pdf). The design and construction of new development projects using LID can protect natural flow regimes and reduce the impacts of hydromodification and thus help prevent adverse impacts to stream and wetland systems. **B-18**

We strongly recommend that Low Impact Development (LID) techniques and landscape-based BMPs be utilized in order to mitigate potentially significant impacts due to storm water runoff from development. Please see the attached list of Storm Water and LID Resources we have included for your benefit. **B-19**

The following summarizes project permits that may be required by our agency:

General Construction Activity Storm Water Permit: Land disturbances on proposed projects of one acre or more require coverage under the general construction storm water permit. If the land disturbance will be in excess of one acre, the owner of the property will need to apply for coverage under this permit prior to the commencement of activities on-site. This permit requires the preparation and implementation of a Storm Water Pollution Prevention Plan (SWPPP) that identifies best management practices (BMPs) to minimize pollutant discharges from a construction site. The permit also requires inspections of construction sites before and after storm events, and every 24 hours during extended storm events. The purpose of the inspections is to identify maintenance requirements for the BMPs and to determine the effectiveness of the implemented BMPs. Owners may call our office to receive a permit package or download it off the Internet at www.waterboards.ca.gov. **B-20**

Water Quality Certification (401 Certification) – Permit issued for activities resulting in dredge or fill within waters of the United States. All projects must be evaluated for the presence of jurisdictional wetlands and other waters of the State. Destruction of or impacts to these waters should be avoided. Under the Clean Water Act Sections 401 and 404, disturbing wetlands requires a permit from the United States Army Corps of Engineers (ACOE) and a State 401 permit. To determine whether wetlands may be present on any proposed construction site, please contact Jane Hicks of ACOE at (415) 503-6771. If wetlands are present, please contact Stephen Bargsten from our office at (707) 576-2653 for a 401 Permit.

California Environmental Protection Agency

Recycled Paper

Ms. Gause -7- June 1, 2009

Waste Discharge Requirements (WDRs) or a Conditional Waiver of WDRs: Under authority of the California Water Code, the Regional Water Board may issue WDRs for any project which discharges or threatens to discharge waste to waters of the State. Projects that impact waters of the State (including any grading activities within stream courses or wetlands) require permitting by the Regional Water Board. The Regional Water Board may also require permits for discharges of post-construction storm water runoff and on-site septic systems accepting 1,500 gallons or more per day. An application may be printed from the State Water Resource Control Board website at: www.swrcb.ca.gov/sbforms/. **B-20**

If you have any questions or comments, please contact me at (707) 576-2065 or by email at jshort@waterboards.ca.gov

Sincerely,

[redacted]

John Short
Senior Water Resources Control Engineer

Enclosures: LID and Storm Water Resources

060109_CMT_SonomaCountyTransportationPlan_DEIR.doc

California Environmental Protection Agency

Recycled Paper

Ms. Gause -8- June 1, 2009

Low Impact Development Resources

Puget Sound LID manual:
http://www.psp.wa.gov/downloads/LID/LID_manual2005.pdf

Resolution of the California Ocean Protection Council Regarding Low Impact Development:
http://www.resources.ca.gov/copc/05-15-08_meeting/05_LID/0805COPC05_%20LID%20Res%20amended.pdf

Low Impact Development Center:
http://www.lowimpactdevelopment.org/

Green Infrastructure Municipal Handbooks:
http://cfpub2.epa.gov/npdes/greeninfrastructure/munichandbook.cfm

Marin County's LID manual:
http://www.mcstoppp.org/acrobat/GuidanceforApplicantsv_2-5-08.pdf

San Diego County's LID manual – has a section on LID for roads:
http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

Low Impact Development – Sustainable Storm Water Management:
http://www.waterboards.ca.gov/water_issues/programs/low_impact_development/

EPA Green Infrastructure Basic Information:
http://cfpub.epa.gov/npdes/greeninfrastructure/information.cfm

Managing Wet Weather with Green Infrastructure:
http://cfpub.epa.gov/npdes/home.cfm?program_id=298

State Water Board Funded Projects That Include Low Impact Development:
http://www.waterboards.ca.gov/water_issues/programs/grants_loans/low_impact_development/

City of Portland's Sustainable Storm Water Management Program – LID for streets:
http://www.portlandonline.com/bes/index.cfm?c=34

Low Impact Development Center – Green Highways and Green Infrastructure:
http://www.lowimpactdevelopment.org/green_highways.htm

Streetscape improvements and water quality design:
http://www.lowimpactdevelopment.org/nhb/lid.htm

Low Impact Development for Roads - Washington State Green Building for Transportation Infrastructure webpage: http://www.metrokc.gov/kcdot/roads/eng/lid/militarys272/index.cfm

LID Urban Design tools – has design software for different BMPs:
http://www.lid-stormwater.net/homedesign.htm

LID design fact sheet:
http://www.coastal.ca.gov/nps/lid-factsheet.pdf

LID Training Program for Linear Transportation Projects:
http://www.lowimpactdevelopment.org/epa03_transportation.htm

Storm Water Management and LID at EPA headquarters – BMP choice and design:

California Environmental Protection Agency

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http://www.epa.gov/owow/nps/lid/stormwater_hq/

http://sustainablesites.org/

A Review of Low Impact Development Policies: Removing Institutional Barriers to Adoption:
http://www.waterboards.ca.gov/lid/docs/ca_lid_policy_review.pdf

Storm Water Resources:

The CASQA Construction BMP manual:
http://www.cabmphandbooks.com/Construction.asp

This is our MS4 website that has storm water and LID links:
http://www.waterboards.ca.gov/northcoast/water_issues/hot_topics/santa_rosa_ms4_npdes_stormwater_permit/

State Water Board Storm Water Program:
http://www.waterboards.ca.gov/water_issues/programs/stormwater/

Erase the Waste Campaign – California Storm Water Toolbox:
http://www.waterboards.ca.gov/water_issues/programs/outreach/erase_waste/

State Water Board Storm Water Grant Program:
http://www.waterboards.ca.gov/water_issues/programs/grants_loans/prop84/index.shtml

The San Francisco Regional Water Board storm water website:
http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/stormwater/avail_docs.shtml

EPA Storm Water Program:
http://cfpub.epa.gov/npdes/home.cfm?program_id=6

Federal Funding Sources for Watershed Protection:
http://cfpub.epa.gov/fedfund/

California Stormwater Quality Association:
http://www.casqa.org/

Stormwater Manager's Resource Center:
http://www.stormwatercenter.net/

Post Construction BMPs:
http://www.stormwaterauthority.org/library/library.aspx?id=190

For more information, please contact Mona Dougherty at mdougherty@waterboards.ca.gov.

Letter B **John Short, California Regional Water Quality Control Board**

Response B-1: Comment noted. The impaired status of these waterways is identified on Draft EIR page 4.8-5 and 4.8-6.

Response B-2: The commenter is referred to Response to Comment B-1.

Response B-3: The commenter is referred to Response to Comment B-1.

Response B-4: The commenter is referred to Response to Comment B-1.

Response B-5: Comment noted. The commenter is referred to Draft EIR page 4.4-16 second paragraph, underneath the heading "State Definition of Covered Waters." The following textual additions are made to Draft EIR Section 4.4 to address the Regional Water Quality Control Board's comments concerning jurisdictional waters of the state.

- Draft EIR page 4.4-29, the following changes are made to the first paragraph:

"Implementation of the proposed 2009 CTP may result in the loss of jurisdictional waters <u>of the state and</u> waters of the U.S., including wetlands."

- Draft EIR page 4.4-29, the following additions are made to the fourth paragraph:

"As described further above, Sonoma County and incorporated city general plans include numerous policies that regulate biological resource issues that are relevant to the 2009 CTP. Applicable goals, policies, and implementation programs from these general plans would assist in reducing any potential biological impacts to waters of the U.S. Additional mitigation measures are proposed below to further protect and minimize impacts to waters of the U.S.<u> The Regional Water Board has jurisdiction over surface waters, groundwater and wetlands, and has jurisdictional authority over any projects which may impact surface waters, groundwater and wetlands."</u>

Response B-6: The following textual additions are made to Draft EIR Section 4.7 to address RWQCB's comments concerning coordination with appropriate agencies.

- Draft EIR page 4.7-15, Mitigation Measure 4.7-3 the following changes are made :

"Subsequent projects under the CTP shall consult all known databases of contaminated sites and undertake a Phase I Environmental Site Assessment or other appropriate hazard assessment in the process of planning, environmental clearance, and construction for projects included in the 2009 CTP. <u>Prior to</u>

development on or near active cleanup sites, the project proponent shall coordinate with all appropriate agencies."

Response B-7: The Draft EIR does not include a Mitigation Measure 4-3. Assuming the commenter meant Mitigation Measure 4.4-1b should be revised, the suggested revisions are made to Mitigation Measure 4.4-1b. It should be noted that this EIR addresses overall implementation of the proposed Comprehensive Transportation Plan (CTP) at a programmatic level of detail as provided under State CEQA Guidelines Section 15168 and is not anticipated to full environmental review for all subsequent transportation improvements under the CTP. Subsequent project-level environmental review will likely be required for projects that impact waterways.

- Draft EIR page 4.4-25, Mitigation Measure 4.4-1b, fourth bullet is deleted and replaced with the following text:

"~~• Individual projects shall minimize the use of in-water construction methods in areas that support sensitive fish species, especially when fish are present.~~

• Individual projects will avoid the use of in-water construction methods in all state of federally jurisdictional surface waters, where feasible."

Response B-8: The EIR addresses overall implementation of the proposed CTP at a programmatic level of detail as provided under State CEQA Guidelines Section 15168 and is not anticipated to perform full environmental review for all subsequent transportation improvements under the CTP. Subsequent project-level environmental review will likely be required for projects that impact waterways. Nevertheless, the BMP's are not an exhaustive list of required pollution prevention practices, rather the Draft EIR describes the types of measures that will be required to be included in project specific SWPPPs and other water quality protection measures.

Response B-9: EIR addresses overall implementation of the proposed Comprehensive Transportation Plan (CTP) at a programmatic level of detail as provided under State CEQA Guidelines Section 15168 and is not anticipated to full environmental review for all subsequent transportation improvements under the CTP. Subsequent project-level environmental review will likely be required for projects that impact waterways. The following changes are made:

- Draft EIR page 4.8-16, Mitigation Measure 4.8-1a, first bullet is revised and replaced with the following text:

~~"BMPs such as those described above shall be in place and operational prior to major earthwork.~~

BMPs shall be in place and operational prior to any construction activities. Post-construction BMPs shall be in place prior to the commencement of any work within the vicinity of waters of the state."

Response B-10: The EIR addresses overall implementation of the proposed CTP at a programmatic level of detail as provided under State CEQA Guidelines Section 15168 and is not anticipated to full environmental review for all subsequent transportation improvements under the CTP. Subsequent project-level environmental review will likely be required for projects that impact waterways. Nevertheless, guidance and preventative measures similar to those recommended and as required by law, will be followed to ensure compliance with all applicable State CEQA Guidelines. Additionally, the following text will be added as MM 4.8-1e.

- Draft EIR page 4.8-16, is revised to include Mitigation Measure 4.8-1e as follows:

  "<u>Mitigation Measure 4.8-1e: Where specific projects are located within or adjacent to a water body that is under the jurisdiction of the Regional Water Quality Control Board, the projects shall implement the following measures:</u>

  - <u>Include construction BMPs specifically targeted towards retaining sediment onsite, preventing erosion of streambanks and pollution from construction vehicles, and collecting and treating storm water runoff onsite.</u>

  - <u>Utilize staging areas for vehicles that are removed from riparian areas and all construction should occur during the dry season. If such measures cannot be taken, the individual project should be required to analyze alternatives and provide mitigation measures for adverse impacts.</u>

  - <u>Where feasible, avoid the removal of riparian vegetation. If not feasible, the individual project shall be required to demonstrate a plan for revegetation including a post-construction monitoring plan to determine the success of revegetation efforts. Monitoring and maintenance plans shall also be in place to ensure that runoff treatment mechanisms such as sediment basins or silt fences continue to function properly. Runoff from all areas of new impervious surfaces should be mitigated for potential impacts to receiving water quality and flow.</u>

  - <u>Where feasible, specific projects shall incorporate Low Impact Development techniques to implement Mitigation Measure 4.8-1e.</u>"

Response B-11: The EIR addresses overall implementation of the proposed Comprehensive Transportation Plan (CTP) at a programmatic level of detail as provided under State CEQA Guidelines Section 15168 and is not anticipated to full environmental review for all subsequent transportation improvements under the CTP. Subsequent project-level environmental review will likely be required for projects that impact waterways. Nevertheless, guidance and preventative measures similar to those recommended above and as required by law, will be followed to ensure compliance with all applicable State CEQA Guidelines.

Response B-12: Comment noted. The following text changes are made to the Draft EIR:

Draft EIR page 4.8-15, the following text change is made to the first bullet, last sentence:

"MM 4.8-1a "Revegetation shall emphasize ~~drought-tolerant perennial vegetation~~ native vegetation."

Response B-13: The mitigation measures provided in the Draft EIR include performance standards to ensure mitigation of water quality impacts pursuant to State CEQA Guidelines Section 15126.4(a)(1)(B).

Response B-14: Comment noted. The EIR addresses overall implementation of the proposed Comprehensive Transportation Plan (CTP) at a programmatic level of detail as provided under State CEQA Guidelines Section 15168 and is not anticipated to full environmental review for all subsequent transportation improvements under the CTP. Subsequent project-level environmental review will likely be required for projects that impact waterways. Nevertheless, the mitigation measures provided in the Draft EIR provide clear performance standards that could require subsequent projects to mitigate at greater than 1:1 mitigation ratios, on-site mitigation and/or conservation easements depending on the extent of the wetlands impact and site conditions.

Response B-15: A description of these regulatory permit/approval activities are provided on Draft EIR pages 4.4-14 through -16.

Response B-16: Alteration of drainage patterns is addressed under Draft EIR Impact 4.8-3 on Draft EIR page 4.8-17, while water quality impacts are addressed under Draft EIR Impact 4.8-1 on Draft EIR pages 4.8-14 through -16.

Response B-17: Water quality impacts are addressed under Draft EIR Impact 4.8-1 on Draft EIR pages 4.8-14 through -16.

Response B-18: The EIR addresses overall implementation of the proposed Comprehensive Transportation Plan (CTP) at a programmatic level of detail as provided under State CEQA Guidelines Section 15168 and is not anticipated to full environmental review for all subsequent transportation improvements under the CTP. Subsequent project-level environmental review will likely be required for projects that impact waterways and water quality.

Response B-19: The commenter is referred to Response to Comment B-17 and B-18.

Response B-20: The commenter provides a summary of project permits that may be required by the RWQCB. Comment noted.

Letter C

STATE OF CALIFORNIA
GOVERNOR'S OFFICE *of* PLANNING AND RESEARCH
STATE CLEARINGHOUSE AND PLANNING UNIT

ARNOLD SCHWARZENEGGER
GOVERNOR

CYNTHIA BRYANT
DIRECTOR

June 2, 2009

RECEIVED
JUN 08 2009
SONOMA COUNTY
TRANSPORTATION

Seana Gause
Sonoma County Transportation Authority
490 Mendocino Avenue, Suite 206
Santa Rosa, CA 95401

Subject: 2009 Comprehensive Transportation Plan Update
SCH#: 2008082011

Dear Seana Gause:

The State Clearinghouse submitted the above named Draft EIR to selected state agencies for review. The review period closed on June 1, 2009, and no state agencies submitted comments by that date. This letter acknowledges that you have complied with the State Clearinghouse review requirements for draft environmental documents, pursuant to the California Environmental Quality Act.

Please call the State Clearinghouse at (916) 445-0613 if you have any questions regarding the environmental review process. If you have a question about the above-named project, please refer to the ten-digit State Clearinghouse number when contacting this office. C-1

Sincerely,

[redacted]

Terry Roberts
Director, State Clearinghouse

1400 10th Street P.O. Box 3044 Sacramento, California 95812-3044
(916) 445-0613 FAX (916) 323-3018 www.opr.ca.gov

Document Details Report
State Clearinghouse Data Base

SCH#	2008082011
Project Title	2009 Comprehensive Transportation Plan Up
Lead Agency	Sonoma County Transportation Authority
Type	EIR Draft EIR
Description	The SCTA is updating its 2004 Comprehensive Transportation Plan, a long-range transportation blueprint that articulates how Sonoma County's transportation infrastructure (e.g. streets, highways, transit systems and bicycle/pedestrian pathways) will be maintained and improved over the next 25 years.

The SCTA has set the following goals for the 2009 CTP update:

1. Reduce Greenhouse Gas emissions
2. Maintain the existing transportation system
3. Relieve congestion
4. Reduce Emissions
5. Plan for Safety & Health

Upon adoption, the CTP would be forwarded to the Metropolitan Transportation Commission (MTC) for inclusion in the federally-mandated Regional Transportation Plan that allocated projected transportation funds for the nine-county Bay Area region. This ensures that the SCTA's projects, priorities, and other initiatives are reflected in the regional plan. The CTP is financially constrained around projected transportation revenues that are reasonably expected to be available over the 25 year planning period. However, the CTP also includes a set of illustrative transportation projects that would have benefits if additonal revenue is secured in the future.

Note: Blanks in data fields result from insufficient information provided by lead agency.

Document Details Report
State Clearinghouse Data Base

Lead Agency Contact

Name Seana Gause
Agency Sonoma County Transportation Authority
Phone (707) 565-5373 *Fax*
email
Address 490 Mendocino Avenue, Suite 206
City Santa Rosa *State* CA *Zip* 95401

Project Location

Cou
City
Region
Lat / Long
Cross Streets County-wide
Parcel No.
Township *Range* *Section* *Base*

Proximity to:

Highways
Airports
Railways
Waterways
Schools
Land Use

Project Issues Aesthetic/Visual; Agricultural Land; Air Quality; Archaeologic-Historic; Biological Resour es; Cumulative Effects; Flood Plain/Flooding; Geologic/Seismic; Growth Inducing; Landuse; Noise; Population/Housing Balance; Public Services; Recreation/Parks; Schools/Universities; Sewer Capacity; Soil Erosion/Compaction/Grading; Solid Waste; Toxic/Hazardous; Traffic/Circulation; Water Quality; Water Supply; Wetland/Riparian; Wildlife

Reviewing Agencies Resources Agency; California Coastal Commission; Department of Conservation; Department of Fish and Game, Region 3; Office of Historic Preservation; Department of Parks and Recreation; Office of Emergency Services; California Highway Patrol; Caltrans, District 4; Air Resources Board, Transportation Projects; Regional Water Quality Control Board, Region 1; Regional Water Quality Control Board, Region 2; Department of Toxic Substances Control; Native American Heritage Commission

Date Received 04/16/2009 *Start of Review* 04/16/2009 *End of Review* 06/01/2009

Note: Blanks in data fields result from insufficient information provided by lead agency.

Letter C **Terry Roberts, Governor's Office of Planning and Research, State Clearinghouse and Planning Unit**

Response C-1: The commenter states that no state agencies submitted comments by June 1, 2009. Comment noted.

Letter D

Department of Toxic Substances Control

Linda S. Adams
Secretary for
Environmental Protection

Maziar Movassaghi
Acting Director
700 Heinz Avenue
Berkeley, California 94710-2721

Arnold Schwarzenegger
Governor

May 27, 2009

RECEIVE
MAY 2 8 2009
SONOMA COUNTY
TRANSPORTATION

Seana Gause
Sonoma County Transportation Authority
490 Mendocino Avenue, Suite 206
Santa Rosa, CA 95401

COMMENT ON THE DRAFT ENVIRONMENTAL IMPACT REPORT, SONOMA COUNTY TRANSPORTATION AUTHORITY 2009 COMPREHENSIVE TRANSPORTATION PLAN UPDATE

Dear Ms. Gause:

The Department of Toxic Substances Control (DTSC) has reviewed the Draft Environmental Impact Report (DEIR) for Sonoma County 2009 Comprehensive Transportation Plan Update of April 13, 2009. The due date to submit comments is June 1, 2009. As you may be aware, DTSC oversees the cleanup of hazardous substance release sites pursuant to the California Health and Safety Code, Division 20, Chapter 6.8 (Hazardous Substances Account). As a potential Responsible Agency, DTSC is submitting comments to ensure that the California Environmental Quality Act (CEQA) documentation prepared for this project adequately addresses any hazardous substance remediation that might be required as part of the project.

D-1

Based on the review of the DEIR, there are a number of contaminated sites within the project region, particularly along U.S. 101. The Mitigation Measure 4.7-3 proposes to "undertake a Phase I Environmental Assessment.... If contamination is found, the implementation agency shall coordinate remediation of contamination in accordance with applicable Sonoma county, Regional Water Quality Control Board, and state standards." Please be advised that in addition to County and RWQCB standards, DTSC may also need to be consulted for investigation and cleanup of hazardous substances contaminated sites. If you have any questions, please contact me at (510) 540-3844 or alee@dtsc.ca.gov.

Printed on Recycled Paper

Seana Gause
May 27, 2009
Page 2

Sincerely,

[redacted]

Alex Lee
Hazardous Substances Scientist
Brownfields and Environmental Restoration Program

cc: State Clearinghouse and Planning Unit (State.clearinghouse@opr.ca.gov)
Office of Planning and Research
P.O Box 3044
Sacramento, California 95812-3044

Guenther Moskat (GMoskat@dtsc.ca.gov)
CEQA Tracking Center
Department of Toxic Substances Control
P.O. Box 806
Sacramento, California 95812-0806

Nancy Ritter (NRitter@dtsc.ca.gov)
Environmental Planner
Office of Planning & Environmental Analysis
Department of Toxic Substances Control
1001 I Street, 11th Floor
Sacramento, California 95812-0806

Letter D **Alex Lee, Department of Toxic Substances Control**

Response D-1: Comment noted. The following changes are made to the Draft EIR.

Draft EIR page 4.7-15, the following text change is made to the first true paragraph:

MM 4.7-3 "If contamination is found, the implementation agency shall coordinate remediation of contamination in accordance with applicable Sonoma County, Regional Water Quality Control Board, <u>the Department of Toxic Substances Control</u> and state standards."

Letter E

TOMARAS & OGAS, LLP

10755-F SCRIPPS POWAY PARKWAY #281 • SAN DIEGO, CALIFORNIA 92131
TELEPHONE (858) 554-0550 • FACSIMILE (858) 777-5765 • WWW.MTOWLAW.COM

Kathryn A. Ogas — kogas@mtowlaw.com
Brenda L. Tomaras — btomaras@mtowlaw.com

RECEIVED
SONOMA
TRANSPORTATION AUTHORITY

June 19, 2009

VIA U.S. MAIL and E-MAIL

Seana Gause, Program & Project Analyst
Sonoma County Transportation Authority
490 Mendocino Avenue, Suite 206
Santa Rosa, CA 95401

Re: Comments on Draft Environmental Impact Report for the 2009 Comprehensive Transportation Plan Update

Dear Ms Gause:

This comment letter is submitted on behalf of the Lytton Rancheria of Caliornia (hereinafter, "Lytton Tribe"), a federally recognized Indian tribe and sovereign government. The Lytton Tribe submits the following comments on the Draft Environmental Impact Report (DEIR) for the 2009 Comprehensive Transportation Plan Update. We request that these comments, as well as any subsequent comments submitted by the Lytton Tribe, be included in the record for approval of the Project.

REQUESTED

The Lytton Tribe formally requests, pursuant to Public Resources Code §21092.2, to be notified and involved in the entire environmental review process under CEQA during the CTP Projects contemplated under this Plan. This includes adding the Tribe to the distribution list(s) for public notices and public circulation of all documents pertaining to those Projects. The Tribe further requests to be directly notified of all public hearings and scheduled approvals concerning those Projects. Finally, the Tribe would request that a copy of these comments be provided to any project sponsors of any CTP Projects. E-1

Letter to Seana Gause
Re: 2009 Comprehensive Transportation Plan Update DEIR
Page 2

THE LEAD AGENCY MUST INCLUDE INVOLVEMENT OF AND CONSULTATION WITH THE TRIBE IN ITS REVIEW PROCESS

It has been the intent of the Federal Government[1] and the State of California[2] that Indian tribes be consulted with regard to issues which impact cultural and spiritual resources, as well as other governmental concerns. The responsibility to consult with Indian tribes stems from the unique government-to-government relationship between the United States and Indian trib This arises when tribal interests are affected by the actions of governmental agencies and departments such as approval of Specific Plans and EIRs. In this case, it is undisputed that portions of the project lie within Lytton Tribe's traditional territory and the Tribe appreciates the Sonoma County Transportation Authority's willingness to consult with the Tribe on this Plan, as well as to keep the Tribe informed of the progress of this Plan.

LYTTON TRIBAL CULTURAL AFFILIATION TO THE PROJECT AREA AND PROJECT IMPACTS TO CULTURAL RESOURCES

E-2

The Lytton Band is not opposed to this project. The Tribe's primary concerns stem from the project's likely impacts on Native American cultural resources. The Lytton Band has a lega and cultural interest in the proper protection of sacred places and all Pomo cultural resources. The Tribe is concerned about both the protection of unique and irreplaceable cultural resources, such as Pomo village sites and archaeological items which would be displaced by development, and with the proper and lawful treatment of cultural items, Native American human remains and sacred items likely to be discovered in the course of development and improvements within the Plan Area.

The Pomo people, and the Lytton Rancheria in particular, traditionally occupied the geographical area known today as the County of Sonoma for thousands of years, including the area of Alexander Valley and within the Town of Windsor. This is verified through stories and songs of the Pomo people that are cultural evidence of the Tribe's cultural affiliation with these lands. Occupation is also evidenced through the location of the Tribe's prior reservation, anthropological studies, archaeological studies, and histories of the area. In addition, Tribal ties to these territories have been maintained to the present day through cultural and governmental actions.

While the Programmatic DEIR did not have any cult ral resources surveys performed as a direct result of the analysis of potential impacts of the Plan on c ltural resources, the DEIR does note that there are over 3600 cultural reso rces within the County. This indicates a rich history of cultural resources within the County of Sonoma and the Tribe believes that it is crucial

E-3

[1] See Executive Memorandum of April 29, 1994 on Government-to-Government Relations with Native American Tribal Governments and Executive Order of November 6, 2000 on Consultation and Coordination with Indian Tribal Governments.

[2] See California Public Resource Code §5097.9 et seq. and Cal. Govt. Code §§ 65351, 65352, 65352.3 and 65352.4.

Letter to Seana Gause
Re: 2009 Comprehensive Transportation Plan Update DEIR
Page 3

that the environmental documents for each specific project (CTP Project) include an analysis of potential impacts to cultural resources. Given that Native American cultural resources may be affected by the CTP Projects, the project sponsors should include adequate consultation with the Tribe in assessing the potential impacts and developing adequate mitigation for such impacts. Thus far in the DEIR, this aspect of consultation is lacking as evidenced by the proposed mitigation measures. E-3

Finally, the Tribe believes that if human remains are discovered, State law would apply and the mitigation measures for the Project must account for this. According to the California Public Resources Code, § 5097.98, if Native American human remains are discovered, the Native American Heritage commission must name a "most likely descendant," who shall be consulted as to the appropriate disposition of the remains. E-4

DRAFT EIR AND MITIGATION MEASURES

Environmental Impact Reports must provide adequate protection for significant archaeological and cultural sites and adequately follow the provisions of CEQA and its Guidelines, including Calif. Pub. Res. Code § 21083.2(b) (avoidance as preferred method of preservation of archaeological resources), CEQA Guidelines § 15126.4(b)(3) (agencies should avoid effects on historical resources of archaeological nature), and CEQA Guidelines § 15020 (lead agency responsible for adequacy of environmental documents). E-5

The Tribe requests the following revisions be made to the proposed mitigation measures (for ease of reading and to reduce space, portions of the measures which are not impacted by the revisions will be left out and noted with elisions):

MM 4.5-2a During the environmental review process for proposed CTP projects, project sponsors, in consultation with the appropriate affiliated tribe(s), shall determine if there is a potential for a significant impact to cultural resources to occur.

. . .

MM 4.5-2b If a potentially significant cultural resource is encountered during subsurface earthwork activities for the project, all construction activities within a 100-foot radius of the find shall cease until a qualified archaeologist, in consultation with the appropriate affiliated tribe(s), determines whether the resource is significant. The project sponsor shall include a standard inadvertent discovery clause, including a requirement for consultation with the appropriate affiliated tribe(s), in every construction contract to inform contractors of this requirement. . . . E-6

MM 4.5-2c The project sponsor shall implement the appropriate mitigation measures presented by a qualified archaeologist, and developed in consultation with the appropriate affiliated tribe(s), for an unanticipated discoveries of significant resources, based upon applicable state and federal regulations. .

Letter to Seana Gause
Re: 2009 Comprehensive Transportation Plan Update DEIR
Page 4

The Lytton Tribe looks forward to working together with the Sonoma County Transportation Authority and other interested agencies in protecting any invaluable Pomo cultural resources found in the Project area. Should you have any questions, please do not hesitate to contact me.

Very truly yours,

TOMARAS & OGAS, LLP

[redacted]

Brenda L. Tomaras
Attorneys for the Lytton Rancheria of California

Letter E **Brenda L. Tomaras, Lytton Rancheria of California**

Response E-1: The Lytton Tribe will continue to be notified of SCTA actions associated with the consideration and implementation of the CTP.

Response E-2: Comment noted. SCTA has considered this comment letter as well as comments received from the Lytton Tribe on the Notice of Preparation (see Draft EIR Appendix A). If it is determined that there is a potential to impact cultural resources, certain projects will be required be required to notify and inform the Lytton Tribe during the environmental review process.

Response E-3: Comment noted. SCTA has considered this comment letter as well as comments received from the Lytton Tribe on the Notice of Preparation (see Draft EIR Appendix A) in the preparation of this EIR. If it is determined that there is a potential to impact cultural resources, certain specific projects will be required be required to consult with the Lytton Tribe.

Response E-4: The commenter is referred to Draft EIR page 4.5-16, mitigation measure MM 4.5-2d.

Response E-5: Comment noted. The Draft EIR provides an analysis of potential archaeological and cultural resource impacts and identifies mitigation measures to be applied to subsequent projects under the CTP to protect such resources (see Draft EIR pages 4.5-13 through -16).

Response E-6: The commenter requests revisions to be made to the Draft EIR mitigation measures.

Draft EIR page 4.5-15, the following text change is made:

"MM 4.5-2a During the environmental review process for proposed CTP projects, project sponsors<u>, in consultation with the appropriate culturally affiliated tribe(s),</u> shall determine if there is a potential for a significant impact to cultural resources to occur."

"MM 4.5-2b If a potentially significant cultural resource is encountered during subsurface earthwork activities for the project, all construction activities within a 100-foot radius of the find shall cease until a qualified archaeologist<u>, in consultation with the appropriate culturally affiliated tribe(s),</u> determines whether the resource is significant. The project sponsor shall include a standard inadvertent discovery clause, <u>including a requirement for consultation with the appropriate culturally affiliated tribe(s),</u> in every construction contract to inform contractors of this requirement**."**

"MM 4.5-2c The project sponsor shall implement the appropriate mitigation measures presented by a qualified archaeologist, and developed in consultation with the appropriate affiliated tribes(s), for any discovery of significant resources, based on applicable state and federal regulations**."**

Letter F

From: Adams, Nancy [mailto:NAdams@srcity.org]
Sent: Tuesday, June 23, 2009 3:00 PM
To: Janet Spilman
Cc: Babauta, Mona; Dunlavey, Robert; Nutt, Jason; Moshier, Rick; Kolin, Jeff; Suzanne Smith; Fruiht, Patricia; @0100 - City Council; Parker, Joanne
Subject: CTP-DEIR

Janet,

The City of Santa Rosa Public Works Department is submitting the following comments on the SCTA's Comprehensive Transportation Plan (CTP) DEIR.

- *We recognize the challenge to achieve the goals of the Plan stretches beyond what is fiscally constrained and that after the implementation of the mitigation measures the impacts remain significant. While it does not reach the goals, the Plan does move the County in a positive direction based on current local land use plans that assume smart growth, transit /bicycle/pedestrian expansion and pricing measures.* **F-1**
- *The Plan supports growth in the County that would increase daily VMT by 2035 over existing conditions, which equates to an increase of 26 percent. The Plan identifies that "The SCTA shall encourage local governments to implement strategies to mitigate increases in VMT such as land use and pricing strategies". Local land use decisions/policies and potential pricing strategies would be the responsibility of the local jurisdiction.* **F-2**
- *The City has provided network and capital project information during the Plan development and we concur with the proposed recommended infrastructure improvements.* **F-3**
- *The City has been successful in constructing ITS, bicycle and pedestrian projects which are consistent with the Plan. We will continue to pursue opportunities to implement these types of projects which help achieve the non- motorized goals.* **F-4**

We appreciate the opportunity to comment on the DEIR. If you have any questions regarding our comments, please contact me.

nancy

Letter F Nancy Adams, City of Santa Rosa Public Work Department

Response F-1: Comment noted. Since no comments regarding the analysis is in the Draft EIR were provided, no further response is required.

Response F-2: Comment noted. Since no comments regarding the analysis is in the Draft EIR were provided, no further response is required

Response F-3: Comment noted. Since no comments regarding the analysis is in the Draft EIR were provided, no further response is required.

Response F-4: Comment noted. Since no comments regarding the analysis is in the Draft EIR were provided, no further response is required.

Letter G

From: Parker, Joanne [mailto:JParker@srcity.org]
Sent: Tuesday, June 23, 2009 11:18 AM
To: Janet Spilman
Cc: Babauta, Mona; Dunlavey, Robert; Adams, Nancy; Nutt, Jason; Moshier, Rick; Kolin, Jeff; Suzanne Smith; Fruiht, Patricia; @0100 - City Council
Subject: Santa Rosa CityBus comments on SCTA CTP-DEIR

Janet,

On behalf of the City of Santa Rosa's Department of Transit (Santa Rosa CityBus), I respectfully submit the following comments on the SCTA's Comprehensive Transportation Plan (CTP) Draft Environmental Impact Report (DEIR).

First, we would like to recognize that SCTA staff have made every effort to include Santa Rosa CityBus in the development of both the CTP and the EIR work accompanying the CTP. In addition to the work on the CTP, SCTA staff has worked in collaboration with Santa Rosa CityBus staff (starting in February 2008) on the Metropolitan Transportation Commission's (MTC's) Regional Transportation Plan (RTP), entitled Transportation 2035, or T2035. **G-1**

Second, we would like to thank the SCTA staff for their support for the inclusion of Santa Rosa CityBus projects in the CTP and T2035. These projects include Santa Rosa Rapid Bus projects, CityBus bus expansion, CityBus technology enhancements and CityBus facility improvements, for a combined total of $76 million in the financially constrained portion of MTC's T2035 over 25 years. These Santa Rosa CityBus capital projects and increases in bus frequency on most corridors are included in the CTP DEIR Preferred Alternative (Section 3.0-1.4), as well as in Alternatives 2, 3 and 4 of the DEIR. **G-2**

Third, we would like to encourage SCTA staff to continue to assist with the programming of actual funds in accordance with the 'planned programming' prioritized in the financially constrained portion of T2035 and in accordance with the various Alternatives from the DEIR that show the implementation of Santa Rosa CityBus improvements. Without actual funding, these long range planning documents are just documents and the projects contained inside will not come to fruition. **G-3**

Finally, one overall point about the CTP DEIR is that although the Preferred Alternative results in increases to Vehicle Miles Traveled (VMT) and Greenhouse Gas (GHG) emissions, we realize that the "do nothing" scenario results in even greater increases in VMT and GHG emissions. The natural growth and land use choices within the county are what is driving the VMT and GHG increases, not the projects included in the CTP Preferred Alternative per se. It is worth mentioning that the City of Santa Rosa has had *Potential Priority Development Areas* designated through the regional FOCUS program around high frequency bus corridors (Sebastopol Road Corridor and Mendocino/Santa Rosa Corridor) as an indication of the City's long-range intent to develop attractive land uses that are well served by transit, bicycle and pedestrian facilities. That potential infill growth, particularly if it is in lieu of the land use choices currently outlined in the CTP DEIR as the predicted growth pattern county-wide, could result in a significant downward shift of the actual VMT and GHG emissions numbers compared to the numbers predicted county-wide in the CTP DEIR. **G-4**

Thank you for the opportunity to comment on the SCTA's Comprehensive Transportation Plan and Draft Environmental Impact Report.

Please let me know if you have any questions about our comment letter.

Thank you,

Joanne Parker | Transit Planner
Santa Rosa CityBus | Department of Transit and Parking
100 Santa Rosa Avenue, Room 6 | Santa Rosa, CA 95404
Tel. (707) 543-4601 | Fax (707) 543-3326
jparker@srcity.org

logo for email signatures

Copy: Santa Rosa City Council

Letter G Joanne Parker, Santa Rosa CityBus

Response G-1: Comment noted. Since no comments regarding the analysis is in the Draft EIR were provided, no further response is required

Response G-2: Comment noted. Since no comments regarding the analysis is in the Draft EIR were provided, no further response is required.

Response G-3: Comment noted. Since no comments regarding the analysis is in the Draft EIR were provided, no further response is required.

Response G-4: As identified on Draft EIR pages 5.0-21 and -22, implementation of the proposed CTP would result in a 21.6% reduction in current GHG emissions as compared to existing conditions, thus no significant greenhouse gas emission impact was identified. This comment is noted.

Letter H

May 18, 2009

Seana Gause
Program & Project Analyst
Sonoma County Transportation Authority
490 Mendocino Avenue, Suite 206
Santa Rosa, CA 95401

Re: Proposed 2009 CTP Draft EIR

Gentlepersons,

After reviewing the proposed 2009 CTP and the draft EIR I do not see any mention of school transportation as a part of the plan. Although local and regional transportation planning does not generally include school transportation I respectfully request that some consideration be given in the future.

School transportation is by far the largest mass transportation system in the state. In Sonoma County, school districts that offer school transportation service do so with comprehensive programs that cover their entire geography. Currently there are over 300 school buses operating in Sonoma County serving approximately 9,000 students daily. That translates to approximately 3,240,000 passenger boardings every school year.

School transportation is funded through the education budget, but funding was frozen twenty-six years ago. We have rarely been given a COLA over the years and the balance of the funding comes directly from classroom budgets. Many school districts have reduced service over the years in response to this poorly funded program. These decisions force parents to drive students in their cars, increasing vehicle miles traveled, fuel consumption, tailpipe emissions and congestion around schools in the mornings and afternoons. Further, the State has raided the Public Transit Account to backfill school transportation funding creating more conflict and division. **H-1**

School is the perfect place to educate young citizens on the benefits of mass transportation and other green transportation options. Instead, however, we as a State and County seem to be adopting policies that discourage bus use and encourage single occupant vehicles.

I urge you in your future planning to consider school transportation as an important and viable element of local transportation planning.

Sincerely,

[redacted]

Michael G. Rea

C: WCTA Board of Directors

West County Transportation Agency, 367 West Robles Avenue, Santa Rosa, CA 95407 (707) 206-9988 Fax (707) 206-9901
www.schoolbusing.com
"Serving the school district transportation needs of Sonoma County"

Letter H Michael G. Rea, West County Transportation

Response H-1: While the proposed CTP does not include specific improvements for school transportation, it does include pedestrian and bicycle improvements as well as traffic safety and safe routes for school projects that would benefit school transportation needs. In addition, the CTP includes an accelerated school bus replacement strategy/action in its strategic projects list to be coordinated with school districts, state and federal government (see CTP page 99).

Letter I

TOWN OF WINDSOR

Town of Windsor
9291 Old Redwood Highway
P.O. Box 100
Windsor, CA 95492-0100
Phone: (707) 838-1000
Fax: (707) 838-7349

www.townofwindsor.com

Mayor
Robin Goble

Vice Mayor
Sam Salmon

Councilmembers
Steve Allen
Debora Fudge
Cheryl Scholar

Town Manager
J. Matthew Mullan

June 17, 2009

Seana Gause, Program and Project Analyst
Sonoma County Transportation Authority
490 Mendocino Avenue, Ste. 206
Santa Rosa, CA 95401
sgause@sctainfo.org

SUBJECT: Comments on the Sonoma County Transportation Authority 2009 Comprehensive Transportation Plan Draft Environmental Impact Report

Dear Ms. Gause,

The Town is concerned that the DEIR identified significant and unavoidable adverse environmental impacts resulting from adoption of the 2009 Comprehensive Transportation Plan (the project). Plan adoption will accommodate an increase of about 3 million miles vehicle trips (VMT) per day by 2035 for the County area. What was the methodology used to promote a project that will lead to the significant increase in VMT? **I-1**

The DEIR identifies the Environmentally Superior Alternative among the alternatives including the project as Alternative 3: "VMT Reduction-Transit Expansion/Smart Growth Scenario." Please provide additional documentation that Alternative 3 is feasible as defined by CEQA and can meet the objectives of the project. Will any of the identified significant and unavoidable adverse environmental impacts be reduced or eliminated by implementation of this alternative? **I-2**

The Town supports city center development and the ABAG Focused Future Smart Growth population forecasts. The Town is seeking funding to prepare a Station Area Plan that will plan for increased residential densities and Smart Growth in the vicinity of the Town's Intermodal Transit Center. **I-3**

The Town requests that we receive notice of availability of the Response to Comments/Final EIR and notice of the SCTA Board of Directors meetings to certify the EIR and consider adoption of **I-4**

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the 2009 Comprehensive Transportation Plan. Please send notice to the Town Manager and Planning Director at Town of Windsor, P.O. Box 100, Windsor, CA 95492. I-4

[redacted]

Peter Chamberlin
Building & Planning Director

cc: Town Council
Town Manager
Public Works Director

I:\60 - Planning & Building Dept\Planning Department\09\09-40 SCTA 2009 CTP EIR\DEIR Comment Letter.Doc

Printed on recycled paper

Letter I, Peter Chamberlin, Town of Windsor

Response I-1: The Draft EIR analysis does acknowledge that VMT is anticipated to increase by approximately 26% over existing conditions. The proposed CTP has identified its desired intent of meeting the VMT reduction target through transit, roadway improvements, land use improvement (smart growth and supportive transit), transportation technology improvements and transportation pricing policies. However, current funding and SCTA authority limitations inhibit the CTP's ability to fully implement these strategic projects (see CTP pages 95 through 99) to meet this VMT reduction (see CTP page 50). Thus, the environmental impact analysis in the Draft EIR is conservatively based on projects and improvements that are feasible for SCTA to implement and have known existing and planned funding sources (e.g., Measure M and funding from the Metropolitan Transportation Commission) (see CTP page 35 and Draft EIR pages 3.0-10 through -13). The methodology and traffic modeling associated with the proposed CTP that was utilized in the Draft EIR is summarized on Draft EIR pages 4.3-27 and -28 and described in detail in Appendix C, vi. Sonoma County Travel Model Update & Analysis of the CTP (see CTP pages 167-199).

The commenter is also referred to Master Response 3.4.5, [i.e., employment and population growth as a factor that leads to increases in VMT (Climate Change and Greenhouse Gas Emission Impacts).]

Response I-2: The commenter is referred to Master Response 3.4.6 (Adequacy of Alternatives Analysis) regarding the development of the range of alternatives (including Alternative 3) evaluated in the Draft EIR that meet the purpose and objectives of the CTP. Final determination of the feasibility of the alternatives evaluated in the EIR will documented in the CEQA Findings of Fact that will made at the time of project approval (should the proposed CTP be adopted). However, it should be noted that Alternative 3 includes transportation improvements that are not currently funded, and actions that are outside SCTA's direct control that will likely limit its ability to be determined a feasible alternative pursuant to State CEQA Guidelines Section 15091 (a)(3).

Draft EIR pages 6.0-38 through -42 provide an analysis and comparison of Alternative 3 to the proposed CTP, including improvements in air quality and traffic. Section 4.0 of this provides an updated analysis of energy and greenhouse gas emission estimates for the proposed CTP and the alternatives that includes identification of improved energy and climate change effects as compared to the proposed CTP. As identified in Draft EIR Table 6.0-21, Alternative 3 would reduce significant impacts identified for the proposed project, but would not eliminate these significant impacts.

Response I-3: Comment noted. Since no comments regarding the analysis is in the Draft EIR were provided, no further response is required.

Response I-4: The commenter request the Notice of Availability of the Response to Comments/FEIR and Notice of the SCTA Board of Director's meeting certifying the EIR adopting the 2009 CTP. SCTA will provide noticing of future meetings when the Final EIR and CTP will be considered by the Board of Directors.

Letter J

CITY OF PETALUMA

POST OFFICE BOX 61
PETALUMA, CA 94953-0061

Pamela Torliatt
Mayor

Teresa Barrett
David Glass
Mike Harris
Mike Healy
David Rabbitt
Tiffany Renée
Councilmembers

Public Works

Administration
11 English Street
Petaluma, CA 94952

Phone (707) 778-4474
Fax (707) 776-3602
E-Mail: publicworks@ci.petaluma.ca.us

Airport
601 Sky Ranch Drive
Petaluma, CA 94954
Phone (707) 778-4404
Fax (707) 778-4405

Corporation Yard
(Maintenance & Operations)
840 Hopper St. Ext.
Petaluma, CA 94952
Phone (707) 778-4303
Fax (707) 778-4437

Transit
555 N. McDowell Blvd.
Petaluma, CA 94954
Phone (707) 778-4421
Fax (707) 776-3799

June 18, 2009

Janet Spilman, Deputy Director Planning
Sonoma County Transportation Authority
490 Mendocino Ave., Suite 206, Santa Rosa, CA 95407
(707) 565-5370 (facsimile)
webscta@sctainfo.org

Re: Sonoma County Comprehensive Transportation Plan (CTP), Draft Environmental Impact Report - Comments

Dear Janet:

Thank you for including the City of Petaluma in the environmental review process. We have reviewed the above referenced document and have the following comments:

Traffic and Circulation

While it is clear that the improvements outlined in the CTP will be beneficial to Sonoma County, several sections suggest that, once these improvements are installed, there will be significant and unavoidable associated impacts. **J-1**

These unavoidable impacts may be lessened with the extension of Measure M for another 10 years. With continuation of this funding, issues relating to additional needed improvements and maintenance could be addressed.

Bicycle Projects

The CTP does not include any of the City of Petaluma's bicycle projects. We are requesting you add the enclosed Attachment A to the plan. **J-2**

Transit Service

The CTP does not include any of the City of Petaluma's transit projects. We are requesting you add the following to the plan:

Petaluma Transit Planned Projects **J-3**

Signal Priority Implementation
Design and installation of transit signal priority system on Petaluma Transit fixed-route fleet

$100,000

Facility Needs Assessment
Study to identify potential facility needs for Petaluma Transit, including additional passenger transfer facilities, expansion of existing passenger transfer facilities, and future space requirements at existing admin, operations, and maintenance facility
$50,000

Upgrade Facility
Acquisition, planning, design, and construction of new or expanded transit facilities identified in Facility Needs Assessment Study
$3,000,000

Registering Fareboxes
Purchase and installation of electronic registering fareboxes on Petaluma Transit fleet
$150,000

Paratransit Dispatching Software
Purchase and installation of paratransit dispatching software system for Petaluma Paratransit
$50,000

Bus Stop Improvements
Bus stop enhancements, including expanded seating, lighting, information, and shelter rehab
$100,000

Surveillance Cameras on Vehicles
Purchase and installation of security surveillance audio and video systems in Petaluma Transit buses
$50,000

Communication Equipment
Purchase and installation of improved radio and GPS communications systems in Petaluma Transit buses
$46,371

J-3

<u>Petaluma Transit Vision Projects</u>

Real Time Transit Information	$1,500,000
Future Fare Reductions / Expansions	$75,000
SRJC Impact Fees	$50,000
Implementation of Transportation Demand Management (TDM) Program	$100,000
Potential Bus Rapid Transit (BRT) Project	$10,000,000
Bus Stop Improvements	$1,000,000
Ferry and Water Taxi	$20,000,000
Airport / Transit Asset	$3,000,000
Parking Structure Next to Transit Mall	$5,000,000

We appreciate the opportunity to work with you on this project and wish to continue close correspondence on its development. Please call me at (707) 778-4467 if you have any questions.

Sincerely,

[redacted]

Vincent Marengo
Director of Public Works

ATTACHMENT A

City of Petaluma
Bicycle Projects

Name	Begin	End	Class	Length	SF BAY AREA REGIONAL ROUTE	Cost	Plan	Existing or Proposed
NWP Trail	Northern UGB Limit	Southern UGB Limit	I	5.68	Yes		Petaluma	Proposed
Petaluma River Trail	Petaluma Blvd. North	Denman Phase I	I	0.52	Yes		Petaluma	Proposed
Petaluma River Trail	Denman Phase I	Corona Road	I	0.25	Yes		Petaluma	Existing
Petaluma River Trail	Corona Road	Factory Outlets	I	0.55	Yes		Petaluma	Proposed
Petaluma River Trail	Factory Outlets	Factory Outlets	I	0.34	Yes		Petaluma	Existing
Petaluma River Trail	Factory Outlets	Lynch Creek	I	1.10	Yes		Petaluma	Proposed
Petaluma River Trail	Lynch Creek	Lakeville Street	I	0.60	Yes		Petaluma	Existing
Petaluma River Trail	Lakeville Street	E. Washington Street	I	0.37	Yes		Petaluma	Proposed
Petaluma River Trail	E. Washington Street	C Street	I	0.24	Yes		Petaluma	Existing
Petaluma River Trail	C Street	NWP Trail at Petaluma River	I	1.47	Yes		Petaluma	Proposed
Petaluma River Trail	Petaluma Marina	Shollenberger Park	I	1.97	Yes		Petaluma	Existing
Petaluma River Trail	Shollenberger Park	Southern City Limit	I	1.77	Yes		Petaluma	Proposed
Frates Road	Eastern City Limit	Ely Road	II	0.71	Yes		Petaluma	Proposed
Frates Road	Ely Road	Lakeville Highway	II	0.44	Yes		Petaluma	Existing
Lakeville Highway	Southern City Limit	East D Street	II	2.85	Yes		Petaluma	Proposed
Lakeville Street	East D Street	East Washigton Street	II	0.14	Yes		Petaluma	Existing
East Washington St	Lakeville Street	Howard Street	III	0.62	Yes		Petaluma	Proposed
Bodega Avenue	Howard Street	Webster Street	III	0.42	Yes		Petaluma	Proposed
Bodega Avenue	Webster Street	Western City Limit	II	0.33	Yes		Petaluma	Existing
Bodega Avenue	Western City Limit	Western UGB Limit	II	0.14	Yes		Petaluma	Proposed
Stony Point Road	Northern UGB Limit	Petaluma Blvd. North	II	0.84	Yes		Petaluma	Proposed
Old Redwood Highway	Eastern UGB Limit	Willow Brook Creek Crossing	II	0.31	Yes		Petaluma	Proposed
Old Redwood Highway	Willow Brook Creek Bridge	North McDowell Blvd.	II	0.27	Yes		Petaluma	Existing
Old Redwood Highway	North McDowell Blvd	101 Interchange	II	0.25	Yes		Petaluma	Proposed
Petaluma Boulevard	101 Interchange	Bailey Avenue	II	0.36	Yes		Petaluma	Proposed
Petaluma Boulevard	Bailey Avenue	Shasta Avenue	II	2.00	Yes		Petaluma	Existing
Petaluma Boulevard	Shasta Avenue	Lakeville Street	II	0.41	Yes		Petaluma	Proposed
Petaluma Boulevard	Lakeville Street	D Street	III	0.71	Yes		Petaluma	Proposed
Petaluma Boulevard	D Street	Southern UGB Limit	II	1.88	Yes		Petaluma	Proposed

Letter J, Vincent Morengo, City of Petaluma

Response J-1: Comment noted. Significant transportation impacts (see Draft EIR Impacts 4.3-1, 4.3-2, 4.3-3 and 4.3-4) are still anticipated based on traffc modeling of the 2009 CTP.

Response J-2: This comment is associated with the proposed CTP and is not related to the adequacy of the Draft EIR and no further response is required. However, this request will be forwarded to the SCTA Board of Directors as part of consideration of comments received on the 2009 CTP.

Response J-3: This comment is associated with the proposed CTP and is not related to the adequacy of the Draft EIR and no further response is required. However, this request will be forwarded to the SCTA Board of Directors as part of consideration of comments received on the proposed CTP.

Letter 1

SIERRA CLUB
FOUNDED 1892

Sonoma Group
Redwood Chapter
P.O. Box 466
Santa Rosa, CA 95402

June 22, 2009

Seana Gause, Program & Policy Analyst
Sonoma County Transportation Authority
490 Mendocino Ave, Ste 206
Santa Rosa, CA 05401

Re: Comment on Draft Environmental Report
SCTA Draft Comprehensive Transportation Plan

Dear Ms. Gause—

We appreciate this opportunity to comment on the above Draft Environmental Report, which states that the Draft Comprehensive Transportation Plan falls short of its own greenhouse gas reduction goals. The Sierra Club is deeply concerned about the effects of greenhouse gas emissions on the Earth. We question why the Draft EIR does not provide policy makers with the information needed to remedy the shortcomings of the Draft CTP. **1-1**

In 2005 the County and all of the cities in the county adopted a GHG emissions reduction target of 25% below 1990 levels by the year 2015. In July, 2008, the SCTA Board concurred with that goal, and also accepted the Metropolitan Transportation Commission goal to reduce GHG emission to 40% below 1990 levels by 2035. It is becoming clear from ongoing climate change research that these goals are not too aggressive. **1-2**

The present atmospheric concentration of 387 parts per million carbon dioxide equivalents appears to be causing grave damage to oceans, biosphere, forests, and agriculture. It is now seriously suggested that concentrations need to decline to 350 ppm or even 300 ppm in order to avoid catastrophic loss of sea ice and unmanageable releases of methane gas. This could require net GHG emissions to fall to near-zero levels in a short space of time. The goals adopted in Sonoma County put us into a position of leadership on an issue where we can develop tools of real value to others.

The Draft EIR makes it clear that we are not making enough progress in Sonoma County to control our carbon foot-print. This is important information, since transportation accounts for 60% of Sonoma County's greenhouse gas emissions. It means that the local government electric vehicle partnership working with Nissan North America, Inc. to acquire up to 1000 zero emission electric vehicles in 2010 must be expanded. Why does the Draft EIR not state how rapidly the expansion should take place? The pilot project to locate battery recharge points at malls and parking garages must also grow, but how quickly? And how extensively should AB 811 funding be applied to solar recharge installations by homeowners and businesses? **1-3**

Bicycle use can be one of the easiest and most economical ways to reduce GHG. Bicycle lanes are already making more people feel safe using their bicycles but the Draft EIR does not state **1-4** how quickly they should be expanded to meet the goals of the plan. How rapidly should plans for expansion of Safe Routes to School programs, the SRJC Hwy 101 bike and pedestrian bridge the SMART Trail, Central Sonoma Valley Trail, Laguna de Santa Rosa Trail from Cotati to Sebastopol and the east-west bicycle pedestrian path through the Russian River Areas be implemented? **1-4**

The Climate Protection Campaign expects attractive, walkable business & residential districts with good public transportation to reduce GHG by about 12% for the county as a whole by 2015. The start of SMART train service in 2014 should be a catalyst for development of such districts. Station-area planning is being implemented for the Santa Rosa Depot Area, is under way in Cloverdale, and should begin soon for the Jennings Station Area. Petaluma and Cotati already have dense and walkable areas close to their historic station areas. All cities in the county have urban growth boundaries, except Cloverdale, which is in the process of adopting such a boundary. How will these developments affect GHG emissions by 2035? **1-5**

The Draft EIR states that over 25 years the Draft CTP results in a significant and unavoidable increase in fuel consumption amounting to 159 thousand gallons per day. [Energy Impact 4.13-1 – Consumption of petroleum-based products. Page 1.0-27.] To what extent does the increase in fuel consumption prevent the accomplishment of Goal 3 of the draft CTP to: "Meet the targets to reduce GHG emissions 25% below 1990 levels by 2015, and 40% below 1990 levels by 2035?" These goals are the equivalent of a 37% reduction from 2005 conditions by 2015, and a 60% reduction by 2035. **1-6**

Elsewhere, the Draft EIR states that instead of reducing GHG (carbon dioxide equivalent) emissions to reach the goal of 40% below 1990 levels by 2035, the financially constrained elements of the plan reduce GHG emissions only to 1990 levels. [Table 5.0-3 Motor Vehicle Forecasts – Greenhouse gas emissions. Page 5.0-21.] The unconstrained elements of the CTP fail to meet 2015 goals for 20 years, reaching them instead in 2035. This failure to satisfy the goals of the plan is of great significance. Why is it omitted from the executive summary? Why does the Draft EIR fail to analyze the financially unconstrained parts of the CTP and their failure to meet the goals? **1-7**

It is important to make relevant additional data available in the Final EIR so that policy makers and the public can intelligently craft a Final CTP that spells out the steps needed to meet the greenhouse gas reduction goals. More funding is likely to become available for GHG reduction programs in the transportation arena. This is an opportune time to develop robust guidelines to make the necessary progress. The plan can also encourage consistency with AB 32, SB 375 and integrate with the SMART train. **1-8**

We are grateful that Sonoma County has led the State and the Nation in devising programs to deal with the threat of global climate change. The Draft EIR suggests that the Final CTP will need to be much more robust to achieve the goals adopted by the SCTA in July, 2008. We ask for an improved and more focused Final EIR so that the Final Comprehensive Transportation Plan can guide us toward its goals. **1-9**

Sincerely,

[redacted]

Steve Birdlebough, Chair

Letter 1 Steve Birdlebough, Sierra Club

Response 1-1: The Draft EIR analyzes the proposed CTP and discloses the environmental impacts of implementing the 2009 CTP (see Draft EIR pages 5.0-9 through -26). As described on Draft EIR page 2.0-2, an EIR is a public informational document that assesses potential environmental effects of the 2009 CTP. It is not an implementation document identifying how to address policy issues of the CTP. The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 1-2: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts). The Draft EIR addresses climate change and greenhouse gases in Section 5.4 (Climate Change) of the Draft EIR.

Response 1-3: The commenter should note that the CTP is a programmatic, policy document. The implementation and timing of individual projects contained with the CTP are unknown. It is beyond the scope of the CTP and Draft EIR to recommend how rapidly the expansion of vehicle partnership with Nissan North America to acquire 1,000 zero emission electric vehicles should occur. It is also beyond the scope of the CTP and Draft EIR to recommend the growth rate of pilot projects for battery recharge points and the extent of AB 811 funding. The proposed actions in the Draft EIR are limited by the current funding and SCTA authority limitations which inhibit the CTP's ability to fully implement these strategic projects (see CTP pages 95 through 99) to meet this VMT reduction (see CTP page 50). The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts)

Response 1-4: The CTP is a policy document and the Draft EIR is a program EIR, therefore the goals, objectives and policy recommendations of the CTP and mitigation measures recommend in the Draft EIR cannot recommend timing for specific projects contained within the CTP because they are outside of the scope of the CTP and Draft EIR documents. Every new project in within the CTP is subject to a project-specific environmental review before it's implementation or construction as required by CEQA. As such, as the project specific environmental review occurs, details regarding the implementation and timing of specific bicycle lanes and bicycle programs may also occur.

The commenter is referred to Master Response 3.4.4 (Program EIR/Level of Detail) and Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 1-5: Scenario 4 of the proposed CTP identifies VMT reduction through transit expansion and smart growth. As further described in Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts), while the CTP has identified its desired intent of meeting its greenhouse gas (GHG) emission reduction target through transit, roadway improvements, land use improvement (smart growth and supportive transit), transportation technology improvements and transportation pricing policies, the SCTA does not have the authority concerning land use decisions. Although all of the communities within the County (with the exception of Cloverdale) have urban growth boundaries, and SMART train service is planned for the CTP area which includes planning for walkable business and residential districts, the CTP is a policy document and the Draft EIR is a program EIR. Therefore, the effects of future land use policies and their implementation within specific jurisdictions will be analyzed as subsequent projects contained within the CTP are subject to project-specific environmental review as required by CEQA. As such, when project specific environmental review occurs, these types of development and their affect on GHG emission reduction, will occur, if applicable.

Response 1-6: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts) regarding correction to energy consumption analysis in the Draft EIR.

Response 1-7: The Draft EIR Section 1.0, Executive Summary provides a brief overview of the types of projects contained within the 2009 CTP and the impacts and mitigation measures associated with these projects. Please refer to Draft EIR Section 3.0, Overview of the CTP, which provides a more detailed description of the goals of the CTP. Section 3.0 also provides the rationale for analyzing the Constrained Project Alternative. The commenter is also referred to Response to Comments 1-1 regarding the purpose of an EIR.

Response 1-8: The commenter is referred to Section 5.0 Cumulative Impacts of the Draft EIR, which discusses the both the regulatory framework of both AB 32 and SB 375 (Draft EIR pages 5.0-17 through 5.0-18) and the CTPs beneficial impacts associated with reducing GHG emissions.

Although more funding may become available for GHG reduction programs in the transportation arena, currently the CTP is limited to projects that are feasible within the financially constrained scenario, as they are the most likely projects to be funded. Moreover, Scenario 4 of the proposed CTP identifies VMT reduction through transit expansion and smart growth which may become funded in the future. Further, the CTP identifies AB 32 compliance in the Greenhouse Gas Emissions Reduction White Paper (Appendix C of the CTP.)

The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts), which specifically notes that additional activities by other public agencies and entities beyond SCTA are needed to meet GHG emission reduction targets. It should be noted that additional GHG emission estimate data for the Draft EIR alternatives has been provided in Section 4.0 of this document and specifically identifies that Draft EIR Alternative 5 comes the closest in meeting this target. The commenter is also referred to Response to Comments 1-1 regarding the purpose of an EIR.

Response 1-9: The commenter is referred to Response to Comments 1-1 through 1-8 that addresses comments regarding the relationship of the EIR and achieving goals in the 2009 CTP.

Letter 2

Climate Protection Campaign, Bicycle Coalition
Sonoma County Transportation & Land Use Coalition
June 22, 2009

Seana Gause, Program & Policy Analyst
Sonoma County Transportation Authority
490 Mendocino Ave, Ste 206
Santa Rosa, CA 95401

Re: Comment on Draft Environmental Report
SCTA Draft Comprehensive Transportation Plan

Dear Ms. Gause—

Thank you for this opportunity to comment on the above Draft EIR. As you know, the Climate Protection Campaign is deeply concerned about the effects of greenhouse gas emissions on the Earth. We have been generally pleased with the direction of the Draft Comprehensive Transportation Plan, which contains a number of strategies to cope with carbon dioxide and other gases that influence climate change. **2-1**

However, the Draft Environmental Report on the plan points out shortcomings that need to be corrected if the we are to reach the goals that were adopted by the SCTA last year.

We hope our comments will lead to the adoption of strategies to mitigate the concerns raised by the Draft EIR. Based on the findings of the Draft EIR, we urge the SCTA to make appropriate revisions that serve to assist the County of Sonoma, and all of the individual cities in reaching the greenhouse gas reduction goals that they established in 2005. **2-2**

We are grateful that Sonoma County has led the State and the Nation in devising programs to deal with the threat of global climate change. We trust that an improved and more focused Comprehensive Transportation Plan will serve to advance this cause. **2-3**

Our comments are attached and arranged in the order that the issues appear in the Environmental Report.

Ann Hancock	**Christine Culver**	**Willard Richards**
Climate Protection Campaign	*Bicycle Coalition*	*SCTLC*

[redacted]

JUN 2 2 2009
SONOMA COUNTY
TRANSPORTATION AUTHORITY

Comments on the Draft Environmental Impact Report for the SCTA Comprehensive Transportation Plan—June 22, 2009

Executive summary narrative (Page 1.0-1)

Goals of the CTP (Paragraph 4)
The Executive Summary sets forth the four goals of the plan but only one part of the plan itself is then outlined—

Why is a description of the complete plan omitted, including both the financially constrained and unconstrained elements? System maintenance, greenhouse gas emissions reduction, safety and health are fully as important as congestion reduction. Also please acknowledge the various policies of the financially constrained and unconstrained parts of the plan. For example, in some instances traffic congestion is best addressed by increasing the number of walkable bikeable places with mixed-use developments that reduce the need to drive. **2-4**

Transit Improvements (Paragraph 7)
Note that the DEIR (reasonably) considers the SMART Passenger rail service and bicycle-pedestrian pathways as part of the financially constrained plan. The Draft Comprehensive Transportation Plan prepared in October, 2008 could not do so prior to the election at which the quarter cent sales tax to fund Sonoma Marin Area Rail Transit Project was approved by the voters. **2-5**

Land Use and Pricing Assumptions (Paragraph 10)
A new framework to guide cities and counties in reaching greenhouse gas emission goals has been initiated under the direction of SB375. Although regional targets to reduce GHG emissions are still being established, the direction to cut sprawling development is clear. Why is the blueprint process that gave rise to this framework not explored?

The following information on SB 375 is available: **2-6**

- The Sacramento Region Blueprint
  http://www.sacregionblueprint.org/sacregionblueprint/home.cfm
- Statewide Summit, Regional Blueprints: A Path Forward (2/09)
  http://www.dot.ca.gov/hq/tpp/offices/orip/faqs.html
  http://calblueprint.dot.ca.gov/summit

Anticipated impacts – Table 1.0-1 (pp. 1.0-3 to 28)

Air Quality Impact 4.2-3 – Emissions (Page 1.0-5)
Adverse health effects of living near a major thoroughfare have been documented and are a significant impact of road expansion regardless of compliance with ambient air quality requirements of the BAAQMD. Why were these effects omitted? Please summarize these effects in the table in the executive summary and detail them in the Air Quality section (Section 4.2). **2-7**

Traffic & Circulation Impact 4.3-1-- Increases in traffic and VMT (Page 1.0-6)

CPC, SCBC, SCTLC – Comments on CTP DEIR 1

The 2.9 million increase in daily vehicle miles traveled (VMT) is described as "significant and unavoidable." Is this finding due to unidentified funding for the alternatives: #2 (financially unconstrained capital improvement scenario), #3 (transit expansion & smart growth scenario), #4 (pricing policy scenario), and #5 (comprehensive "do everything" scenario). Or is the finding due to flaws in the mitigation measures proposed for each alternative of the CTP, or is it due to the fact that some mitigations in each alternative are under the control of entities other than SCTA? Why not state in the executive summary the extent to which the projected VMT increase departs from Policy 3A of the draft CTP to "Reduce vehicle miles of travel (VMT) per capita by 10% below 2005 levels by 2035. **2-8**

Energy Impact 4.13-1 – Consumption of petroleum-based products (Page 1.0-27)
An increase in daily fuel consumption of 159 thousand gallons is predicted, and this is described as "significant and unavoidable." To what extent does the increase in fuel consumption prevent the accomplishment of Goal 3 of the draft CTP to: "Meet the targets to reduce GHG emissions 25% below 1990 levels by 2015, and 40% below 1990 levels by 2035?" Note that the extent of this prediction may differ
event, please identify the mitigations that cause reductions in VMT and greenhouse gas emissions to meet the stated goals. **2-9**

Climate Change Impact 5.0-1 – Greenhouse gas emissions (omitted from chart)
The projected failure to reach 2035 greenhouse gas (carbon dioxide equivalent) reduction goals is critical. Why is it omitted from the executive summary? The SCTA has adopted the goal to reduce greenhouse gas emissions 25% below 1990 levels by 2015, and 40% below 1990 levels by 2035. These goals are the equivalent of a 37% reduction from 2005 conditions by 2015, and a 60% reduction by 2035. Table 5.0-3 suggests that by 2035 only a 21.6% reduction would occur under the financially constrained CTP. Should policy makers and the public not know the extent of shortfalls by the financially constrained plan, and by each alternative scenario for the year 2015 and for the year 2035? **2-10**

Introduction & review process (Section 2, page 2.0-4)
It is stated that comment letters on the Notice of Preparation are included in Appendix A, but they do not appear in the Internet version of Appendix A. Please post these comment letters. **2-11**

Air Quality (Section 4.2)

Existing ambient air quality (Pages 4.2-5 & 6)
The description of present air quality contains an implicit assumption that air quality will be maintained. However, this assumption is inconsistent with the March, 2009 Draft Biennial Report of the State Climate Action Team, which projects increases in "criteria" pollutants from higher temperatures and other factors associated with global warming. **2-12**

> Californians experience, on a cumulative basis, the worst air quality in the nation. Ozone and particulate matter (PM) are the pollutants of greatest concern, especially in the problematic South Coast and San Joaquin air basins. The current control programs for motor vehicles and industrial sources cost about $10 billion per year. As the population of California increases, the climate warms, and forests, croplands, and native

CPC, SCBC, SCTLC – Comments on CTP DEIR 2

vegetation become altered, scientists expect that air pollution in coming decades may worsen. Climate change could slow progress toward attainment of health-based air quality standards and increase pollution control costs by increasing the potential for high ozone and high particulate days. Reductions needed to counter man-made and natural biogenic emissions will be particularly important during strengthened temperature inversion events and summertime stagnation episodes. (See, *Draft Report to the Governor and Legislature*, Page 1.26 http://www.energy.ca.gov/2009publications/CAT-1000-2009-003/CAT-1000-2009-003-D.PDF) **2-12**

How can the ambient air-quality assumptions in the DEIR be reconciled with and tested under air pollution conditions more likely to occur in the future, based on emerging CARB data?

Health effects

The air quality analysis fails to address the health effects of freeway expansion under the Draft CTP, including increased incidence of asthma, increased coronary heart disease and impaired lung development in youth. Are these health effects not significant impacts of the plan? What is the extent to which these impacts can be mitigated by measures such as zoning or additional building ventilation? A suggested draft to describe this impact follows along with reasons supporting this addition.

Impact 4.2-__ (New)
Implementation of the 2009 CTP would increase the capacity and therefore the traffic volumes on Highway 101. Epidemiological studies have shown that individuals living near freeway traffic suffer from diseases that are independent of and in addition to the adverse health effects of regional air pollution. Health conditions associated with living near freeways include increased coronary heart disease and asthma as well as diminished lung function development between age 10 and age 18. The relationship between diminished lung function in adulthood and morbidity and mortality is well established.

Many epidemiological studies have shown that the adverse health effects of living near a freeway are independent from and added to the adverse health effects of regional air pollution. (See attachment A.) These studies also indicate that the effects are great enough that they should be considered when making land use decisions near freeways and when designing the ventilation systems for buildings near freeways. These effects deserve to be rated significant and mitigation measures should be proposed. **2-13**

The statement at the beginning of Section 5.2 of the DEIR addressing cumulative air quality impacts (page 5.0-3) confirms that the health effects of living near a freeway are not adequately analyzed. The statement is: "The analysis of air quality impacts is inherently cumulative in its approach, as air quality planning is done at the regional level." It appears that the analysis relies upon ambient air conditions, and ignores the exposures that are experienced by those living near freeways.

Table 4.2-9 – Criteria pollutant emissions (Page 4.3-18)

The data in this table are difficult to understand and require explanation. Why are large decreases in ROG, NO_x, and CO projected while SO_x, PM_{10}, and $PM_{2.5}$ are projected to increase by percentages equal to or greater than the 26 percent increase in VMT? If revised, these calculations may require conforming changes in the text of Section 4.2 and in Impact 4.2-3, as well as the Air Quality Executive Summary. **2-14**

CPC, SCBC, SCTLC – Comments on CTP DEIR 3

Traffic & Circulation (Section 4.3, pp. 4.3-29 to 31)

Increase in VMT (Page 4.3-29)
Impact 4.3-1 and Table 4.3-15 state that implementing the Draft CTP would cause increases of vehicle miles traveled (VMT) amounting to nearly three million miles per day, or 26%. This finding appears to depart from Policy 3A on page 46 of the Draft CTP which calls for a 10% *reduction* of per capita VMT. To what extent do per capita VMT under the plan diverge from Policy 3A? **2-15**

Which of the eleven strategies in Policy 3 of the Draft CTP are most influential on VMT? To what extent would each strategy need to be extended in order to meet the goal of the Draft CTP> **2-16**

Objective 2A (Page 4.3-30)
Under what specific circumstances would the expansion of *roadway capacity* as described in the cited objective of the Draft CTP decrease VMT? **2-17**

- Objective 2A: Implement strategic transit *and roadway* capacity expansion to meet current and future needs." (Em

Expanding roadway capacity does not decrease VMT. It is recommended that the words, "and roadway" be deleted from the Draft EIR. Correcting this will suggest mitigating changes in the CTP. **2-18**

Land Use Disruption or Displacement (Pages 4.9-14 & 15)

Land use planning – Impact 4.9-1 (Pages 4.9-14 & 15)
The impacts of the plan on land use are deemed "less than significant" because the plan encourages policies and projects that will promote cohesive communities that are consistent with local land use policies, including transit-oriented development that seeks to promote livable, walkable communities that support land use strategies in general plans. The plan thus relies on local plans and policies to reduce greenhouse gases and includes an objective of reducing vehicles miles traveled per capita by 10 percent below 2005 levels by 2035. **2-19**

How will such reductions occur through local land use policy changes? What is the required timeline for adoption of local land use documents to assure that the plan meets its GHG reduction goals by 2015 and 2035. **2-20**

What would be the effects on GHG from a 20 percent reduction in vehicle miles traveled below 2005 levels by 2035? An alternative analysis should be performed to show how such a reduction could drive implementation of necessary policies needed to help reach the GHG reduction goals. **2-21**

Are reasonable mandatory employer GHG reduction programs for employee commutes more effective than voluntary programs? To what extent would reasonable mandatory programs help achieve GHG reduction goals? **2-22**

Energy (Section 4.13, pages. 4.13-10 to 14)

CPC, SCBC, SCTLC – Comments on CTP DEIR 4

Increase in Fuel Consumption (pages. 4.13-10 to 11)
Impact 4.13-1 is said to be significant
will accommodate substantial growth and increases in fuel and energy consumption by 2035. This impact projects a 20 percent increase in gasoline consumption and a 7 percent increase in diesel fuel consumption. How does this additional fuel consumption translate into emissions of greenhouse gases and criteria pollutants? **2-23**

The draft Comprehensive Transportation Plan proposes to: "Meet the targets to reduce GHG emissions 25% below 1990 levels by 2015, and 40% below 1990 levels by 2035 by working with government agencies and the public." (DCTP, Page 46.) What is the extent of shortfalls by each of the financially unconstrained Draft CTP alternative scenarios for the year 2015 and for the year 2035? **2-24**

Alternative 2 (the unconstrained capital improvement scenario) in the Draft CTP calls for the widening and construction of roads in addition to projects identified in the financially constrained plan. Which projects in Alternative 2 would reduce energy use, and which would lead to increases in energy use? Please list these projects in order of their contribution to the GHG reduction goals. **2-25**

Note that there is an inconsistency between Impact 4.13-1 and Impact 5.0-1. The Cumulative impacts analysis at pages 5.0-21 & 22 states that although VMT will increase 26% by 2035, fuel economy will increase by 62%. If a similar improvement in fuel economy is projected for all vehicles, gasoline and diesel fuel consumption would decrease by 22%. This inconsistency should be resolved and consistent data should be used throughout the report and Executive Summary. **2-26**

An incorrect citation to Appendix D (Noise) appears at the top of page 4.13-11. **2-27**

Transit fuel consumption (page 4.13-11 & 12)
Tables 4.13-2, 3, & 4 appear to contain errors in the data for fuel use by transit. The footnotes to Table 4.13-4 on page 4.13-12 indicate that the contractor's calculations began with annual data, and it appears the numbers were never converted to daily data. Please insert correct quantities and re-compute all affected totals. **2-28**

Transportation-based energy consumption (Page 4.13-13)
What is the cost-effectiveness of each listed objective? To what extent does accomplishment of the objective cause beneficial or detrimental changes in: **2-29**

1) consumption of energy
2) consumption of petroleum
3) emission of greenhouse gases

With respect to Objective 2A, under what circumstances would expansion of *roadway* capacity lead to lower use of energy? **2-30**

Climate Change (Cumulative impact 5.4, Pages 5.0-9 to 5.0-23)

Climate change (Page 5.0-9)

CPC, SCBC, SCTLC – Comments on CTP DEIR 5

Item 5.4, in the second paragraph, it is recommended that the following statement be deleted: "While emitting CO2 into the atmosphere is not itself an adverse environmental effect, it is the increased concentration of CO2 in the atmosphere resulting in global climate change and the associated consequences of climate change that results in adverse environmental effects."

The above line of reasoning would be highly unusual in an EIR analysis of other 2-31
environmentally damaging tailpipe emissions such as nitric oxide. Nitric oxide emitted by an automobile must react with ozone and be converted to NO_2 before it can discolor the atmosphere. The NO_2 must further react with ROG in order to cause smog, yet it has adverse environmental effect. By contrast, CO_2 begins absorbing infrared radiation and causing adverse environmental effects the instant it is emitted. Because concentrations of carbon dioxide in the atmosphere exceed 350 parts per million, any further emissions have an adverse environmental effect. The quoted text should be deleted here and at other points where it is repeated, such as at the top of page 5.0-20.

Climate action plan (Page 5.0-19)
The GHG reduction goals adopted by Sonoma County and all of its cities in 2005 acknowledge the region's interest in taking a leadership role on an important issue of worldwide significance. In July 2008 the SCTA Directors reaffirmed this goal for the CTP (to reduce greenhouse gas (GHG) emissions 25% below 1990 levels by 2015). The Directors also adopted a goal for the CTP to reduce GHG emissions 40% below 1990 levels by 2035 to correspond with the Metropolitan Transportation Commission's goal in the Bay Area Regional Transportation Plan. (See SCTA Minutes, July 14, 2008, page 4.)

Since the transportation sector accounts for about 60% of GHG emissions in Sonoma County, it is important for this sector to contribute most of the GHG reductions required to meet the overall goal. The task is great: many more trips must be by bicycle or on foot, and fleet fuel economy must rise 1.42 MPG each year until 2035 to meet the goal for that year. Average fuel consumption in that year needs to be close to 50 MPG in Sonoma County. As an illustration of one avenue toward meeting the goal, Prius owners regularly achieve more than 50 MPG per gallon: so if an average of 45 residents per day purchase such a vehicle over the next 25 years,
the targeted 2035 GHG reductions would occur. 2-32

The transportation studies for the Community Action Plan (CAP) published by the Climate Protection Campaign (See, *Transportation: Opportunities for GHG Reduction in Sonoma County*, August 2008, attached) set forth three fundamental paths to reduce transportation GHG emissions:

1) Use vehicles more efficiently by increasing the average number of passengers in each auto, bus and train. Reformed pricing policies requiring drivers to pay at the time of travel the full costs of using and parking cars would reduce vehicle miles traveled.
2) Reduce the need for car trips and shorten trip lengths. This approach relies upon teleconunute alternatives and upon changes in land use and community design that encourage walking, bicycling, and transit ridership.
3) Make vehicles more carbon efficient through use of non-carbon fuels and increased vehicle efficiency. This approach relies strongly on shifting to a fleet of lighter automobiles with more efficient drive trains and regenerative braking systems (such as the plug-in Prius).

CPC, SCBC, SCTLC – Comments on CTP DEIR 6

The study concludes that numerous strategies are needed, including promotion of electric cars, scooters, car-share services and carpools, parking management and unbundled pricing, safe routes to schools, greatly improved, well-shaded sidewalks and walkable places with short crosswalks at intersections; traffic calming, safe, improved bicycle path connections with bicycle priority on narrow streets, consistent shoulders for use by cyclists; frequent, inexpensive, and convenient public transportation. Achievable and likely GHG reductions are estimated in the CAP by assessing the effects of each strategy on 1) the proportion of single occupant vehicle users, 2) average trip length, 3) number of trips, and 4) fossil fuel efficiency of the vehicle fleet. **2-32**

Many of the strategies mentioned above are incorporated in the Draft CTP, and evaluated in the financially unconstrained scenarios. (See Draft CTP, Appendix C.) However, the Draft EIR does not consider them robust enough to reach the stated goals, *and the document suggests no mitigations to achieve them.* Would it not be usefil to describe the extent of shortfalls by each Draft CTP alternative for the year 2015 and for the year 2035, and suggest a range of strategies that are sufficient to correct the deficiencies in the draft plan?

Methodology (Page 5.0-20)
The first paragraph is misleading and should be deleted. It states that: "Emitting CO2 into the atmosphere is not itself an adverse environmental effect. It is the increased concentration of CO2 in the atmosphere resulting in global climate change and the associated consequences of climate change that results in adverse environmental affects (e.g., sea level rise, loss of snow-pack, severe weather events). Although it is possible to estimate the proposed project's incremental contribution of CO2 into the atmosphere, it is typically not possible to determine whether or how an individual project's relatively small incremental contribution might translate into physical effects on the environment. Given the complex interactions between various global and regional-scale physical, chemical, atmospheric, terrestrial, and aquatic systems that result in the physical expressions of global climate change, it is impossible to discern whether the presence or absence of CO2 emitted by the project would result in any altered conditions." **2-33**

Every molecule of CO_2 has the same effects on climate as any other CO_2 molecule. Therefore, it is "...possible to determine whether or how an individual project's relatively small incremental contribution might translate ..." It is indeed true that understanding climate change completely enough that it can be accurately represented by computer simulations is complex, but that has been done. The unequivocal conclusion of the scientific community is that CO_2 emissions are a major cause of climate change. Fifty seven percent of the CO_2 emitted into the atmosphere since the beginning of the industrial revolution is still in the atmosphere. Each additional molecule of CO_2 emitted has a very long expected atmospheric lifetime and contributes to climate change in proportion to the amount of CO_2 emitted.

Should the DEIR contain a disclaimer like this about traffic congestion because we do not know which vehicle caused the traffic jam?

Signifance Criteria (Page 5.0-20 & 21)
The Sonoma County Transportation Authority, Sonoma County, and all nine cities in the County have set targets to *decrease* GHG emissions, in recognition of the looming threat of global climate change. The Comprehensive Transportation Plan adopted by the SCTA is based upon this fact, and the consultants can not adopt a threshold for significance that departs from that which is locally established. **2-34**

The language at the top of page 5.0-21 should be revised to declare that the plan's contribution to global climate change is considered significant if it would:

- *result in greenhouse gase and CO2 emissions that would prevent the County of Sonoma, or any of the cities in the county from coming within 5% of their target reductions for those emissions.* 2-34

We recognize that it will be some time before various state agencies recommend thresholds for GHG emissions to be used in other CEQA analyses. However, AB 32 mandates decreases in GHG emissions and SB 375 proposes changes in land use to cut such emissions. The purpose of an EIR is to inform policy makers and citizens of the effects of the proposed plan, and it would be foolish to ignore the locally established goals in an effort to be consistent with an undeveloped state or regional threshold.

Greenhouse Gas (Page 5.0-21)
Impact 5.0-1 contains the following incorrect statement: "Implementation of the 2009 CTP would help decrease emissions of carbon dioxide equivalents (CO-2e) from motor vehicles . . ." The financially constrained plan results in increased daily VMT. State fuel economy regulations, not the Draft CTP, are projected to result in a decrease in emissions. In order to have a beneficial effect, the Final CTP will need to *reduce* VMT. 2-35

The purpose of the EIR process is to provide important information to policy makers and to the public. Please revise the impact statement to state that the unconstrained plan increases VMT and makes more difficult the task of reaching the established targets for GHG reduction.

GHG Forecasts (Page 5.0-21)
Table 5.0-3 appears to contain tons per year rather than pounds per day in the bottom line of figures. The description should be amended accordingly. 2-36

Recommended mitigation measures (Page 5.0-23)
How effective would these seven mitigation measures be in reducing GHG emissions, compared with the twenty measures proposed on pages 133 and 134 of the Draft CTP. Why not display estimates of the relative cost and benefits, with clear examples of each measure?

The following are some examples:

1) Make the full costs of automobile use transparent to drivers. 2-37
There are some 410 thousand adults in Sonoma County most of whom are licensed to drive, and according to the CPC transportation study their vehicles are responsible for more than $5 billion per year in transportation costs. However, most of the costs are hidden. Of the more than $1,000 monthly average cost to operate a car, drivers are most conscious of their $100 average monthly out-of-pocket cost for fuel and repairs. Car payments, insurance, garage, and other ownership costs tend to be paid in a lump-sum that doesn't change much whether the car is driven short or great distances. The public now contributes an average of more than $200 per month for each vehicle, including most of the on-street parking costs. If drivers pay half of total costs based on mileage, they will have a steady incentive to reduce VMT and fuel use, which will lead to

CPC, SCBC, SCTLC – Comments on CTP DEIR 8

reductions of GHG.
million tons of GHG from driving to about 2 million tons per year, closing more than half of the gap toward that year's target for GHG reduction.

Some steps are already being taken to make drivers more aware of the actual costs of their cars. Donald Shoup, author of *The High Cost of Free Parking*, will make presentations here in August. A possible near-term project would encourage all public agencies (especially high schools) to charge the full cost of parking. Another project could address the problem of bundled parking costs throughout the county. The State Insurance Commissioner is also developing an optional mileage-based auto insurance plan, and there is pending legislation (AB 744) for high occupancy toll lane development. An acceptable county gas tax measure to provide every resident with bus passes MPG gauges in gas powered vehicles or credits toward electric vehicle purchases could be developed to make the cost of driving more visible.

2) Make electric vehicles welcome & commonplace on local streets
There are some 420 thousand registered cars, trucks, & vans in Sonoma County and they produce about 2.5 million tons of GHG per year. To reduce greenhouse gas from driving to about 2 million tons per year, it would be necessary to replacing about 40 gasoline powered cars per day with electric vehicles (EVs) that use solar power for recharge between now and 2015. This is about twice the normal fleet replacement rate, and significant financial incentives would probably be required. Alternatively, it would be necessary to replace about 120 gasoline powered cars per day with EVs that rely on the grid for recharge to accomplish the same objective. **2-37**

At present, gasoline-electric hybrids are commonplace and many drivers are interested in plug-in hybrids, expected to be available in 2010. There are also a number of short-range electric cars, pick-up trucks, scooters & bicycles in use, with several dealers entering the market, and SRJC has a vehicle converter training program for mechanics & activists. Sonoma County has an agreement with Nissan for up to 1000 EV purchases in 2010 and is seeking grants to cover the additional costs in excess of fleet replacement. A pilot project to locate battery recharge points at malls and parking garages is evolving, and AB 811 funding is available for solar recharge installations by homeowners and businesses. These developments can make drivers comfortable that an EV is a reliable choice for economical transportation.

Near-term projects to expand the EV market include publicizing the local electric vehicle infrastructure, encouraging home-owners to install capacity to charge automobile batteries, and locating EV re-charge stations in every garage. To make short-range EVs attractive, half-day hybrid car rentals should be readily available. EV subsidy & rebate programs for auto dealers may also be necessary. We understand that SRJC has $25K vehicle conversion grant, and that the current cost to convert a sub-compact car from gas to electric is about $15 thousand; Electric bicycles & scooters cost $300-$3,000 each; a $3 million grant (State, DOE) for battery recharge stations & plug-in hybrids is pending, a $300 thousand Sonoma County EV purchase grant application is pending. About $20 million in private or public sector funds would seem to be sufficient to make EVs commonplace in Sonoma County.

3) Make public transportation convenient & ubiquitous
Attractive, walkable business & residential districts with good public transportation can reduce GHG by about 12% for the county as a whole by 2015, according to the CPC study of the

transportation sector. (See, *Transportation Opportunities for GHG Reduction in Sonoma County, Appendix 4,* Page 41.) The start of SMART train service in 2014 should be a catalyst for development of such districts. Station-area planning has already taken place for the Santa Rosa Depot Area, is under way in Cloverdale, and should begin soon for the Jennings Station Area. Petaluma and Cotati already have dense and walkable areas close to their historic station areas. All cities in the county have urban growth boundaries, except Cloverdale, which is in the process of adopting such a boundary. Renewal of these boundaries as they expire is an important signal to landowners and developers. And it is important to locate every new development, especially schools, hospitals, and entertainment venues within walking distance of rail stations and transit nodes.

Work has begun to assure seamless, well advertised connections between train, bus & ferry services, and to make fares as well as ticket media compatible; this needs policy approval and direction from governing boards as well as budgetary support. The bicycle-pedestrian pathway along the rail right of way is to assure connections between the network of trails and the rail stations. Planning for the pathway along with lockers and bike stations is in the early stages, and it could be accelerated in some areas to encourage VMT reductions.

Funding of public transportation in recent years has been precarious, with the result that most service has been aimed to serve individuals who are transit dependent. Approval of the SMART Train and Pathway Project is designed to change the role of public transportation, initially by almost doubling the funds available for public transportation and connecting local buses with trunk-line passenger rail service between Cloverdale and the Larkspur Ferry Terminal in Marin County. Over the long term, at least $20 million per year in additional funding will be needed to make public transportation a sufficiently robust option for 2035 conditions. **2-37**

4) Make it easier to live well without owning a car.
A City Car-Share fleet, inexpensive jitneys, vanpool and subsidized taxi services would all make car ownership less important; if car-ownership becomes optional, many more people will find it easy and comfortable to limit their driving. If house-call medical services and grocery delivery become commonplace, along with high-band-width computer connections and internet shopping, the reasons to drive will be further reduced. Agency policies that routinely find ways to reward those who do not drive through design of projects, streetscapes, and all elements of interaction with the public bring about cumulative reductions in VMT.

5) Improve pedestrian and bicycle safety & comfort
Bicycle use and improved sidewalks can be one of the quickest and most economical ways to reduce VMT and GHG. There are also benefits to the community including improved health for both children and adults, reduced auto congestion and better air quality. Projects listed in the regional, county, and cities bicycle and pedestrian plans can be given high priority. Inexpensive class-2 bicycle lanes and shared narrow streets are already bringing about more bicycle use, and should be expanded, along with Safe Routes to Schools programs at all schools; building the SRJC Hwy 101 bike and pedestrian bridge near the planned Jennings Station; and accelerated completion of bicycle-pedestrian pathways such as the SMART Trail, Central Sonoma Valley Trail, Laguna de Santa Rosa Trail from Cotati to Sebastopol and a east-west bicycle pedestrian path through the Russian River areas.

In order to counter public perceptions that bicycling is inconvenient or risky, it is important to provide incentives for commuting by bicycle as well as to offer bicycle safety courses. For example, events with 1500 or more participants can offer secure attended valet bicycle parking, parking fees can be raised at places of employment to at least cover costs, while rewarding those who ride, walk, bike, bus or carpool. An ordinance making harassment of a bicyclist or pedestrian a misdemeanor could address problems sometimes experienced by bicycle riders.

6) Calm traffic and reduce vehicle speeds.
Low speed roads are less dangerous to pedestrians, make less noise, use less energy, produce less GHG, and generally improve the quality of surrounding neighborhoods. The comparative advantages of transit and bicycle use also improve when drivers are not habituated to speed. Side striping and bicycle lanes can be substituted for center striping to reduce speed; the county's Heritage Roads can be signed for low speeds; roundabouts and stop signs can often be used instead of traffic signals. **2-37**

7) Change land-use patterns
An active program to infill with walkable places and to retrofit auto-dependent neighborhoods not only leads to lower VMT, but the savings tend to be ongoing and cumulative. Convenience stores for every neighborhood, housing units with reduced parking requirements, attractive pathways for pedestrians and bicyclists, and an inventory of brownfield opportunity sites near public transportation have cumulative effects over time. Many leading firms have sustainability officers to monitor progress toward carbon-neutrality and to search out projects to meet goals. Each planning agency should consider designating an individual or group for this assignment.

DEIR Appendices:

Appendix A does not include the scoping comment letters on the Notice of Preparation. They should be included. **2-38**

Appendix D provides backup data for noise calculations, and it should be cited in Section 4.10, not at page 4.13-11 **2-39**

Appendix E on energy and fuel use does not contain enough information to enable understanding the calculations. It has also been suggested that an incorrect assumption has been made in computing miles per gallon for the year 2035. That should be remedied in the Final EIR and any errors in the calculations corrected. At a minimum, the methods used to derive the multipliers should be documented and the role of the multipliers in the tables should be explained. The effects of these corrections should be propagated through all affected values and translated into the list of environmental impacts. **2-40**

It is also important to include values for 2015, as Sonoma County goals should be met in those years. **2-41**

At the top of page 3 of Appendix E, the "VMT Conversion" table needs explanation. The two VMT numbers are the same as at the top of page 1 of Appendix E, but other numbers in that table cannot be reproduced. **2-42**

Appendix E is not cited in the body of the DEIR. Comments on the content of this appendix are under the Energy heading. 2-43

Appendix F seeks to represent a one-page summary of the cumulative GHG emissions of the Draft CTP modeling scenarios. However, the values appear to be incorrect. Daily VMT for all vehicles in Sonoma County in 2005 is 11,441,811 miles per day. We would expect emissions of more than 11 million pounds of CO2 per day, but the figures in the appendix are all less than three million pounds per day. 2-44

Some numbers in Appendix F are reported to ten significant figures. The conditions affecting the estimating processes, and projections based thereon cannot support results that are accurate beyond three significant figures. Please use rounded numbers in all charts; if preservation of data is desired that can be done in footnotes. 2-45

Five of the six modeling scenarios from the Draft CTP are included, but renumbered as DEIR Alternatives #1 (No-build), #2 (Financially un-constrained capital improvements), #3 (Transit & smart growth), #4 (Pricing policy), #5 (Comprehensive "do everything"). Data for the financially constrained CTP plan is omitted from this appendix, which inhibits clear understanding. The use of different numbering for the alternatives in the Draft EIR Appendix and for the scenarios in the Appendix to the Draft CTP can be confusing. 2-46

The content in Appendix F is not cited in the body of the DEIR. All references to Appendix F in the body of the DEIR are actually to Appendix G and should be corrected. 2-47

Attachment A

Epidemiological studies showing that the adverse health effects of living near a freeway are independent from and added to the adverse health effects of regional air pollution

Effect of exposure to traffic on lung development from 10 to 18 years of age: a cohort study

W James Gauderman, Hita Vora, Rob McConnell, Kiros Berhane, Frank Gilliland, Duncan Thomas, Fred Lurmann, Edward Avol, Nino Kunzli, Michael Jerrett, John Peters

Published Online January 26, 2007 DOI:10.1016/S0140- 6736(07)60037-3

Introduction

Both cross-sectional and longitudinal studies have shown that lung function in children is adversely affected by exposure to urban, regional air pollution. Evidence has emerged that local exposure to traffic is related to adverse respiratory effects in children, including increased rates of asthma and other respiratory diseases. Crosssectional studies in Europe have shown that deficits in lung function are related to residential exposure to traffic. However, does traffic exposure have an adverse effect on lung-function development in children? The answer to this question is important in view of the extent of traffic exposure in urban environments and the established relation between diminished lung function in adulthood and morbidity and mortality. We investigated the association between residential exposure to traffic and 8-year lung-function development on the basis of cohort data from the Children's Health Study. We also studied the joint effects of local traffic exposure and regional air quality on children's lung development.

Summary

Findings Children who lived within 500 m of a freeway (motorway) had substantial deficits in 8-year growth of forced expiratory volume in 1 s (FEV1, −81 mL, p=0·01 [95% CI −143 to −18]) and maximum midexpiratory flow rate (MMEF, −127 mL/s, p=0·03 [−243 to −11]), compared with children who lived at least 1500 m from a freeway. Joint models showed that both local exposure to freeways and regional air pollution had detrimental, and independent, effects on lung-function growth. Pronounced deficits in attained lung function at age 18 years were recorded for those living within 500 m of a freeway, with mean percent-predicted 97·0% for FEV1 (p=0·013, relative to >1500 m [95% CI 94·6–99·4]) and 93·4% for MMEF (p=0·006 [95% CI 89·1–97·7]).

Interpretation Local exposure to traffic on a freeway has adverse effects on children's lung development, which are independent of regional air quality, and which could result in important deficits in attained lung function in later life.

Prospective Analysis of Traffic Exposure as a Risk Factor for Incident Coronary Heart Disease: the Atherosclerosis Risk in Communities (ARIC) Study

Haidong Kan, Gerardo Heiss, Kathryn M. Rose, Eric A. Whitsel, Fred Lurmann, and Stephanie J. London doi:10.1289/ehp.11290 (available at http://dx.doi.org/)
Online 8 July 2008

Results: Over an average of 13 years of follow-up, 976 subjects developed CHD. Relative to those in the lowest quartile of traffic density, the adjusted hazard ratio in the highest quartile was 1.32 (95%CI 1.06-1.65) (p for trend across quartiles =0.042). When traffic density was treated as a continuous variable, the adjusted hazard ratio per one unit increase of log-transformed density was 1.03 (95%CI 1.01-1.05, p=0.006). For residents living within 300 m of major roads compared to those living further away, the adjusted hazard ratio was 1.12 (95%CI 0.95-1.32, p=0.189). Little evidence of effect modification was found for gender, smoking status, obesity, LDL cholesterol level, hypertension, age or education.

Conclusion: Higher long-term exposure to traffic is associated with incidence of CHD, independently of other risk factors. These prospective data support an effect of traffic-related air pollution on the development of CHD in middle-aged persons.

Traffic-Related Air Pollution and Asthma Onset in Children: A Prospective Cohort Study with Individual Exposure Measurement

Michael Jerrett,1 Ketan Shankardass,2 Kiros Berhane,2 W. James Gauderman,2 Nino Künzli,3 Edward Avol,2 Frank Gilliland,2 Fred Lurmann,4 Jassy N. Molitor,5 John T. Molitor,5 Duncan C. Thomas,2 John Peters,2 and Rob McConnell2

BACKGROUND: The question of whether air pollution contributes to asthma onset remains unresolved.

OBJECTIVES: In this study, we assessed the association between asthma onset in children and trafficrelated air pollution.

METHODS: We selected a sample of 217 children from participants in the Southern California Children's Health Study, a prospective cohort designed to investigate associations between air pollution and respiratory health in children 10–18 years of age. Individual covariates and new asthma incidence (30 cases) were reported annually through questionnaires during 8 years of follow-up. Children had nitrogen dioxide monitors placed outside their home for 2 weeks in the summer and 2 weeks in the fall–winter season as a marker of traffic-related air pollution. We used multilevel Cox models to test the associations between asthma and air pollution.

RESULTS: In models controlling for confounders, incident asthma was positively associated with traffic pollution, with a hazard ratio (HR) of 1.29 [95% confidence interval (CI), 1.07–1.56] across the average within-community interquartile range of 6.2 ppb in annual residential NO_2. Using the total interquartile range for all measurements of 28.9 ppb increased the HR to 3.25 (95% CI, 1.35–7.85).

CONCLUSIONS: In this cohort, markers of traffic-related air pollution were associated with the onset of asthma. The risks observed suggest that air pollution exposure contributes to new-onset asthma.

KEY WORDS: air pollution, asthma onset, children, nitrogen dioxide, traffic.
http://dx.doi.org/

Childhood Asthma and Exposure to Traffic and Nitrogen Dioxide

W. James Gauderman, • Edward Avol, • Fred Lurmann,† Nino Kuenzli, • Frank Gilliland, • John Peters, • and Rob McConnell•*

Background: Evidence for a causal relationship between trafficrelated air pollution and asthma has not been consistent across studies, and comparisons among studies have been difficult because of the use of different indicators of exposure.

Methods: We examined the association between traffic-related pollution and childhood asthma in 208 children from 10 southern California communities using multiple indicators of exposure. Study subjects were randomly selected from participants in the Children's Health Study. Outdoor nitrogen dioxide (NO2) was measured in summer and winter outside the home of each child. We also determined residential distance to the nearest freeway, traffic volumes on roadways within 150 meters, and model-based estimates of pollution from nearby roadways.

Results: Lifetime history of doctor-diagnosed asthma was associated with outdoor NO2; the odds ratio (OR) was 1.83 (95% confidence interval_ 1.04 –3.22) per increase of 1 interquartile range (IQR_ 5.7 ppb) in exposure. We also observed increased asthma associated with closer residential distance to a freeway (1.89 per IQR; 1.19 –3.02) and with model-based estimates of outdoor pollution from a freeway (2.22 per IQR; 1.36 –3.63). These 2 indicators of freeway exposure and measured NO2 concentrations were also associated with wheezing and use of asthma medication. Asthma was not associated with traffic volumes on roadways within 150 meters of homes or with model-based estimates of pollution from nonfreeway roads.

Traffic, Susceptibility, and Childhood Asthma

Rob McConnell,[1] Kiros Berhane,[1] Ling Yao,[1] Michael Jerrett,[1] Fred Lurmann,[2] Frank Gilliland,[1] Nino Künzli,[1] Jim Gauderman,[1] Ed Avol,[1] Duncan Thomas,[1] and John Peters[1]
[1]Department of Preventive Medicine, Keck School of Medicine, University of Southern California, Los Angeles, California, USA; [2]Sonoma Technology Inc., Petaluma, California, USA

Results from studies of traffic and childhood asthma have been inconsistent, but there has been little systematic evaluation of susceptible subgroups. In this study, we examined the relationship of local traffic-related exposure and asthma and wheeze in southern California school children (5–7 years of age). Lifetime history of doctor-diagnosed asthma and prevalent asthma and wheeze were evaluated by questionnaire. Parental history of asthma and child's history of allergic symptoms, sex, and early-life exposure (residence at the same home since 2 years of age) were examined as susceptibility factors. Residential exposure was assessed by proximity to a major road and by modeling exposure to local traffic-related pollutants. Residence within 75 m of a major road was associated with an increased risk of lifetime asthma [odds ratio (OR) = 1.29; 95% confidence interval (CI), 1.01–1.86], prevalent asthma (OR = 1.50; 95% CI, 1.16–1.95), and wheeze (OR = 1.40; 95% CI, 1.09–1.78). Susceptibility increased in long-term residents with no parental history of asthma for lifetime asthma (OR = 1.85; 95% CI, 1.11–3.09), prevalent asthma (OR = 2.46; 95% CI, 0.48–4.09), and recent wheeze (OR = 2.74; 95% CI, 1.71–4.39). The higher risk of asthma near a major road decreased to background rates at 150–200 m from the road. In children with a parental history of asthma and in children moving to the residence after 2 years of age, there was no increased risk associated with exposure. Effect of residential proximity to roadways was also larger in girls. A similar pattern of effects was observed with traffic-modeled exposure. These results indicate that residence near a major road is associated with asthma. The reason for larger effects in those with no parental history of asthma merits further investigation.

Key words: air pollution, asthma, child, epidemiology, traffic.
Environ Health Perspect 114:766–772 (2006).
doi:10.1289/ehp.8594 available via *http://dx.doi.org/* [Online 16 February 2006]

Transportation: Opportunities For Greenhouse Gas Emission Reduction In Sonoma County

Community Climate Action Plan

Prepared by

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Climate Protection Campaign
www.climateprotectioncampaign.org

August 2008

Abstract

This paper analyzes the cost and carbon emissions reduction potential of measures in the transportation sector.

Reducing carbon emissions from transportation takes three fundamental paths: (1) using vehicles more efficiently, (2) Reducing the need for trips and average trip length, and (3) using more “carbon efficient” vehicles. Using vehicles more efficiently involves mode share shift. Shifting mode share from single occupant vehicle to walking, bicycling and transit is one of the top objectives of most transportation public policy because of its effect on traffic congestion. Increasing the use of more efficient transportation modes is also one of the most cost effective means of reducing carbon emissions from transportation. This mode share shift generally takes place by employing publicly funded investments in transportation infrastructure.

Reducing the need for trips and average trip length is related to increasing population density in urban core areas. This is an area of overlap between land use planning, the locations of jobs and housing, and how communities can ultimately reduce their reliance on the automobile. These solutions are necessarily longer term in their effect.

However, from the perspective of achieving the level of reduction required by climate science, there must be significant additional mode share shifted from the fossil fuel powered vehicle. This paper proposes a method to make a significant number of non-emitting personal vehicles available on a short term rental basis. These vehicles would include all electric (EV), plug-in hybrid (PHEV) and low carbon fuel vehicles (biofuels, hydrogen). A method for a large scale deployment of low carbon vehicles is given. A program for construction of biofuel manufacturing facilities using municipal revenue bonds is discussed.

i

Transportation: Opportunities For Greenhouse Gas Emission Reduction In Sonoma County

Table of Contents

Definitions

Average Distance. Average trip length of a mode, or of all modes.

General policy measures. Measures that tend to have a wide-spectrum effect favoring modes that generate less greenhouse gases (GHGs).

Modes. A mode designates a form of travel, such as walking, or riding in a car. Although many possible modes of travel exist, we limit the number of modes to those that are most relevant to our discussion. Our interest is in shifting from one mode of travel to another to reduce energy requirements while still meeting actual travel needs. From that perspective, seven modes are addressed in this report:

1. Walking including wheelchairs
2. Bicycling including tricycles and electric motor assisted bicycles
3. Transit including trains, transit buses, and paratransit
4. Car driving including light trucks and private vans
5. Car passenger meaning occupying passenger seats in private vehicles[1]
6. Other motorized traveling including motorcycles and motor scooters
7. Non-emitting, which would include all electric, or biofuel powered vehicles

Mode Share. Percentage of all trips via this mode.

Mode Specific Improvement Measures. Measures that *primarily* affect use of that mode. Few measures will not have minor effects on other modes however.

Trip. Although "trip" often signifies a journey from origin to destination, its meaning is slightly different in this report. For the purpose of this report, "trip" means travel on a single mode from beginning on that mode to the point of leaving that mode. In the official language of transit, this is called an "unlinked" trip. As an example of four unlinked trips, a traveler 1) walks to a bus stop, 2) boards a bus, rides to another point on the route, and exits the bus, 3) connects to another bus, rides to another stop, and exits, and 4) walks to the destination.

Trip Generation. Trip generation is the first step in a model of travel usually used for the purposes of forecasting. It refers to a model of the types of trips that are taken and is usually jurisdiction-specific. Other steps in this model of travel are trip distribution, mode choice and route assignment. Trip types and their distribution are normally determined by a travel survey.

Vehicle Miles Traveled or VMT. This is the standard measurement for vehicle activity, and the primary metric related to generation of greenhouse gas (GHG). VMT is applied to a standard vehicle inventory on a percentage basis, and then fuel use is calculated based on the average fuel efficiency for each vehicle class in the inventory. VMT is usually an estimate that is calculated from transportation computer models.

[1] Car pool isn't used here because it is somewhat ambiguous. Its intent is captured in the two defined modes, car driver and car passenger, which together are more explicit than "car pool."

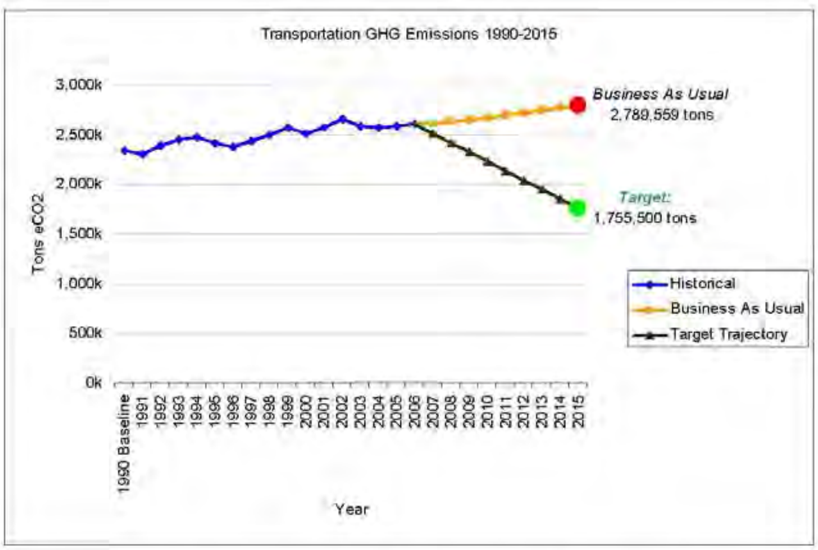
Introduction

Transportation today is responsible for approximately 60 percent of the greenhouse gases (GHG) emitted in Sonoma County. If overall GHGs must be reduced by 25 percent below 1990 levels by 2015, can we reduce transportation system emissions that much, or must the burden be carried disproportionately by other sectors?

Total emissions from transportation in 1990 are estimated to be 2,340,667 tons, based on total annual vehicle miles traveled (VMT) of 3,007 million miles.[2] 75 percent of this level (25 percent below 1990 levels – Sonoma County's target) is 1,755,000 tons. This is the level that should be achieved to avoid impacting other sectors.

The "business as usual" (BAU) VMT for 2015 is projected to be 2,789,559 tons, based on an estimated annual VMT of 4,441 million miles. Reaching the target, then, involves a 37 percent reduction from the projected 2015 BAU level, or a 32 percent reduction from the 2005 level.

Figure 1



To calculate the possible ways to reduce emissions in the transportation sector, we must first look at three transportation parameters:

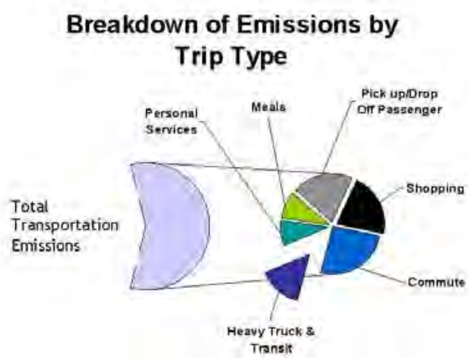
1. Trip generation
2. Mode selection
3. Average trip length

[2] Estimate provided by MTC staff based on Highway Performance Monitoring System (HPMS) data extracted 4/18/2006. Figures confirmed by Sonoma County Transportation Authority staff in private conversation, May 2008.

Trip Generation

The following chart shows the distribution of total emissions among various trip types. This breakdown shows how total transportation emissions are related to trip generation.[3]

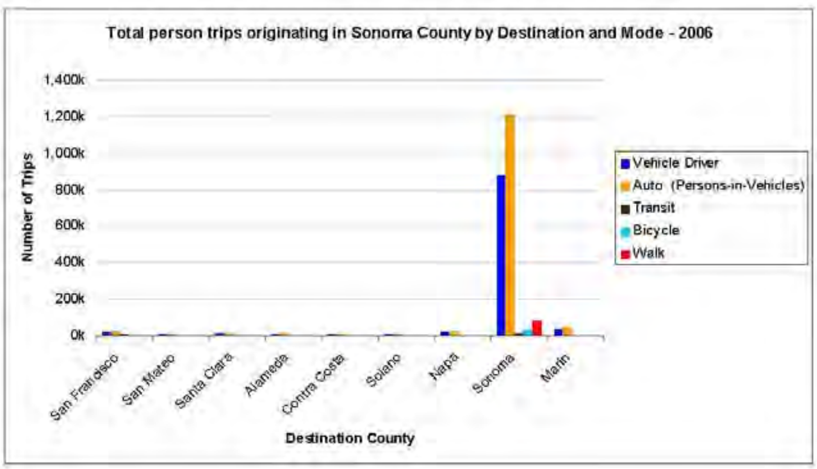
Figure 2



Mode Selection

Figure 3 shows the current distribution of mode selection for travel originating in Sonoma County, with "drive alone" by far the dominant mode.[4]

Figure 3



[3] Based on data supplied in the Travel Forecast Data Summary 2005, Metropolitan Transportation Commission

[4] Data from San Francisco Bay Area Travel Survey 2000 – Regional Travel Characteristics Report, Metropolitan Transportation Commission

Average Trip Length

Average trip length is most influenced by land use. Factors such as "regional accessibility" can affect the total number of miles traveled by an individual, rather than the total number of trips. Overall vehicle miles traveled increase the farther Sonoma County residents live from the 101 corridor.[5] Average trip length is much higher for residents who live in less dense areas of the County.[6]

The number of trips required or "trip generation/production" is also affected by land use. The characteristics of the households in the region of interest also impact trip generation/production. Another way to look at trip generation/production is that "trips are what we need." Demand for trips or mobility is what drives the transportation system. To the extent that trips can be avoided altogether, GHG reduction can be very cost effective. Trip reduction is similar to conservation in the energy realm, in terms of giving the greatest GHG reduction per dollar. Because the cost of the trip influences trip generation, if the traveler were to pay the true cost of the trip, i.e., including all currently externalized costs, trips generation would be reduced.

Accounting for Trips and Passenger Miles

The way travel behavior is accounted for relies on art as well as science. Local travel surveys are rarely undertaken because they are very laborious and hence expensive. The Decennial Census long form from the National Household Travel Survey (NHTS) and the National Personal Travel Survey (NPTS) provides actual data. Experts use this information to develop travel models, playing with various parameters until there is a cohesive picture – at least according to the model. The model then becomes the representation of travel behavior. Extrapolations based on the model fill in gaps where directly observed data does not exist.

[5] "Greenhouse Gas Emission Inventory for all sectors of Sonoma County, California," 2005, http://climateprotectioncampaign.org/news/documents/AP_INVEN.PDF
[6] Using Residential Patterns and Transit To Decrease Auto Dependence and Costs by John Holtzclaw, June 1994

Overview

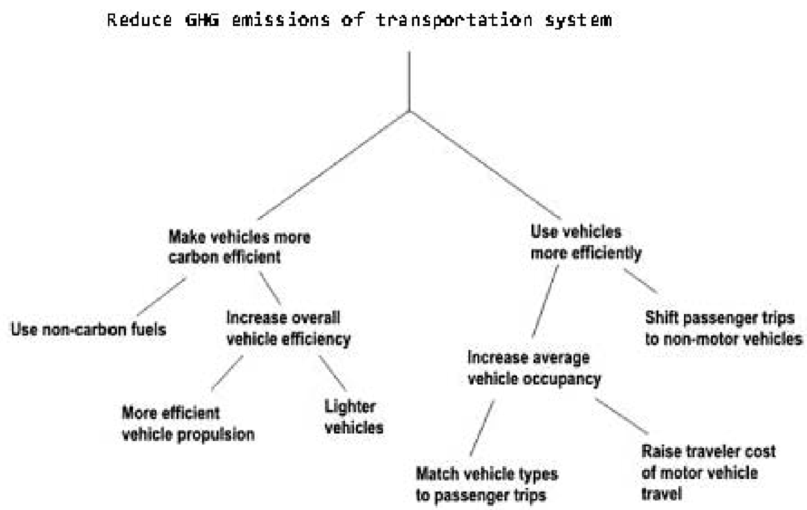
There are three basic ways to reduce the amount of GHG produced by the transportation sector:

1. Reduce the number of trips taken and/or reduce the average length of trips
2. Improve the efficiency of propulsion
3. Shift travel from less efficient modes to more efficient modes.[7]

Logic Framework for Efficiency and Mode Shifting

A logic framework for understanding general measures for efficiency and mode shifting follows.

Figure 4



Estimates for the amount of travel in Sonoma County and for the amount in each modal category are shown in Table 1. Also shown are the corresponding modal percentages that might exist in 2015, the target year, and if we are to be on track for solving our GHG problem. Table 2 shows modal percentages that have actually been achieved in locales that lead the nation in reducing GHG emissions from transportation.[8]

[7] The efficiency of a mode is measured in terms of the amount of energy required per mile of passenger movement. The mode efficiency has two components: (1) efficiency of propulsion; (2) number of miles of passenger movement per mile of vehicle movement.

[8] Table 1 data on possible modal distribution from private international study conducted by Joel Woodhull. Data on modal distribution in US jurisdictions provided by Chris Barney, Sonoma County Transportation Authority.

5

Transportation: Opportunities For
Greenhouse Gas Emission Reduction In
Sonoma County

Table 1. Mode Share Shifts for GHG Reduction

Mode	Walk		Bicycle		Transit		Car Driver		Car Passenger		Other Motorized		All	
	Current	2015	Current	2015	Current	2015	Current	2015	Current	2015	Current	2015	Current	2015 (1)
Share (%)	3.1	12.0	1.9	9.0	1.0	6.0	74.0	37.0	15.0	23.0	2.0	10.0	97.0	97.0
Av Dist. (Mi)	0.4	0.4	2.0	2.0	5.8	4.0	5.0	4.0	7.0	7.0	3.0	3.0	4.9	3.9

Mode Specific Improvement Measures	sidewalks tree lanes, shade street crossing priority intensified network	path construction better connections priority on narrow streets consistent shoulder widths	construct, operate rail passenger service expand bus services fixed facilities for transit passengers	car-sharing services light truck rental rural service network congestion pricing	facilitate car-pooling ride auctions??	parking conversions to provide favorable spaces
General Policy Measures	Land use changes favoring shorter trips New tax policies, e.g. local gas tax, with revenues applied to favor GHG reductions when shifting mode shares General reduction of road speeds to promote energy reduction and safety of all road users Expansion of delivery services Telecommute programs to reduce numbers of trips Manage parking with pricing					

NOTES
Transit includes bus and train
Car includes light trucks, vans
Other Motorized includes scooters, motorcycles
(1) Mode shares add to 97% because school bus trips aren't accounted for. They may carry about 3% of trips

Table 2. Mode Share In Other Jurisdictions

Mode	Walk	Bicycle	Transit	Car Driver	Car Passenger	Other Motorized	All
ACS 05	4.0		2.0	75.0	11.0	**US Census American Community Survey 2005 Data**	
SF2000	19.7	1.0	17.2	62.2		**San Francisco Mode Share #s**	
SF2025	18.7	1.0	19.6	60.8			
MTC2000	9.2	1.5	5.6	71.0	13.0	**MTC 9 County Bay Area Mode Share #s**	
MTC2030	9.2	1.4	6.6	68.1	13.9		
BOULDER03	18.6	14.0	4.6	39.0	23.5	**Boulder, CO Mode Share #s**	
PORTLAND05	6.6	1.1	4.0	58.3	30.0	**Portland Ore, Metro Mode Share #s**	
PORTLAND2035	7.5	1.2	5.5	53.2	32.6		
CP LOW 2015	6.6	6.9	6.0	57.5	19.0	6.0	
	2005 Portland Mode Share %	5% easy shift to bike	4% easy shift to transit		4% easy shift to car/vanpool	telecommute/other	

Even in the best case scenario, if Sonoma County's non or low emitting modal percentages were to exceed what has been achieved elsewhere, transportation's contribution to Sonoma's GHGs would be 80 percent of what it is today. The projected level of achievable emissions reduction is approximately 12 percent below the 1990 level. This is less than halfway to our goal of 25 percent below the 1990 level.

Public Transportation for GHG Reduction

At the local level, the right side of the tree in Figure 4, "Use vehicles more efficiently," is most straightforward to accomplish via public sector actions. The importance of enhancing walking and biking infrastructure and increasing the public transportation system cannot be overstated. These fall within the purview of public transportation agencies, i.e., Sonoma County Transit Authority and the Metropolitan Transportation Commission, that have developed and continue to develop these transportation options.

While upgrading these modes is mandatory for reducing GHG emissions, the rate and scale of improvements are limited by the availability of taxpayer dollars, a political matter beyond the scope of this report to fully address. As policymakers and the public recognize the connection between enhanced public transit infrastructure and GHG reduction, more funding may become available.

6

This report identifies options to encourage shifting from single occupant, fossil fuel-powered automobiles to more efficient modes. Public sector options, such as those identified above, tend to have greater cost effectiveness in terms of the cost per ton of GHGs reduced. But because these options rely on funding from tax revenues, the ability to achieve the optimum level of mode share shift is highly uncertain.

Role of Personal Transportation

The total GHG emission reduction that can be expected as a result of the mode share shift to public transit, walking and biking is not sufficient to reach the target in the transportation sector.[9] Thus this report also examines the impact of the left side of logic tree in Figure 4, "Make vehicles more carbon efficient." To the extent that low-cost access to high efficiency vehicles can be provided, a mode share shift can be significant. This report describes a funding mechanism and a technology to give drivers and passengers an alternative to owning and depending upon a private automobile.

Findings of 1997 Sonoma County Transportation Study

In the past, transportation studies focused primarily on relieving congestion. However, a 1997 report known as the Calthorpe Study[10] presented some conclusions that are consistent with the goal of reducing GHG emissions. The team that developed report was tasked with determining "how to most efficiently spend public money on transportation improvements and how to create a pattern of land use that can most efficiently take best advantage of transportation options while maintaining a high quality of life for Sonoma and Marin County residents."

The approach the team took is described as follows:

> *In order to determine the best and most efficient transportation network and urban form for the North Bay, five transportation and two land use scenarios were evaluated. These scenarios included a wide range of potential improvements such as High Occupancy Vehicle (HOV) lanes, reconfigured freeway interchanges, improvements to state highways and local roads, the introduction of commuter rail service, improvements to the existing bus transit system, and bicycle and pedestrian improvements. The land use analysis explored the effects of focusing some new mixed-use development in locations with good access to transit.*

The findings of the Calthorpe study most relevant to transportation and GHG reductions are as follows:

No Scenario Will Substantially Change Fundamental Travel Behavior — The increment of population growth projected between 1995 and 2015 is not large enough to change the fundamental character of the North Bay; future County

[9] Reductions from expected mode share shifts are quantified in the Appendix.
[10] *Sonoma/Marin Multi-Modal Transportation and Land Use Study*, June 6, 1997, Calthorpe, et al.

residents will likely continue to have a strong propensity to drive due in part to the semi-rural nature and dispersed population density of the County.

Rail Works — All of the Scenarios with rail transit had projected more ridership than expected. Rail can be implemented with a relatively low cost, because the major element of its infrastructure is already in place and publicly owned.

Bus/HOV Lane is the Least Cost Effective Transit Investment — A continuous Bus/HOV lane is more expensive than the rail system on a net cost per new trip basis.

Benefits of HOV Lanes Vary Along the Corridor — The HOV lane is of variable effectiveness at relieving congestion on Highway 101. For example, the section between Cotati and Petaluma is relatively uncongested in all the Scenarios and would not benefit from an HOV lane.

Compact Land Use Policies are Not Necessary Everywhere — Some Opportunities Areas are less effective at reducing traffic impacts on Highway 101 and improving rail ridership than others, such as those in Cloverdale and other outlying areas. Also, some Opportunity Areas may not be politically viable.

The goals and methodology of the Calthorpe study were similar in many respects to this evaluation of transportation solutions for reducing GHG emissions. The conclusions of this study, in terms of its focus on the set of potential improvements, echo those of the Calthorpe study. The only exception, perhaps, is the assessment of additional HOV lanes. Although Calthorpe concluded they were less cost-effective than other options, they were still proposed as a congestion management option. From a GHG emissions perspective, the addition of HOV lanes represents roadway capacity increase, which leads to an increase in VMT.[11] Because increasing VMT increases GHG emissions, HOV lanes are not a viable option for this report.

Regional and Countywide Transportation Endeavors

Both the Bay Area Metropolitan Transportation Commission (MTC) and the Sonoma County Transportation Agency (SCTA) have recently incorporated climate protection as part of their planning. MTC's 2035 plan incorporates the targets of reducing carbon dioxide emissions 40 percent below 1990 levels by 2035, and reducing per capita VMT 10 percent by 2035.[12] Similarly, SCTA's Comprehensive Transportation Plan includes as one of its five goals to reduce greenhouse gas emissions.[13]

[11] "Induced Travel Demand: Research Design, Empirical Evidence, and Normative Policies," Robert Cervero, Journal of Planning Literature, 2002; 17; 3.
[12] "Travel Forecasts for the San Francisco Bay Area 2009 Regional Transportation Plan Vision 2035 Analysis Data Summary, November 2007, http://www.mtc.ca.gov/planning/2035_plan/tech_data_summary_report.pdf
[13] SCTA Comprehensive Plan Update, May 2008, http://www.sctainfo.org/pdf/Agenda_Packets/2007/200705_scta.pdf

New Methodology for Estimating GHG Impact of Mode Share Shifts

To date, the impact on GHG emissions of mode share shifts has not been well defined. This report presents a new methodology for estimating both the marginal and total effects of projected mode share shifts on VMT and therefore on GHG production. A method for estimating the GHG reduction impact of a decrease in average trip length is also given.

A model of the sources of GHG emissions in the transportation sector, detailed in Appendix 2, was created to estimate the effects of mode share shifts and generate data for this report. In brief, the model uses data from the year 2000 MTC Transportation Forecast to estimate total vehicle miles traveled in Sonoma County. It uses data on numbers of trips, broken down by trip type and mode share, along with average trip distance. The effects on VMT of shifting mode share from single occupant vehicle to walking, bicycling and transit can be estimated. Total VMT is converted to fuel consumption, based on vehicle inventory and average fuel efficiency for each vehicle category.

Findings

Impact of Mode Share Shifts

One way to illustrate the relationship between GHG reductions and various mode share shifts is as a ratio of percent emissions reduction to percent change in mode. How much emissions reduction will result from 1 percent mode shift?

Results can be summarized as follows:

- 1 percent reduction in average trip length: 1 percent GHG reduction
- 1 percent shift of trips to non-emitting vehicles: 1 percent GHG reduction
- 1 percent shift from car driver to transit: 0.46 percent GHG reduction
- 1 percent shift from car driver to non-motorized transport: 0.38 percent GHG reduction

As travel modes shift from cars toward more fuel efficient alternatives, passenger trips (counted separately each time a unique mode is used) may become somewhat more numerous overall because the average journey will utilize more non-car modes. However, total vehicle miles will decrease markedly and GHG emissions will decrease concurrently.

Opportunities by Travel Mode

The following section describes, in general terms, policies and programs addressing specific travel modes. All estimates given below as "achievable" based on a private global survey.[13] The "likely" estimates were based on U.S. data as applied to Sonoma County.[14] For each mode, the anticipated GHG reduction compared to business as usual is calculated.

Walking

	Mode share shift from SOV	*GHG reduction from BAU*
Achievable	*8.9%*	*4.3%*
Likely	*3.5%*	*1.7%*

Over time, transportation planning priorities have increasingly favored car travel to the disadvantage of pedestrians. Sidewalks have often neglected been over the years, chopped up as roadways are widened to accommodate ever more auto travel, and laden with power poles and pedestrian obstacles. Varying sidewalk standards have resulted in widespread elimination of tree lanes and consequent lack of shade for pedestrians. In both urban and rural areas, pedestrians frequently must walk adjacent to high speed car traffic. As roads have been widened, especially at intersections, pedestrian accident exposure at crossings has increased, while crossing times allotted to pedestrians have diminished.

The road-building programs that often caused the degradation of the pedestrian environment had strong funding mechanisms. Nothing equivalent exists for pedestrians in built out urban environments. Repairing this bleak pedestrian environment will be costly, so well-funded programs must be established. This might be done under the "routine accommodation" concept now being considered as part of road funding.

Bicycling

	Mode share shift from SOV	*GHG reduction from BAU*
Achievable	*7.1 %*	*3.4%*
Likely	*5.0%*	*2.4%*

Bicycling, the most energy efficient travel mode, holds great potential for the United States judging by its use in other developed nations. Even greater potential exists for Sonoma County given its mild climate, beautiful landscape, and relatively flat terrain.

Cycling is limited by some of the same obstacles that hinder walking, particularly conflicts with fast-moving motor vehicles and unsafe and unpleasant accommodations in the street network. Advances are being made as funding is being expanded, and it is happening faster with bicycles than with pedestrian facilities. The greatest shortcoming today may be a lack of recognition of the need for a travel network that is denser than the motor vehicle network. Cyclists are often expected to be content with a sparse network -- a few key safe-routes through the dangerous motorized maze.

To greatly expand bicycle travel we need to greatly expand the network of routes and their safety. This will encourage new riders and accommodate more experienced cyclists over the entire network now available to motor vehicles. In addition to path construction, attention must be given to the connections between routes, to bicycle preference on narrow streets, and to consistent shoulder widths along rural roads. There must be complete and widespread distribution of secure bike parking, and accommodation when possible for bicycles on buses and trains. More discussion of the needs for improving the infrastructure for bicycles is offered in Appendix 3.

Transit

	Mode share shift from SOV	*GHG reduction from BAU*
Achievable	*5.0 %*	*3.3%*
Likely	*4.0%*	*2.6%*

In the shift away from car dependence, transit can be viewed as an adjunct of walking and bicycling, accommodating the longer trips that people make less frequently, so that they won't be compelled to own cars simply to be able to make their longer trips.

There is room on the buses for a lot more passengers, but service has to be intensified to attract them. Fortunately, an increasing return to scale can be expected; doubling the frequency will bring more than twice the riders. Extending the service will also be necessary, although there is little or no scale economy in that direction.

As a nationwide average, the percentage of seats filled on buses is about the same as for cars, primarily because there is a lot of wasted bus service. Most of the waste is in providing service where the demand is insufficient to fill many seats.

The easy answer for why there is insufficient demand is because there is insufficient density. While true, this oversimplifies the situation. Other factors to consider are:

- Route patterns: From the perspective of the traveler they need to be reasonably direct.
- Trip path concentration: Concentration of trip desires along a single path is advantageous for transit and disadvantageous for single occupancy vehicles.
- Price: Price, both actual and perceived, relative to other modes of travel impact travelers' decisions.
- Travel time: Travelers' decisions are also based on the amount of time required from trip origin to destination including wait times.

One factor that many people would put on this list is bus size. It is not included here because it bears little relation to rider attraction. For riders, the best size is a bus with some empty seats. The desire of the non-riders is usually inspired by how few of the seats are utilized, and the wish to have the buses smaller. All else being equal, smaller would be better, but size is limited at the low end by the economics of bus system operation. The key question is how often the passenger load exceeds the number of seats. If there is an answer, it depends on the following factors:

- Route Structure: Can it be changed to reduce the passenger load variance and thereby reduce overloading?
- Fares: Can they be restructured to be in better proportion to distance traveled? Can higher fares be charged for smaller buses?
- Service frequency: Can it be increased judiciously to cope with overloads?
- System operations: Can different size buses be utilized without losing operation and maintenance economies of scale? In an efficient operation buses may shift among lines throughout the day. The more that buses differ within a fleet, the less flexibility they have for line service.

Reorganization of bus services is much needed, based on service policies that will put the services where they are most likely to be used. The contemplated SMART rail passenger system will provide a useful frame element for reorganizing bus services around rail station hubs.

In addition to service expansion, far more attention must be given to the ancillary facilities that serve transit passengers: bus stops and shelters, sidewalks and cross walks near bus stops, secure bike parking, and readily available information on routes and schedules.

The role of school buses in the GHG picture is not clear. They are positive to the extent that they are replacing the need for parents to ferry their children to and from schools. But to the degree that they are providing road safety to children that could otherwise be walking or biking, a more appropriate course might be to make the roads safe for all modes. School siting and school design standards have been major factors in suburbanization, so reforms there should be a consideration in planning for school travel.

The Special Role of Rail in the Transit System
According to the SCTA, Sonoma County has over 2,300 lane miles of city streets and county roads, plus 250 miles of state roads. When the SMART rail system is approved we will also have 50 miles of rail route. The effect of those 50 miles is likely to be far greater than would be implied by its length relative to the rest of the transportation network.

Aside from the relatively modest number of long trips it will carry, SMART will:

- Establish an organizing spine for the entire transit system
- Justify more frequent bus service by providing key bus destinations that will increase bus ridership
- Spark development patterns that lead to far more walking and biking

Long trips determine the need for car ownership, especially when there is no reasonable alternative. People buy cars to make long trips, then use them for their more frequent shorter trips. Rail service with stations spaced 5 miles apart on average, and with service only in a single corridor, would be providing a means of serving those long trips that are most causal for car dependence.

Car Driver

	Mode share shift from SOV fossil fuel powered to non-emitting vehicle	*GHG reduction from BAU*
Achievable	*10.0 %*	*10.0%*
Likely	*Unknown*	*Unknown*

Two primary factors contribute to the car's popularity: Its usefulness and convenience for a great variety of trips, and the public's willingness to accept its exorbitant external costs. In a GHG reduction program, the policy objective for cars should be to eliminate their use wherever feasible while allowing for continued use when essential.

People's commitment to automobiles is largely caused by the way personal costs are structured, i.e., large initial vehicle purchase price, followed immediately by rapid depreciation, but with continuing low costs at time of use. Once the initial buy-in has occurred, there is little to be saved by daily or weekly decisions to use alternate modes of travel, so car usage is essentially locked in. Car commitment can be reduced by restructuring the costs so they are mostly avoidable on a short term basis.

The most comprehensive way of restructuring personal driving costs is through short term auto rental, known as car sharing. Car sharing firms have been formed in a number of western countries, and now operate in many of the larger U.S. cities. To gain a large enough local scale of operation they require fairly high density of users, but over time ways may be found to provide the service in lower density situations. (See section on Public Financing for Personal Transportation below.)

If car-sharing organizations offer a range of vehicle options, such as light trucks for example, people will be less likely to buy specialized large vehicles to meet needs that rarely arise.

Unlike fuel costs, auto insurance costs are borne by the car owner regardless of how much the car is used. Using "Pay-As-You-Drive" (PAYD) insurance to decrease the amount of driving is an idea that has been discussed for perhaps twenty years. Insurance companies oppose the concept because PAYD threatens their business. If drivers have the option of reducing their insurance costs by leaving their car parked, they will do so as often as they can.

This situation creates an opportunity for individual companies offering PAYD insurance. They can gain market share by offering a desirable product to low risk drivers. Progressive, a large auto insurance company has been patenting system technology, presumably so it moves fast and first when the market is ready for PAYD insurance.

Other means of encouraging car drivers to seek alternate ways to travel involve eliminating driver subsidies wherever possible. (See Wide Spectrum Solutions below.)

Measures for encouraging drivers to seek alternatives are most applicable in urban areas because that is where car driving is least necessary, and alternatives most competitive. Nevertheless, because one third of Sonoma County's residents live outside municipal boundaries and have high travel distances, it is important to reduce the car miles generated here, too. The establishment of rural service networks may eliminate some of the errands that people do in their cars. (Please see Private Sector Opportunities below.)

Car Passenger

	Mode share shift from SOV	GHG reduction from BAU
Achievable	7.0 %	.9%
Likely	4.0%	.5%

Actions taken to promote carpooling have had a mixed record. It is as if the level of riding in the passenger seats goes up or down depending on unrelated factors, e.g. state of the local economy, gas prices, density, etc. Although the emphasis in transportation planning in Sonoma County and elsewhere has been to "encourage" car and vanpooling, the level of uptake has never met expectations. There are excellent programs such as 511.org, which have made an impact, however. Unfortunately, tax advantaged programs such as "Commuter Choice[14]" to encourage car and vanpooling are not implemented by most employers. Incentives for car and van pooling typically take the form of regional, state or federal efforts, because there is little that the local governments can typically do to increase use of these modes. We address the potential for expanding federal income tax incentives for car and van pooling in Appendix 4.

Other Non-Car Motorized Modes

	Mode share shift from SOV	GHG reduction from BAU
Achievable	Less than 10 %	Probably small
Likely	Unknown	Probably small

Spurred by fuel prices, there appears to be a modest trend toward motorcycles and motor scooters. If Italy represents the potential for these vehicles, there could be a huge shift away from cars as we encounter fuel prices of the magnitude long endured by Italians. The trend could be accelerated by parking conversions to accommodate these efficient modes, beginning by designating the most favorable parking spaces for them.

[14]Pre-tax payroll deduction program. Funds can be used to pay for transit, vanpool or parking cash out. See www.commuterchoice.com for more information.

Travel Mode and GHG Impact Summary

	Mode share shift from SOV	*GHG reduction from BAU*
Walking		
Achievable	*8.9 %*	*4.3 %*
Likely	*3.5 %*	*1.7 %*
Bicycling		
Achievable	*7.1 %*	*%*
Likely	*5.0 %*	*2.4 %*
Transit (including Rail)		
Achievable	*5.0 %*	*3.3 %*
Likely	*4.0 %*	*2.6 %*
Car Driver		
Achievable	*10.0 %*	*10.0 %*
Likely	*Unknown*	*Unknown*
Car Passenger		
Achievable	*7.0 %*	*.9 %*
Likely	*4.0 %*	*.5 %*
Other Non-Car Motorized Modes		
Achievable	*Less than 10.0 %*	*Probably small*
Likely	*Unknown*	*Probably small*
Total		
Achievable	*40%*	*11.5%*
Likely	*25%*	*7.6%*

Likely total GHG reductions from mode share shifts fall in the range of 7.6 to 11.5 percent below business as usual. Given that our reduction target is 37 percent below business as usual, wide spectrum solutions must make up the difference.

Wide Spectrum Solutions

Certain policy changes will simultaneously shift all modes in the direction of GHG reduction. For example, establishing equal access policies for transit stations, shopping centers and other major centers of activity can encourage the use of transit, bicycles and walking. To the extent that such centers subsidize access (e.g., free parking in shopping malls) an equal access policy assures that investment is equal for each mode of access, on a per person basis.

Land Use and Development

GHG reduction impact: 1 percent reduction in GHG for each 1 percent reduction in average trip length or number of trips. Average trip (segment) length is currently estimated at 4.9 miles. If this were reduced to 3.9 miles (22 percent), the corresponding GHG reduction would be 22 percent.

Reliance on the car created today's land-use pattern that now relegates Sonoma County to high fossil-fuel dependency. To reverse this, we must explicitly return to land use patterns in place before the car overran us. Otherwise, any near term energy reductions will be wiped out in the long term.

The current effort to increase density in Sonoma County relies primarily on making buildings taller while maintaining a high level of car access. This course will not increase the energy efficiency of our transportation system. In favoring city centered development in Sonoma County, high density development must be tightly coupled with transit access.

More than just density, economic development and activity that relies on long distance car access must be reconsidered. Large regional retail centers accessible only by car undercut the neighborhood vendor and are incompatible with high density development where people are encouraged to live, work, walk, bike, and take public transit.

High Density Development
The loss of density in the urban centers over the years has been attributed by some to the convenience of the automobile, a misconception based on its speed and ease in getting between any two points. The dominant cause was actually the way that space consumption — the auto's great weakness — was kept out of sight and out of mind.

There is a little noted urban/rural asymmetry, which causes the high space cost of automobiles (for both roads and parking) to be borne disproportionately by the urban economy. Urban areas competed with each other economically by offering free parking, to attract increasingly suburban motorists.

The subsidy of free parking was achieved not through direct local government payments, but by using government power of regulation to require development to provide the parking at much higher levels than would have been provided by a free market. The remedy is to adopt free market policies, eliminating requirements for off-street parking and applying free market prices to curb parking. The key to gaining neighborhood acceptance of paid parking is to return most parking revenues to the neighborhoods where the revenues are generated.

Policies and rules should be revised first in the highest density development nodes near the train stations, where the transit service will be most competitive and auto ownership is less necessary.

Low Density Development
Low-density development is inherently weak in transportation options. Cars will continue to be the predominate mode of transportation, but there can be ways of using them more efficiently and introducing other options. Low-density communities can set up rural service districts that would:

- Own and manage car-sharing organizations
- Manage ride-sharing and provide goods delivery depots
- Operate fuel distribution facilities
- Pay for trunk line bus service to connect with major urban centers and rail stations.

Some of these solutions are addressed in more detail in the section on Personal Transportation Options.

Demand Management
Parking management and pricing, speed reduction and local gasoline taxes fall under the category of "demand management". These are policies that are directed at reducing the demand for trips by raising the cost or lessening the convenience of travel for basic short trips.

GHG reduction impact: 1.05 percent reduction in GHG for each 1 percent reduction in average number of trips.

Pricing for Parking
Few cities have parking rules and policies appropriate for an era of energy reduction. There has been a longstanding powerful urge to make parking free or cheap to the driver, regardless of the actual cost of providing it. This must change if people are to choose transit whenever feasible, because subsidized parking is the strongest incentive they have to drive.

Like land-use changes in general, parking in particular is very much the purview of local government. Municipal governments need to look carefully at what they've been doing, and make some big changes. Don Shoup proposed a change in the normal municipal practices that may seem radical in today's context:

- Stop requiring off-street parking,
- Charge market rate for on-street parking, and
- Return parking revenues to districts where collected.[15]

These are closely coupled rules, which if carried out, would reduce the urban space wasted on excessive parking, reduce the number of car trips, assure that there is always enough parking available where it is most wanted, and produce revenue for neighborhood public purposes. Those purposes could include better facilities for walkers and bicyclists, and better transit services – all achievable when people have fewer financial rewards for driving.

New city parking policies should be guided by these principles:

- The determination of how much parking there should be must always be based on price. It should be a market determined price, which will mean that prices will vary according to location and time.

[15]Donald Shoup. *The High Cost of Free Parking*.

- The cost of parking should be borne by drivers, not the developers or property owners, or by people who aren't driving.
- Parking arrangements should be simple and easy for drivers. As long as drivers are willing to pay the market price, they should not be hassled by inconvenience.
- Physical arrangements of parking should induce efficient use, i.e., high average occupancy of the spaces. This will be achieved only if parking spaces are readily shared. For example, parking for residents should be available to non-residents when residents are not using them. Time-sharing is often inhibited by security concerns, so those need to be addressed.
- Parking costs should not be bundled with the costs for the primary uses of property, whatever the zoning.

Speed Reduction

A general reduction of permitted road speeds will have many direct and indirect GHG reducing benefits:

- Propulsion energy is reduced by lower speeds.
- Safety of all road users is increased as top speeds are brought down.
- If people are using heavy vehicles to increase their own safety while bringing greater risk to others, safety improvements related to speed reduction may be an inducement to choose smaller vehicles.

New Tax Policies

A local gas tax would be more appropriate than sales taxes to finance all kinds of transportation related expenditures because it increases the incentive to use modes with lower fuel requirements.

Although the driver pays the tax, the incidence of the tax is partly shifted back to the producer. If the oil is coming from a foreign country, that country helps pay the tax. In other words, when the tax is levied on top of the price charged, the underlying price goes down somewhat, depending on consumer price elasticity. This principle was long recognized in countries without internal sources of oil. Unfortunately the U.S. never made the adjustment when it became a net importing country.

Localities with higher gas taxes are better insulated against fuel price volatility.

Prices and Costs of Travel Modes

Total motor vehicle costs for the United States are shown in Table 3.

Table 3[16]

Motor Vehicle Annualized Cost Summary (2000 U.S. dollars)

Costs	Distribution	Totals (millions)	Per Capita	Per Vehicle	Per Veh-mile	
Travel Time	Int.-Var.	$840,000	$3,000	$3,818	$0.34	28%
Vehicle Ownership	Internal-Fixed	$600,000	$2,143	$2,727	$0.24	20%
Crash Damages	66% Int.-Var.	$500,000	$1,786	$2,273	$0.20	17%
Non-residential Off-street	90% External	$300,000	$1,071	$1,364	$0.12	10%
Vehicle Operation	Int.-Var.	$250,000	$893	$1,136	$0.10	8%
Roadway Costs	66% Int.-Var.	$120,000	$429	$545	$0.05	4%
Traffic Congestion	External	$100,000	$357	$455	$0.04	3%
Environmental Costs	External	$100,000	$357	$455	$0.04	3%
Roadway Land Value	External	$65,000	$232	$295	$0.03	2%
Residential Parking	Internal-Fixed	$50,000	$179	$227	$0.02	2%
Fuel Externalities	External	$40,000	$143	$182	$0.02	1%
Traffic Services	External	$30,000	$107	$136	$0.01	1%
Land Use Impacts	External	?	?	?	?	
Equity Impacts	External	?	?	?	?	
Totals		**$2,995,000**	**$10,697**	**$13,613**	**$1.20**	**100%**

This table summarizes estimates of various motor vehicle costs.

For Sonoma County, there were approximately 275,000 automobiles, 100,000 trucks and 8,500 motorcycles registered in 2005. According to the table above, the total cost of travel is over $5 billion dollars annually for these vehicles. That cost is over $11,000 per capita, for all internal (80% paid by the user) and external (20% paid by society) costs.

If a traveler had to pay the full cost of travel on each mode, and pay the price at

[16] From Victoria Transport Policy Institute, TDM Encyclopedia.

the time of travel, the transportation system would be far less car dependent, and the suburbs as we know them today would not exist.

Car ownership as well as payments for insurance and license on an annual basis, and maintenance that is paid for only occasionally, all tend to lower the "out-of-pocket" costs of travel, and thereby create loyalty to car use.

Anything done to bring price more into line with cost will likely evoke negative reactions. Those who pay more will protest that they are being "penalized" and those who pay less may not see the potential advantages. Therefore, measures intended to bring transport efficiency should always be coupled with benefits of convenience and other amenities.

Private Sector Opportunities

With a little bit of help from public sector financing sources to provide seed capital, along with the increasing cost of travel by private automobile, some significant opportunities for new businesses are likely to emerge. These opportunities leverage broad-based access to the Internet, along with the increasing integration between television and online services.

Expansion of Delivery Services

Delivery services coupled with online shopping are proven means of enabling people to acquire what they need without travel. However, the attraction of "going to the store to shop" is deeply rooted in the culture of today. The only possible way to promote the alternatives is to simultaneously make car travel to the store more expensive and inconvenient, while making the online option easier and more attractive to use, ubiquitous and inexpensive.

One possible expression of improvement of the online option might be to provide an online shopping experience using video game or "virtual world" technology. Another name for this technology might be "first person shopper." This option would be included as part of cable television services. The first person shopper virtual shopping experience would duplicate the experience of being present in the store, and would give the user the opportunity to "pick up" and examine items, to walk the aisles, talk to sales people, etc. This virtual shopping experience could be linked with local merchants, such that an order placed by a virtual shopper could be delivered from local stores or shipping depots.

Telecommuting

Management of telecommuting workers involves adapting management style to engaging with workers that are not physically present. Rather than being a technological challenge, this is more of a management challenge for managers that are accustomed to working with an onsite workforce. Although a description of management techniques for a "tele-work" force is beyond the scope of this paper, there are associations that have developed training for managers of teleworkers.[17] Further efforts to encourage and incentivize employers and

[17] For example, see *Home Workplace: A Handbook for Employees and Managers*, by Brendan Read.

employees to develop a teleworkforce might be packaged into a tax-advantaged program similar to the "Car(e)-Free" program described in the Appendix.

Personal Transportation Options

The automobile will continue to account for a significant share of vehicle miles traveled for the foreseeable future. Public transportation improvements are critical for reducing the carbon emissions due to transportation. However, increases in use of the public transportation system, walking and biking options will not account for sufficient reduction of emissions.[18] The best case reduction is less than 15 percent below projected GHG emissions for 2015 for the transportation sector.[19] Since this leaves over 20 percent reduction still required to meet our target, walking, bicycling and transit options need to be augmented significantly with other personal transportation options that are low or non-emitting.

Although some auto use is inevitable, eliminating the market imperfections that underlie its overuse can lessen it. The following solutions mentioned earlier in this document will impact personal choice:

- Create provision of car sharing to obviate the need to own or lease when the need for a car is occasional or sporadic
- Unbundle: Charge separate rents for parking from the rents of both residential and commercial developments
- Shift auto insurance to pay-as-you-drive
- Raise the gas tax in the county

As shown in Figure 4 (see page 5), there are two paths to reducing the GHG emissions of automobile transportation. One path is to use vehicles more efficiently. That is, to increase the number of passengers in the vehicle so that there are more passenger miles per mile of vehicle movement. The other path is to use vehicles that are more carbon efficient. That is, there are more miles of vehicle movement per pound of equivalent carbon dioxide created by that movement.

[18] Relative to the target of 25 percent below 1990 levels.
[19] Based on potential mode share shift estimates from the Sonoma County Transportation Agency.

Table 4

% Change in CC Emissions*		Technology or Fuel
- 100		Electric car (renewable source)
- 77		B100 (100% biodiesel)
- 20 to -50		Hybrid car (gasoline)
-32		Electric car (US grid)
-28		B20 (20% biodiesel + 80% diesel)
- 22		E85 (85% ethanol from corn, 15% gas)
- 15		Propane (LPG)
- 13		CNG (compressed natural gas)
ICE	*FCV*	-- *Vehilces using hydrogen* gas
-7	-53	Hydrogen (H_2) from CNG
+138	+21	H_2 from today's US electric grid
-100	-100	H_2 from renewable electricity

*negative CC numbers are good, positive are bad

Ultimately, there must be zero equivalent carbon dioxide emissions created by mobility in any form, either of passengers or cargo. As shown in Table 4, the only zero emissions option currently known is to power the vehicle with renewably generated electricity, or with hydrogen created by renewably generated electricity.

Alternative fuel vehicles may have a very low carbon impact or not, depending on how the alternative fuel is made. Similarly, hydrogen vehicles using fuel cells may have no positive impact on carbon emissions.

The social and economic investment in our present transportation system limits the speed it can be converted into more efficient alternatives, e.g., SkyTran.[20] However, there are many ways of improving the present system and many ways of using the present vehicles in a more effective manner. Future additions to the system can be purchased with the best fuel efficiency and the capability of running on renewable energy.

Improving Vehicle Use

We can gain improvements in three ways:

1. **Use our present vehicles in a more fuel-efficient manner:** Presently, vehicles across all modes of transportation in Sonoma County and the US average 20 to 25 miles per gallon. Many well known ways to improve this exist such as:

    - Carpooling
    - Vanpooling

[20] SkyTran is an innovative, low-cost, mass transit system that uses small "pods" that are dispatched using the same methods used by computer networks for switching and routing. See http://www.unimodal.net/ for full description.

- Increasing the riders on each bus
- Using the smallest, lightest vehicle to do the job (bicycle ,scooter, motorcycle, hybrid car)
- Reducing speed (55 mph speed limit, obeying posted limits)

2. **Convert some of the present vehicles to alternative fuels and electricity:** Some vehicles can be converted to run on electricity and/or biofuels. Many trucks can be run on biofuels and/or converted to Plug-in Hybrid Electric Vehicles.[21] PHEVs run for an initial distance on primarily electricity. This power is taken from the grid and so has the carbon makeup of the grid. These designs can greatly reduce GHG, typically doubling fuel efficiency. Additionally PHEVs lead the way to EVs by creating the infrastructure of convenient plug-in stations.

3. **Purchase new infrastructure, vehicles, and systems that are extremely efficient and run on renewable energy:** Bike lanes and paths can promote perhaps the greatest individual trip savings. Cell phones, GPSs, and the Internet can create more efficient van and carpooling. Hybrids and PHEVs can be purchased. Larger projects such as mass transit can use newer technologies such as SkyTran, an electrically powered magnetic levitation system based on the Internet packet routing concept that use one-tenth the power of traditional mass transit and is much cheaper to build. Electric trolley buses can replace fuel burning buses in suburban/urban areas at a much lower cost than light rail.[22]

With the limited time to make changes to our transportation system and the dangers the current path guarantees, a rapid change needs to occur. More roads are not needed; more occupants per vehicle are. Government agencies and utility companies can lead the way, establishing markets for potentially clean zero-GHG vehicles and transit systems that can run on grid power or other renewably generated electricity.

Public Financing for Personal Transportation

In order to achieve a 20 percent total shift in VMT to low or non-emitting vehicles, between 30,000 and 40,000 of such vehicles would need to be made available on a convenient, low-cost basis.[23] Probably the most viable such basis would be the short term rental, or "car share" described above. In keeping with the overall orientation of the Community Climate Action Plan to frame solutions in terms of public works projects, two principles can be applied:

1. Use of bond financing to acquire the fleet of vehicles
2. Integrate with renewable energy infrastructure

[21] See, for example, www.evpowersystems.com and www.pluginpartners.org.
[22] See, for example, www.tbus.org.uk/home.htm.
[23] These figures are based on a projected annual VMT of 4,440 million miles in the year 2015. Average vehicle mileage for a fully utilized fleet vehicle is assumed to be approximately 24,000 miles/year.

3. Develop "portfolio" of vehicle types that are appropriate for the types of mobility required for different areas of Sonoma County. Another way of stating this is "match vehicle types to passenger trips" as formulated in the Figure 2 logic tree.

The short term rental vehicle fleet should be deployed in areas where population density is not sufficient for economical mass transportation options such as bus or train. The fleet should be used to provide access to transit centers where public transportation is available, or to local destinations that are too far or impractical to walk or use a bicycle.

If this rental fleet is integrated with local renewable energy infrastructure, some interesting financial arrangements become possible. Use of card lock technology for access to the vehicles, along with vehicles equipped with "smart metering" would enable tight integration with Community Choice Aggregation (CCA), a description of which is in the Source Material section of the Community Climate Action Plan.[24] The CCA may issue municipal revenue bonds against guaranteed revenue streams associated with electricity sales. Thus, if electricity sold by the CCA is used by a vehicle in the rental fleet, such sales could be used to secure bond financing to purchase and or build the fleet.

Additionally, vehicles batteries and generation capacity for vehicle charging can be integrated into the renewable portfolio of the CCA. As has been proposed elsewhere[25], Vehicle-to-Grid technology can provide battery storage as required for the renewable portfolio described in the Energy Element of the CCAP. The charging bays for the vehicles, using solar PV or other generation technology, can also be put on the grid as elements of the portfolio. In the case of both the batteries and the charging bay power sources, the CCA can purchase these using municipal revenue bonds. The batteries and charging bays can then be leased to the operator of the car share fleet.

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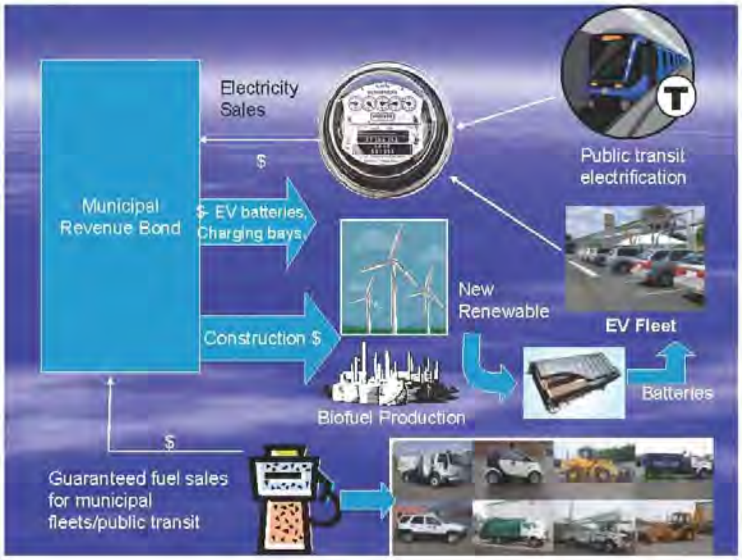
[24] Energy Solutions - A Plan to Achieve Accelerated, Scaled & Cost-Effective Greenhouse Gas Emission Reductions in the County's Energy Sector by 2015, Local Power Incorporated, March 2008
[25] "PG&E sees plug-in hybrids as potential profit centers," http://news.cnet.com/2100-11392_3-6174672.html

Figure 5



Smart Meter and Card Lock
For the CCA to issue bonds against electricity sales used for vehicles, each vehicle must be equipped with an electricity meter, just as each home is currently equipped with a meter. However, since the vehicle is mobile, and needs to be able to be charged in locations that might not be served by the CCA, the onboard electric meter needs to be "smart" enough to know when it is being charged by electricity from the CCA. This could be accomplished by specially identified charging ports or stations, or by other means.

Any customer of the CCA that wished to participate in the car share program would be issued a card that would be used to gain entry to a car share vehicle. This card lock system would enable the CCA to bill the customer for the use of the vehicle. The charge for the use of any CCA-owned car share vehicle would appear on the electric bill every month.

In this way, repayment of the revenue bonds used to finance the vehicle fleet can be made through electricity purchases made from operating the vehicles.

Car Share Rental Fleet Portfolio
The car share rental fleet would be composed of a variety of all electric and hybrid vehicles depending on the application and expected use. These vehicles would be deployed in areas of less dense population. Their primary purpose would be to give access either to public transportation or to shopping or personal service destinations where walking or bicycling is impractical. These vehicles could range in size from single passenger, limited range neighborhood electric vehicles

(NEVs), to plug-in hybrid electric vehicles (PHEVs) that carry multiple passengers and have longer range.

In addition, the fleet would include delivery trucks that could be used by local merchants as described in Expansion of Delivery Services.

Walking and Bicycles: Implementation and Costs

Most of the anticipated costs for directly encouraging walking and cycling would be incurred to remedy the errors and omissions of the past. The concept of "routine accommodation" that is now being discussed in the legislature may be the key. It means that whenever roads are built, improved or maintained, all users of the roadway will be considered and provided for, as a matter of routine. Road construction might be somewhat more expensive when all users are considered, but it's a lot less costly than coming back later to fix the omissions.

In the longer term, more comprehensive land-use planning that achieves a more finely tuned distribution of activities and services, and thereby improves convenience of bike and pedestrian access, is probably the least costly approach for these modes.

Bus and Train: Implementation and Costs

Initial cost of the train (SMART) has been fairly well established. Other train costs will be added as growth in ridership occurs. After the initial capital investment, subsequent improvements will come in small increments. Both capital and operating costs will be covered by the sales tax to go before the voters in November of 2008.

Unlike highways and cars, both trains and buses offer increasing returns to scale, as long as scaling up is accomplished by intensification. To illustrate, if a route has had buses that come every half hour, and the buses now come every 15 minutes, it is no longer the same service. It is a better service for the prior riders and is more attractive to new riders.

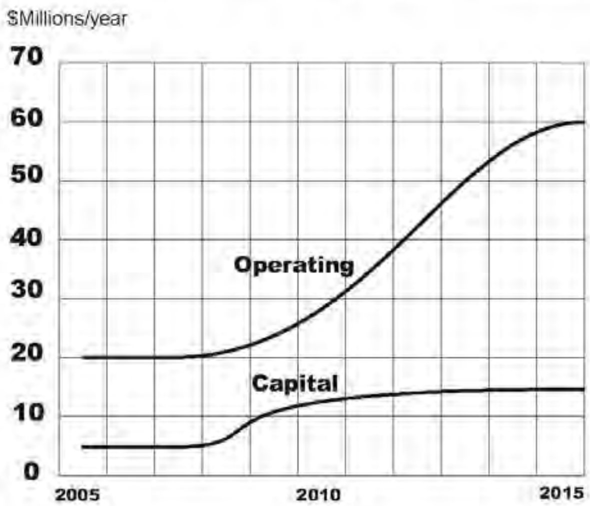
Scheduled bus services in Sonoma County are poorly financed and accordingly very thin. Only about 1 percent of the person trips are on transit. Funding of operations can have greater reliance on fares and local group payment as the system expands and transportation policies are rationalized (i.e., become more market oriented).

An increase in the transit mode share from 1 percent currently to 6 percent in 2015 will require increasing service by a factor of 3 and increasing average loadings by a factor of 2.

The existing 1 percent is accommodated by an annual countywide expenditure of $20 million in operating costs plus $5 million capital costs. The annual expenditures would be something akin to the Figure 6 below.

Although electrification is not part of the initial planning for rail in the County, the municipal bond arrangement could be used to finance it. In the same way that electricity sales for vehicle propulsion would secure bond funding for the fleet, electricity sales to the rail operation would secure funding for electrification infrastructure. The card lock system could also be applied as a "transit pass" on the train. Use of the card to access the train would be billed on the electric bill.

Figure 6:
Approximate Expenditures Required to Meet Transit Mode Share Goal by 2015



Car Share Fleet: Implementation and Costs

As described above in Car Share Rental Fleet Portfolio, the fleet would consist of a set of vehicle types designed to serve the widest variety of individual transportation needs possible. The fleet would be deployed in phases that would coincide with bond issuance. To the greatest extent possible, existing gasoline or diesel powered vehicles would be converted to plug-in hybrid. This could be done very cost effectively using conversion kits being developed today for pickup trucks. Fleet pricing for electric vehicles could bring down the average cost of the vehicle. It is estimated that a vehicle fleet numbering 30,000 EVs and PHEVs could be deployed for between $5,000 and $10,000 per vehicle. This would put the total cost at $300 million. Using 30 year municipal revenue bonds to acquire the fleet would give the lowest possible financing cost. The bond repayment would be made through the charge for electricity used to power the vehicles as described in Public Financing for Personal Transportation.

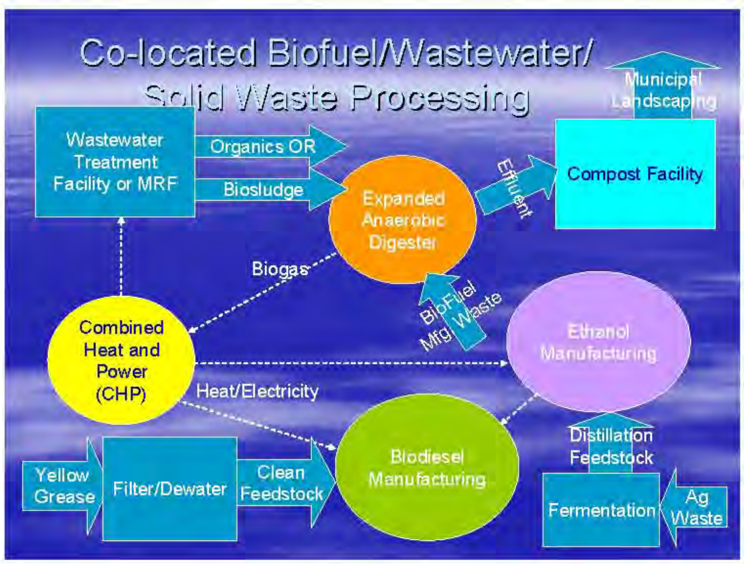
Biofuels

Recently biofuels have been under scrutiny due to controversy over whether they have a net negative impact on carbon emissions. Biofuels made from virgin feedstocks take a slice out of food production as well. However, biofuels made from wastes could make a significant contribution to overall reduction in GHG emissions due to combustion of transportation fuels. As shown in Figure 7, co-located waste processing and energy production facilities have an impact much greater than the sum of the parts. Harvesting both the organic content of the municipal solid waste (MSW) stream, along with agricultural waste and waste from food processing can provide a significant energy/compost/fuel source.

The total magnitude of this source of transportation fuel is somewhat limited however. The current estimate of the waste vegetable oil available in Sonoma County is less than 1 million gallons per year. Total fuel production from waste material, assuming cellulosic ethanol production (or similar low energy production technology) is thus probably in the 2 million gallon per year range. If this fuel was “triaged’ to be used only for public transportation and municipal service vehicle fleets, it would provide the most overall benefit. When and to the degree public transportation and municipal vehicle fleets became electrified, the fuel could potentially be sold to the public or other consumers.

Since the guaranteed biofuel sales to public vehicle fleets would secure revenue bonds, the same financing program used to build renewable energy facilities and vehicle fleets could be used to build and operate the biofuel production facilities.

Figure 7



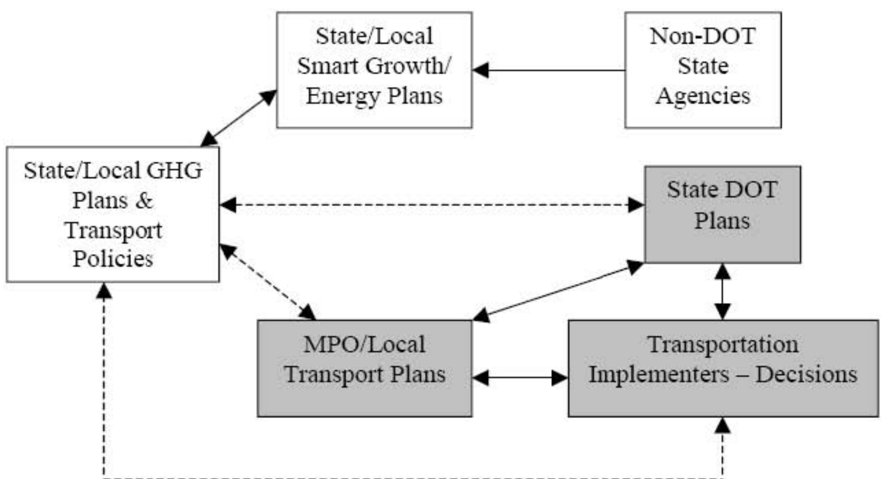
Transportation, Land Use and GHG Planning Integration

Currently, there are gaps in the planning process that make it difficult to create policies that minimize GHG. There is also a need to coordinate local planning processes with state and federal policy-making. Figure 8 below reflects the relationship among the various planning aspects.

Land use, transportation and climate protection planning at the local level should be carried out as an integrated whole. From a policy-making standpoint, the following factors are important:

- Direct linkage between quantified GHG reduction target and land use, transportation and energy planning.
- Involvement of agencies representing other sectors
- Development of a system of metrics and feedback

Figure 8



The following land use factors have a large impact on trip generation:

- Roadway design including signalization and traffic calming
- Pedestrian and bicycle accessibility
- Parking availability, including the size and locations of park-and-ride lots
- Development of energy resources that have an impact on reducing transportation emissions, such as biofuel production and renewable electricity generation. Developing these resources requires dedicated land area.

30

In general, certain practices increase VMT, such as:

- UGBs that are too large and/or not enforced
- Segregated zoning that increases the distance between residential and commercial areas, or enforces the development of single use areas such as business parks that are remote from housing.

In addition, there are land use policies that may have a direct bearing on local energy production. Although not directly related to transportation, there may be a potential to significantly reduce GHG emissions through co-location of housing and commercial buildings to locally available energy resources such as geothermal, hydro and wind.

Transportation Information Needs

Because the current transportation system is, by orders of magnitude, very climate-unfriendly, approximate data is adequate for analyses that can point us in the right direction. But soon a parallel effort to improve transportation data is needed to ensure the availability of necessary information to make fine scale adjustments and stay on course. We must be able to quickly evaluate the impact of our efforts and expenditures to intervene in a system that currently is taking us in the wrong direction.

The central variables that must be monitored -- and monitored on a highly disaggregate basis -- are VMT and PMT (passenger miles traveled). To a degree this is already being done with transit, but there needs to be a concerted effort to have better data on car usage. Also, we need far better data for walking and bicycling as a measurement of success in shifting modes.

Addressing this topic, the Climate Protection Campaign issued a report, "Greenhouse Gas Emission Measurement in the Transportation Sector: Status, Problems and Possible Solutions."[26]

Summary and Conclusion

There is no question that significantly reducing GHG emissions from transportation is highly problematic. No one solution is going to produce significant change of behavior or cause widespread use of a particular technology. The effort to reduce GHG emissions from transportation is going to require action at state and federal levels to augment local efforts. However, the overlap between land use and transportation needs is almost entirely under local control. In addition, the public transportation infrastructure, including roads, the walking and bicycling environment and transit, are largely administered by local governments. Policies that have high impact on automobile use such as parking pricing, congestion pricing and gasoline taxes are enacted by local government.

[26] "Greenhouse Gas Emission Measurement in the Transportation Sector: Status, Problems and Possible Solutions," Jehan Sparks, August 2007, http://www.climateprotectioncampaign.org/reports/jehanrep07.pdf

There is a high degree of certainty that the most cost effective means to reduce VMT and GHG emissions due to transportation is reducing the number and average distance of trips through:

- Increased density through infill development
- Repair and revitalization of walking and bicycling environments through routine accommodation and equal access
- Full funding of transit improvements (including rail) in the most dense areas

Land use planning incorporating GHG emissions reduction assessments is critical for controlling the growth of emissions due to new development.

In conjunction with these measures, demand management strategies can both reduce the frequency of trips, and generate funding for transit and walking and bicycling infrastructure improvements. Parking pricing is one of the most notable methods for reducing the frequency of trips.

Beyond public sector policies and programs, a variety of private sector services and public-private partnerships can be defined and funded using seed capital from public and private sources. These services can provide for the mobility needs of the community, cost effectively, thereby reducing the need for automobile ownership. Ultimately, in order to reduce emissions from transportation to the level required to stabilize atmospheric carbon dioxide at a safe level, the fossil fuel powered automobile will have to be abandoned. This plan is the beginning of that process.

Appendix 1: Required and Achieved Mode Share Shifts

Figure 9

Mode	Walk		Bicycle		Transit		Car Driver		Car Passenger		Other Motorized		All	
	Current	2015	Current	2015	Current	2015	Current	2015	Current	2015	Current	2015	Current	2015 (1)
Share (%)	3.1	12.0	1.9	9.0	1.0	6.0	74.0	37.0	15.0	23.0	2.0	10.0	97.0	97.0
Av Dist. (Mi)	0.4	0.4	2.0	2.0	5.8	4.0	5.0	4.0	7.0	7.0	3.0	3.0	4.9	3.9
ACS 05	4.0				2.0		75.0		11.0	US Census American Community Survey 2005 Data				
SF2000	19.7		1.0		17.2		62.2			San Francisco Mode Share #s				
SF2025	18.7		1.0		19.6		60.8							
MTC2000	9.2		1.5		5.6		71.0		13.0	MTC 9 County Bay Area Mode Share #s				
MTC2030	9.2		1.4		6.6		68.1		13.9					
BOULDER03	18.6		14.0		4.6		39.0		23.5	Boulder, CO Mode Share #s				
PORTLAND05	6.6		1.1		4.0		58.3		30.0	Portland Ore, Metro Mode Share #s				
PORTLAND2035	7.5		1.2		5.5		53.2		32.6					
CP LOW 2015	6.6		6.9		5.0		57.5		19.0			5.0		
	2005 Portland Mode Share %		5% easy shift to bike		4% easy shift to transit				4% easy shift to car/vanpool		telecommute/other			

Mode Specific Improvement Measures	sidewalks tree lanes, shade street crossing priority intensified network	path construction better connections priority on narrow streets consistent shoulder widths	construct, operate rail passenger service expand bus services fixed facilities for transit passengers	car-sharing services light truck rental rural service network congestion pricing	facilitate car-pooling ride auctions??	parking conversions to provide favorable spaces
General Policy Measures	Land use changes favoring shorter trips New tax policies, e.g. local gas tax, with revenues applied to favor GHG reductions when shifting mode shares General reduction of road speeds to promote energy reduction and safety of all road users Expansion of delivery services Telecommute programs to reduce numbers of trips Manage parking with pricing					

NOTES
Transit includes bus and train.
Car includes light trucks, vans.
Other Motorized includes scooters, motorcycles
(1) Mode shares add to 97% because school bus trips aren't accounted for. They may carry about 3% of trips.

33

Appendix 2: Transportation GHG Model

The Transportation GHG Model is a method for estimating the GHG reduction from an intervention in the Business as Usual (BAU) scenario. The GHG Model consists of three sections:

1. Intervention Category and Total Mode Shift
2. Trip Distribution and Total VMT Calculation
3. Vehicle Inventory and Total GHG Calculation

Model Overview

The Transportation GHG Model produces an estimate of GHG emissions based on Vehicle Miles Traveled. By modeling the effect of transportation system changes on the mode share distribution or other travel metrics, estimates can be made of the effectiveness of these measures in reducing GHG emissions.

Interventions can change either (1) mode share distribution; (2) average trip length; (3) total number of trips; (4) fossil fuel efficiency of vehicle fleet.

Mode share distribution, average trip length and total number of trips are used in the model to calculate total annual VMT. This total is distributed to vehicle categories based on an "On Road Stock Turnover" model. The "total miles traveled in each vehicle" category is then converted to a fuel consumption figure, based on the average fuel efficiency of vehicles in that category. Finally, total gasoline and diesel fuel consumption is calculated using standard emission factors for each fuel type.

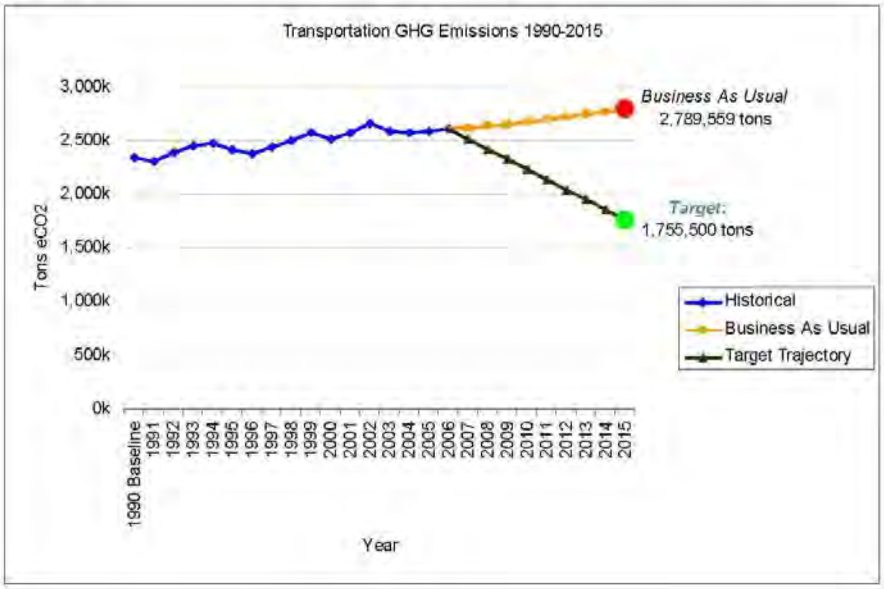
For a .more detailed description of the Transportation GHG Model, please see the section, "The Carbon Model" in the source materials.

Appendix 3: Safe Bicycling Needed to Increase Mode Share

A Really Big Problem

None of us have yet experienced personally the likely effects of climate change, so few of us can imagine that we will soon be desperate to cut back the emissions generated by our fossil fuel guzzling transportation system. The graph below shows what is already planned for Sonoma County, in terms of goals for GHG reduction.

Figure 10



The goal is based on what will be needed if Sonoma County is to meet its obligations as a member of the global community – a 25 percent reduction from the base year of 1990. This graph shows that we expect transportation to make a GHG reduction of approximately 30 percent in 9 years, in the face of having gotten worse nearly every year since the 1990 baseline.

What Can We Do?

First of all, we can try to stop thinking that traffic congestion is the problem, and stop providing the additional road capacity that isn't at all relevant for the "new" problem. The problem isn't really new of course. It's been growing for years, but we've only noticed it recently, just as it is starting to look like a monster.

Since the transportation system is mostly automobiles, automobile driving will have to be curtailed the most. Some of the people now driving cars will have to ride in cars as passengers. Some will be using far more efficient motorized vehicles, such as scooters. Others will be in buses and trains, or biking, or even walking

The more that people make their trips in these other ways, the less road capacity will be needed. Any of the major alternatives – transit, bikes or walking – can move 6 times the volume of passengers through a 10 foot wide space than can automobiles, under typical congested urban conditions and vehicle loadings.

If the conversion has to be done rather quickly – and we think that will be the case – then bicycles could be one of the quickest and most important ways of reducing CO2 generation, for these reasons:

- Most people already have bicycles – they just aren't using them.
- Virtually all the pavement needed is already in place.
- Many of the trips currently taken by car are short enough to be taken by bicycle.
- Bicycling has pizzazz, and many people are ready to switch if their safety is assured.
- There is safety in numbers – injuries per bike rider will fall as more bicycles are seen on the road.

What about Safety?
In Sonoma County there is lots of hoopla and happy talk about cycling, but there isn't much riding. Fewer than 2 percent of the trips in Sonoma County are taken by bicycle, as far as we know. If it's 2 percent on average, then there are lots of streets and areas where bicyclists are rarely seen. To be there on a bike is dangerous, because car drivers see what they expect to see, and they tend not to see cyclists unless there are a lot of them around. Many, if not most, drivers drive too fast for the conditions of the road. They drive unprepared for the unexpected.

Well trained and experienced cyclists understand the shortcomings of the road/auto system, and have usually developed coping mechanisms. But how can inexperienced riders become experienced when they are too scared to start? Cycling advocacy is largely carried on by experienced cyclists. Knowing that the primary reason bicycle use stays at a low level is the fear of being hit from behind by cars, the advocates have focused on separate lanes, and sometimes on separated pathways, even though their own riding encompasses a far wider range of bicycle accommodations.

Considering the dismal state that the bike-riding environment only a few years ago, and the lack of resources for improvement, much has been accomplished in the last decade. But if bicycling in Sonoma County is to rise at least six fold in the next nine years, which will be required, some new approaches must be added to what is already being done.

Crosscurrents
When cycling advocates encountered opposition from the vast majority of society, they had to limit their objectives. That has meant settling for a safe path across town, rather than safe use of the entire road system available to the automobilist majority. That has meant traffic segregation on some of the major cross-town roads or the wider roads through the countryside. In the process, advocates came to equate bicycle lanes with bicycle safety, because it makes sense on major thoroughfares with fast traffic. But of

late, conflicts have arisen as the segregation concept has been extended to narrower roads.

One source of conflict is a recent trend toward narrower streets advanced as a traffic calming measure, a way to foster pedestrian safety. Unfortunately, narrower streets usually don't have room for both bike lanes and parking lanes, and thus arises the conflict between car parking and bike travel.

Most of the narrow streets are still in the old street networks, where the conflict is even greater because more cyclists are there, and because the need for street parking is more acute. The cyclists argue that a continuous lane for cycling is more important than a continuous lane of parking on the street, and ask that this conflict be resolved by moving the parking off-street. But that proposition runs counter to another, newly evolving conflict: that the proper management of parking is to charge market rate prices at the curb and not to require off-street parking. Another line of thought is that a line of parked cars along the curb acts as a shield to reduce anxiety of pedestrians walking along the street.

Broadening Program for Bike Safety
Assuming that a higher safety level is required to get more travel onto bicycles, can it be improved more rapidly than bike lanes can be acquired? Bike lanes that segregate bicyclists from fast-moving cars are a legitimate need. But what about those fast moving cars?

Speed and Safety
The chance that a cyclist or pedestrian will survive a collision with a car is shown by this table from the NHTSA:

Table 5

(Fatality + serious injury) rates by posted speed limits, by pedestrian age.
(Florida, 1993-1996; pedestrians in single-vehicle crashes)

	Speed Limit							Row Total
Pedestrian Age	<=20 mph (N=1,244)	25 mph (N=1,626)	30 mph (N=4,905)	35 mph (N=3,409)	40-45 mph (N=4,948)	50+ mph (N=1,212)	None/Oth (N=6,771)	(N=24,115)
Ages 14 or less	17.2%	21.7%	26.8%	29.3%	38.5%	58.7%	20.5%	26.3%
Ages 15 - 24	11.5%	21.4%	25.0%	32.0%	43.2%	55.0%	20.5%	29.2%
Ages 25 - 44	13.0%	24.9%	29.5%	43.6%	50.4%	60.2%	26.2%	37.2%
Ages 45 - 64	12.3%	27.8%	34.5%	48.3%	59.9%	68.1%	27.7%	41.8%
Ages 65 +	17.9%	41.8%	42.9%	54.8%	66.6%	82.4%	33.7%	47.4%
All Pedestrians	14.5%	24.4%	29.4%	40.2%	50.5%	61.8%	24.8%	34.5%

In spite of this stark relation of car speed and death rate for cyclists and pedestrians, streets in U.S. urban areas are routinely posted for speeds greater than 30 miles per hour.

Given that such speeds are attained only in fits and starts, and otherwise held down by traffic to an average level of around 20 mph in most cities, why should higher speeds be encouraged by the posted limits, which tend to be treated as "suggested speed?"

There seem to be two primary causal factors at work. One is the U.S. traffic engineering practice of providing a "margin of safety" in street design widths. The other is the arbitrary 85th percentile rule, which prevents effective speed enforcement if the posted limit is disobeyed by more than 15 percent of the drivers. The "margin of safety" acts as an invitation to go faster, and the 85th percentile rule makes sure the tendency to go faster is incorporated in the posted speed limits. Of course neither of these causal factors has anything to do with bicycles or cyclist safety.

Presumably, if numerous bicyclists were magically to appear on a street and consistently ride there, engineering and enforcement would somehow reflect their presence after a while. Unfortunately, the erstwhile cyclists are waiting for safety that never comes.

Hierarchical Streets

In the U.S., and to a lesser degree elsewhere, road networks evolved into a hierarchy of roads specialized by function.

Table 6

Type	Function
Local	Direct property access
Collector	Gather traffic from local streets and feed it to the arterial system
Arterial	Longer distance mobility and not intended to serve as immediate access to properties
Freeways	Fully grade-separated so no signals are required for traffic on the freeway. No direct access from property.

The purpose of a hierarchy is travel speed; longer trips can be made faster, with the car driver moving up the hierarchy and back down during the course of a journey. At each higher level, the street arrangement becomes more complex, as do the intersections.

A consequence of the transition from the simpler urban grids of yore to the hierarchy of streets was congestion on the high level roads. That led to "cut-through" traffic in the residential neighborhoods, which led in turn to a more dendritic or "tree-like" structure to keep the through traffic out of the neighborhoods. Thus the hierarchical street system, intended for having faster, higher volumes in a coarse grid, became plagued by congestion. Cycling was neglected in the quest for long distance speed of motor vehicles.

The means of assuring bike and pedestrian safety in the hierarchical street system will differ within the hierarchy, and will differ in high and low density areas. For transit-oriented development (TOD), space is at a premium and the space requirements of hierarchy are too burdensome. Hierarchy will have to be lessened and more shared use will be required. Speed must be low everywhere within a TOD.

At the other end, in suburban situations, the basic hierarchy will likely remain. Bike and pedestrian safety there will depend on far more attention to the local and collector streets, where the speeds must be curtailed.

Bike Safety on All Streets
By law, streets can't be ruled off-limits to bicyclists, whether or not they have bike lanes or other provisions for bikes. But if the streets are scary enough, they are off-limits by default, which is why most bikes remain in garages, keeping company with all the other things families buy but seldom use. The requisite intensity of bike use will never come about as long as cyclists are effectively limited to bits and pieces of the overall street network. Therefore, all streets need to be made safe. Rather than wait decades for bike lanes, or forever for a set of separated bike paths that duplicates the existing street network, there needs to be a new working policy, expressed in local ordinance thusly: Bicycles have priority on all streets without bike lanes.

How the priority would be realized (e.g., in signage, enforcement, engineering changes) could differ from one street to another. The primary thrust would be to greatly reduce the speed differential between cars and bicycles. Where there are no bike lanes, the complexity of mixed traffic can be made safe if the speeds are slow enough that people have time to react to surprises. This is especially the case in a dense environment.

More Effective Traffic Calming
Traffic calming began in Europe years earlier than in the U.S., so it is reasonable to look there for models of progress. One innovation that came along after the initial focus on individual streets and intersections was "30 Km Zones" where all streets within a bounded area would be limited in speed to 30 Km/hr. (This was later followed by 20 mph Zones in U.K.). These were generally applied at the neighborhood level, and sometimes in larger areas. Their use continues to spread. Their effectiveness depends on using the site-specific physical calming measures and enforcement.

Two very different local sites can serve as examples of another approach to bicycle and pedestrian safety. Both are current subjects of planning activities. One is the prospective urban TOD to be located in the general area around the planned train station in Railroad Square. The other is the Northwest Neighborhood – a suburban archetype where formerly vacant lands are gradually filling in on a random site-by-site basis. It borders the same railroad tracks, but doesn't have a station.

What they have in common are networks of narrow streets subject to a forced choice between lanes for parking or lanes for bicycles. The objective in both cases is to devise a solution based on mixed traffic operations that offer the same level of safety that would be afforded by bike lanes. Perhaps it should not be surprising that a Zone 20 deployment would be a common element in each.

Downtown Station Area[27]
This Transit Oriented Development would be the center of a high density mixed use community that includes the downtown. There will be a strong emphasis on both walking and bicycling. It will be the hub of the Class 1 bike path system, but car access to the train will not be encouraged. Today, with little of that expected development in

[27] Comprised of two adjacent neighborhoods, No. 14 – Railroad Square 5 and No. 32 – West End. Please see Santa Rosa Neighborhoods map:
http://ci.santarosa.ca.us/city_hall/Neighborhoods%20Website/Neighborhood_Org_Map.pdf

place, it has a walk score of 89 on scale of 100.[28] A Walk Score can help people find houses and apartments in walkable neighborhoods. Walk Score shows you a map of what's nearby and calculates a Walk Score for any property. Living in a walkable neighborhood is good for the environment and good for your health.

Northwest Santa Rosa Neighborhood[29]
This neighborhood is nearly uniformly residential in use, and has a fairly typical discontinuous network of streets with numerous cul-de-sacs, overlaid by several continuous collector streets with full direct residential access. It might be characterized as a close-in auto-dependent commuter suburb.

In the all-too-common fashion, an elementary school was sited just beyond the urban edge because the land was cheap, leaving problems of access to be solved by the city. Except perhaps for recreational walking, little foot traffic is likely in this neighborhood even with continuous sidewalks, because of the uniformity of land-use. Its current walk score is only 28. While it is unlikely to become a true walkable community, it could be a bikeable community with proper attention to bike safety.

At approximately a square mile, having a uniform zone speed limit throughout would scarcely add to travel times for people exiting and leaving the neighborhood, but it would still discourage cut-through traffic, if that should become a problem as the neighborhood is built out.

[28] This is one point higher than the White House. See http://www.walkscore.com
[29] Composed of Neighborhood No. 9 – Concerned Homeowners of Northwest Santa Rosa.

Appendix 4: Car(e)-Free: Moving toward Car Independence

One of the glaring problems in our program to reduce emissions from transportation is the lack of viable options to the single occupant vehicle for day-to-day mobility needs. Our transportation analysis reveals that the best that can be achieved through enhancing the public transportation system, including enhancements to walking and biking environments, is a 12 percent reduction in emissions, relative to 2015 BAU. Not, bad, but we have to do better. The land use and train options, while essential, are longer term in their effect. We need a lot more, a lot sooner.

One possible approach to compete with the personal private automobile as the mode selection of choice is to substitute a menu of options for replacing the various functions that a car serves, at a lower cost. This menu of functions would be paid for via a pre-tax payroll deduction.

The program would be called Car(e)-free and might work something like this:
A participant signs up with the plan through work, or through a plan administrator, similar to health insurance. The participant would then get a detailed transportation audit that would assess the total costs of transportation, including automobile, air and other travel. The transportation needs would also be assessed. The participant would then be allowed to deduct the full annualized cost of transportation determined by the audit, pre-tax, to be placed in a fund. The participant would then be entitled to use this fund to pay for a menu of services up to the value of the fund.

Basic services would be:

1. Access to a certified vanpool service similar to the airport transporter that would provide transport to work and school with guaranteed ride home.
2. Access to a certified car share fleet.
3. Enrollment in a certified telecommute training program
4. Broadband/wide area wireless internet access
5. Hardware/Software support for and access to "first person shopper" online shopping, with guaranteed 1 hour delivery for essentials such as food and pharmaceuticals, next day for everything else.
6. Discounted air travel with certified airlines
7. "Universal" public transportation pass, valid in all participating cities, internationally.
8. "Never stranded" guaranteed pick up and drop off using certified taxi fleet for those who don't drive
9. Access to "house call" services for mobile dentist, physician clinic, banking services and miscellaneous repair services.

Alternatively, a participant could use the funds to lease a plug-in hybrid that is charged using the CCA charging bay and uses fuel manufactured by the CCA owned fuel production facility.

Letter 2, Ann Hancock, Climate Protection Campaign; Christine Culver Bicycle Coalition; Willard Richards, Sonoma County Transportation and Land Use Coalition

Response 2-1: Comment noted. Since no comments regarding the analysis is in the Draft EIR were provided, no further response is required.

Response 2-2: As indicated on page 2.0-2 of the Draft EIR, an EIR is a public informational document that assesses potential environmental effects of the 2009 CTP EIRs are not required or intended to assist agencies to meet greenhouse gas reduction goals that have been adopted. The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts) regarding correction to consumption analysis in the Draft EIR.

Response 2-3: Comment noted. Since no comments regarding the analysis is in the Draft EIR were provided, no further response is required.

Response 2-4: The Draft EIR Executive Summary provides a brief overview of the goals of the 2009 CTP, please refer to Draft EIR Section 3.0, Overview of the CTP, which provides a more detailed description of the goals of the CTP. Section 3.0 also provides the rationale for analyzing the Constrained Project Alternative.

Response 2-5: Comment noted. Since no comments regarding the analysis is in the Draft EIR were provided, no further response is required.

Response 2-6: SB 375 requires that California Metropolitan Planning Organizations (MPOs) develop a "Sustainable Communities Strategy" that is intended to demonstrate how GHG emission reduction targets for cars and light trucks provided by the California Air Resources Board (CARB) for each MPO (provision of emission reduction targets are currently anticipated to occur in September 2010) can be met. The Metropolitan Transportation Commission (MTC) is the MPO for Sonoma County (rather than SCTA) and is currently working on the eventual development of Sustainable Communities Strategy as part of the Joint Policy Committee involving Association of Bay Area Governments (ABAG), Bay Area Air Quality Management District (BAAQMD), and Bay Conservation and Development Commission (BCDC). The CTP includes land use improvement (smart growth and supportive transit) strategies and actions in its strategic projects list that would likely compliment the future Sustainable Community Strategy (see CTP pages 95 through 99).

Response 2-7: The Draft EIR addresses potential impacts associated with implementation of the CTP on criteria pollutants as well as efforts to improve air quality and meet state and federal air quality standards (see Draft EIR pages 4.2-14 through -20). The Draft EIR also identifies the health effects of these air pollutants, current ambient air quality standards and existing ambient air quality conditions (see Draft EIR pages 4.2-1 through -8). The Draft EIR specifically identifies that reductions in traffic congestion will improve average vehicle speeds on roadways in combination with turnover in older vehicles for new vehicles and increasingly stringent emission controls (factored in the CARB EMFAC Air Quality Model) that will reduce running emissions of air pollutants, with specific reductions in reactive organic gases (ROG) and oxides of nitrogen (NOx) that create ozone as well as reductions in carbon monoxide (CO) (see Draft EIR pages 4.2-17 and -18 and Draft EIR).

As identified in Draft EIR Section 3.0, the proposed CTP consists of improvements to existing roadway facilities to improve traffic conditions and mobility in Sonoma County. The CTP does not propose new major roadway facilities that could expose existing and future residents to new air pollutants.

It is acknowledged that approximately 60 percent of California's diesel exhaust (a toxic air contaminant) is emitted on roadways by heavy-duty trucks, buses, and light-duty passenger vehicles. CARB adopted an Airborne Toxics Control Measure (ATCM) as part of the Particulate Matter Risk Reduction Plan to specifically deal with diesel emissions from school buses. This measure became effective July 16, 2003. The school bus–idling ATCM includes the following requirements:

a) The driver of a school bus or vehicle, transit bus, or heavy-duty vehicle (other than a bus) shall manually turn off the bus or vehicle upon arriving at a school and shall restart no more than 30 seconds before departing. A driver of a school bus or vehicle shall be subject to the same requirement when operating within 100 feet of a school and shall be prohibited from idling more than five minutes at each stop beyond schools, such as parking or maintenance facilities, school bus stops, or school activity destinations. A driver of a transit bus or heavy-duty vehicle (other than a bus) shall be prohibited from idling more than five minutes at each stop within 100 feet of a school. Idling necessary for health, safety, or operational concerns shall be exempt from these restrictions.

b) The motor carrier of the affected bus or vehicle shall ensure that drivers are informed of the idling requirements, track complaints and enforcement actions, and keep track of driver education and tracking activities. According to CARB, implementation of the above requirements would eliminate unnecessary idling for school buses and other heavy-duty vehicles, thus reducing localized exposure to TAC emissions and other harmful air pollution emissions at and near schools and protecting children from unhealthy exhaust emissions.

In addition to the school bus–idling ATCM, CARB adopted an idling-restriction ATCM for large commercial diesel-powered vehicles that became effective February 1, 2005. In accordance with this measure, affected vehicles are required to limit idling to no longer than 5 minutes under most circumstances. CARB is currently evaluating additional ATCMs associated with the CARB's Diesel Risk Reduction Plan, Emission Reduction Plan for Ports and Goods Movement, and implementation of AB 233 intended to further reduce TACs associated with mobile sources. Thus, existing state programs will continue to address and reduce TAC emissions associated with diesel.

Response 2-8: Draft EIR Table 1.0-1, Projects Impacts and Mitigation is a summary of the anticipated impacts of implementation of the proposed 2009 CTP and proposed mitigation measures to reduce impacts from increased VMT. The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts) regarding VMT increases. As well as the Draft EIR Section 4.3 (Traffic and Circulation) for a detailed discussion and analysis of traffic impacts of the 2009 CTP.

Response 2-9: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts). The Draft EIR's analysis of future energy consumption for year 2035 under the proposed CTP and Draft EIR alternatives has been revised and corrections to this analysis is provided in Section 4.0, (Minor Revisions to the Draft EIR). Specifically, the analysis now includes consideration of the federal CAFE and State fuel economy standards under AB 1491 (Pavley). There is a 22% reduction in fuel consumption for light duty autos and trucks, as they are the vehicle classes that are subject to federal CAFE and State fuel economy standards under AB 1491 (Pavley). However, the 26% increase in VMT from the other vehicle classes results in concomitant increases in fuel consumption. Overall, the vehicle fleet is projected to reduce fuel consumption of gasoline and diesel fuels by 9% under the 2035 CTP scenario when compared to existing conditions. Draft EIR Table 4.13-2, Table 4.13-3 and the analysis in the Executive Summary, Energy section, and Cumulative Impacts sections of the Draft EIR have been revised accordingly (see Section 4.0, Minor Revisions to the Draft EIR). This updated analysis has resulted in the determination of Draft EIR Impact 4.13-1 to be changed from significant and unavoidable to less than significant. The commenter is referred to response 2-2 regarding the need for the EIR to assist SCTA and other agencies in meeting greenhouse gas emissions reduction goals.

Response 2-10: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts) as well as Section 4.0 of this document that provides additional GHG emission estimate data for the Draft EIR alternatives that have been provided in Section 4.0 of this document and specifically identifies that Draft EIR Alternative 5 comes the closest in meeting this target. The commenter is referred to response 2-2 regarding the need for the EIR to assist SCTA and other agencies in meeting greenhouse gas emissions reduction goals.

Response 2-11: A complete version of Draft EIR Appendix A was made available in CD and hard copies of the Draft EIR that are available SCTA offices. The SCTA website has been corrected to contain the entire contents of Appendix A.

Response 2-12: The existing setting condition description of ambient air quality conditions provided on Draft EIR pages 4.2-1 through -8 is consistent with the requirements of State CEQA Guidelines Section 15125(a):

An EIR must include a description of the physical environmental conditions in the vicinity of the project, as they exist at the time of the notice of preparation is published…

Setting conditions and anticipated environmental effects of climate change are addressed on Draft EIR pages 5.0-9 through -26. It is acknowledged that the environmental effects of climate could result in worsening air quality conditions in the future.

Response 2-13: The commenter is referred to Response to Comment 2-7. The following text changes are made to the Draft EIR regarding mobile diesel emissions:

- Draft EIR page 4.2-17, the following text is added to the end of the page:

"In addition to these criteria air pollutants, County roadways would continue to include diesel-powered vehicles. Approximately 60 percent of California's diesel exhaust (a toxic air contaminant) is emitted on roadways by heavy-duty trucks, buses, and light-duty passenger vehicles. CARB adopted an Airborne Toxics Control Measure (ATCM) as part of the Particulate Matter Risk Reduction Plan to specifically deal with diesel emissions from school buses. This measure became effective July 16, 2003. The school bus–idling ATCM includes the following requirements:

a) The driver of a school bus or vehicle, transit bus, or heavy-duty vehicle (other than a bus) shall manually turn off the bus or vehicle upon arriving at a school and shall restart no more than 30 seconds before departing. A driver of a school bus or vehicle shall be subject to the same requirement when operating within 100 feet of a school and shall be prohibited from idling more than five minutes at each stop beyond schools, such as parking or maintenance facilities, school bus stops, or school activity destinations. A driver of a transit bus or heavy-duty vehicle (other than a bus) shall be prohibited from idling more than five minutes at each stop within 100 feet of a school. Idling necessary for health, safety, or operational concerns shall be exempt from these restrictions.

b) The motor carrier of the affected bus or vehicle shall ensure that drivers are informed of the idling requirements, track complaints and enforcement actions, and keep track of driver education and tracking activities. According to CARB, implementation of the above requirements would eliminate unnecessary idling for school buses and other heavy-duty vehicles, thus reducing localized exposure to TAC emissions and other harmful air pollution emissions at and near schools and protecting children from unhealthy exhaust emissions.

In addition to the school bus–idling ATCM, CARB adopted an idling-restriction ATCM for large commercial diesel-powered vehicles that became effective February 1, 2005. In accordance with this measure, affected vehicles are required to limit idling to no longer than 5 minutes under most circumstances. CARB is currently evaluating additional ATCMs associated with the CARB's Diesel Risk Reduction Plan, Emission Reduction Plan for Ports and Goods Movement, and implementation of AB 233 intended to further reduce TACs associated with mobile sources. Thus, existing state programs will continue to address and reduce TAC emissions associated with diesel and would not result in an increase in these emissions."

Response 2-14: The Draft EIR specifically identifies that reductions in traffic congestion will improve average vehicle speeds on roadways in combination with turnover in older vehicles for new vehicles and increasingly stringent emission controls (factored in the CARB EMFAC Air Quality Model) that will reduce running emissions of reactive organic gases (ROG) and oxides of nitrogen (NOx) that create ozone as well as reductions in carbon monoxide (CO) (see Draft EIR pages 4.2-17 and -18 and Draft EIR). PM emissions estimated by air quality modeling are primarily based on how changes in VMT impact tire wear. Air quality model inputs are provided in Draft EIR Appendix B.

Response 2-15: The proposed actions in the Draft EIR are limited by the current funding and SCTA authority limitations which inhibit the CTP's ability to fully implement these strategic projects (see CTP pages 95 through 99) to meet this VMT reduction (see CTP page 50). The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 2-16: The commenter's statements are not related to the adequacy of the Draft EIR and no further response is required. It should be noted that Draft EIR Section 6.0 (Project Alternatives) provides VMT comparisons of the proposed CTP to the five Draft EIR alternatives that each contain variations in measures to address VMT. The commenter is also directed to the GHG Reduction White Paper and Strategic Projects Matrix in the Appendix of the CTP.

Response 2-17: The commenter's statements are not related to the adequacy of the Draft EIR and no further response is required. The commenter is advised that roadway projects in the CTP are focused on the expansion of the HOV system, which encourages carpooling, higher vehicle occupancies, thereby lowering VMT.

Response 2-18: The commenter requests that the term "and roadway" in association with capacity improvements be taken out of the Draft EIR in reference to Draft EIR pages 4.3-29 through -31. The only place these terms are utilized on these pages of the Draft EIR are in reference to proposed CTP objectives listed on Draft EIR pages 4.3-30 and -31. This request is not related to the adequacy of the Draft EIR and no further response is required. This comment will be forwarded to the SCTA Board of Directors as part of consideration of comments received on the 2009 CTP. The purpose of the CTP is to improve mobility on Sonoma County's streets, highways, transit system and bicycle/pedestrian facilities, as well as to reduce transportation-related impacts. As demonstrated in Draft EIR Table 4.3-15, the proposed CTP would result in an improvement in VMT as compared to not adopting an updated CTP under year 2035 conditions.

Response 2-19: This conclusion suggested by the commenter is not made in any of the text related to Draft EIR Impact 4.9-1 on pages 4.9-14 and -15. As specifically identified on these pages, the analysis identifies that implementation of the CTP would not cause any land use disruption or displacement and would be consistent with local land use plans and polices. No mention of GHG emissions or VMT is made under this impact.

Response 2-20: The commenter asks how reduction in GHG emissions and VMT would be made under local land use polices and changes to these policies. The commenter is referred to Response to Comment 2-19 and Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts). See scenario 3 performance and assumptions in the alternatives analysis, Appendix A, Strategic Projects Matrix of the CTP, and Appendix C. i., Greenhouse Gas Emissions Reductions White Paper of the CTP.

Response 2-21: The commenter asks how reduction in GHG emissions and VMT would be made under local land use polices. The commenter is referred to Response to Comment 2-19 and Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts) and Master Response 3.4.6 (Adequacy of Alternatives Analysis.)

Response 2-22: These comments are not related to the adequacy of the Draft EIR and no further response is required.

Response 2-23: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts). The Draft EIR's analysis of future energy consumption for year 2035 under the proposed CTP and Draft EIR alternatives has been revised and corrections to this analysis is provided in Section 4.0, (Minor Revisions to the Draft EIR). Specifically, the analysis now includes consideration of the federal CAFE and State fuel economy standards under the AB 1491 (Pavley). There is a 22% reduction in fuel consumption for light duty autos and trucks, as they are the vehicle classes that are subject to federal CAFE and State fuel economy standards under the AB 1491 (Pavley). However, the 26% increase in VMT from the other vehicle classes results in concomitant increases in fuel consumption. Overall, the vehicle fleet is projected to reduce fuel consumption of gasoline and diesel fuels by 9% under the 2035 CTP scenario when compared to existing conditions. Draft EIR Table 4.13-2, Table 4.13-3 and the analysis in the Executive Summary, Energy section, and Cumulative Impacts sections of the Draft EIR have been revised accordingly (see Section 4.0, Minor Revisions to the Draft EIR). This updated analysis has resulted in the determination of Draft EIR Impact 4.13-1 to be changed from significant and unavoidable to less than significant.

The alteration in energy consumption analysis in the Draft EIR would not change the air quality modeling results reported in Draft EIR Table 4.2-9.

Response 2-24: Section 4.0 of this document includes updated GHG emission estimates for each of the Draft EIR alternatives. None of the five Draft EIR alternatives meet these targets, though Alternative 5 (Comprehensive/"Do Everything" Scenario) is the closest in meeting the targets for 2035. Given that the 2009 CTP is a planning document and the EIR is a program EIR, an interim year analysis was not appropriate. The commenter is referred to the CTP Modeling Appendix for more information.

Response 2-25: The energy modeling analysis evaluates the overall function of the entire alternative and thus does not report separately sub-components as it is related to VMT. Section 4.0 provides estimated fuel consumption estimates for Alternative 2. This programmatic EIR analyzes the aggregate effects of the CTP projects. Individual project level environmental review would look closer at individual projects and are the proper venue for this detailed level of analysis.

Response 2-26: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts), which identifies that the energy consumption analysis was corrected to account for future improved fuel economy standards that was utilized in the GHG emission analysis under Impact 5.0-1. The result of this correct is that the conclusion of Draft EIR Impact 4.13-1 is changed from significant and unavoidable to less than significant.

Response 2-27: The commenter notes an incorrect citation to Appendix D on Draft EIR page 4.13-11. Comment noted.

- Draft EIR page 4.13-11, the last sentence before Table 4.13-2 is revised as follows:

  "See **Appendix E~~D~~** for CARB's BURDEN model documentation."

Response 2-28: As identified in Section 4.0 of this document, the forecasts for CNG fuel use by transit buses have been corrected. Transit buses are estimated to consume 1,300 gallons per day of diesel-fuel equivalent gallons under existing conditions.

Response 2-29: While neither the CTP nor the EIR require a cost-effectiveness analysis for energy indicators, each of the eight CTP objectives cited in this section are intended to reduce petroleum-based fuel consumption from on-road vehicles that will reduce GHG emissions from reductions in fuel combustion. The projected reductions in fuel consumption are anticipated based on a combination of travel demand management (e.g., reductions in driving) and systems management (e.g., improving the efficiency of the roadway system to improve travel speeds and reduce vehicle idling as well as fuel efficiency improvements).

Response 2-30: The energy modeling analysis evaluates the overall function of the entire CTP and thus does not report separately sub-components as it is related to VMT.

Response 2-31: Exposure to carbon dioxide as an air pollutant is not the issue associated with climate change. It is the effect of increased concentrations of carbon dioxide in combination with other GHG emissions that result in the absorption of infrared radiation that further warm the atmosphere result in climate change (see Draft EIR pages 5.0-9 through -16). No changes to the Draft EIR are recommended.

Response 2-32: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts). Section 4.0 of this document includes updated GHG emission estimates for each of the Draft EIR alternatives. None of the five Draft EIR alternatives meet these targets, though Alternative 5 (Comprehensive/"Do Everything" Scenario) is the closest in meet the targets. See also Modeling Appendix in CTP, and Policies chapter (especially the Conclusion pages). Given that the document is a long-range planning document and its EIR is a Program EIR, an interim year analysis was not appropriate.

Response 2-33: This paragraph is intended to clarify that it is impossible to determine the proportional impact of a project's contribution to global GHG emissions and physical effect on the environment as a resulting from climate change. For example, it is not possible to determine how much of the anticipated sea level rise identified under Draft EIR Exhibit 5.0-1 will be a result of mobile GHG emissions in Sonoma County. The Draft EIR does not dispute that environmental effects are anticipated from GHG emissions and climate change.

Response 2-34: The Draft EIR significance criteria on Draft EIR page 5.0-21 are consistent with CEQA requirements as they compare the project against existing conditions (see State CEQA Guidelines Sections 15125 and 15126.2 – definition of existing physical conditions and addressing project impacts in relation to existing physical conditions); addressing exposure to physical environmental effects of climate change; and whether the proposed CTP would be inconsistent with state and local (including GHG emission reduction targets) requirements and efforts to address climate change (see State CEQA Guidelines Appendix G, IX. Land Use and Planning). In addition, these significance criteria are consistent with State Resources Agency proposed changes to the State CEQA Guidelines that are intended to address climate change.

As further described in Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts), while the CTP has identified its desired intent of meeting its greenhouse gas (GHG) emission reduction target through transit, roadway improvements, land use improvement (smart growth and supportive transit), transportation technology improvements and transportation pricing policies, current funding and SCTA authority limitations inhibit the CTP's ability to fully implement these strategic projects (see CTP pages 95 through 99) to meet its benchmarks (including GHG emission reductions) (see CTP page 50). Thus, the environmental impact analysis in the Draft EIR is conservatively based on projects and improvements that are feasible for SCTA to implement and have known existing and planned funding sources (e.g., Measure M and funding from the Metropolitan Transportation Commission) (see CTP page 35 and Draft EIR pages 3.0-10 through -13).

While the Draft EIR acknowledges that the CTP would not fully meet the GHG emission reduction targets set forth in CTP Policy 3 or the SCCCAP target, the proposed CTP would improve county-wide mobile GHG emissions by approximately 22% from existing conditions through improved VMT under year 2035 conditions (without the 2009 CTP) as well as through expected improvements fuel economy from implementation of AB 1493. In addition, the CTP includes SCCCAP solutions as both CTP objectives (see CTP pages 43 through 49) as well as strategic projects (see CTP pages 95 through 99). Thus, the CTP does not conflict with the SCCCAP. It should be noted that the SCCCAP itself states that some of its transportation and land use solutions are expected to have varied levels of feasibility to implement and would require other agencies beyond SCTA to implement to meet the target (see SCCCAP pages 41 through 44). Given that the proposed CTP would improve on existing mobile GHG emissions as well as anticipated GHG emissions under year 2035 no project conditions and would include many of the SCCCAP transportation and land use solutions, no significant climate change impact was identified in the Draft EIR.

Response 2-35: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 2-36: The commenter notes that the GHG forecasts are incorrectly labeled as pounds per day. The following correction is made to the Draft EIR:

- Draft EIR page 5.0-21, the following change is made to Table 5.0-3:

TABLE 5.0-3
MOTOR VEHICLE FLEET TRAVEL AND GHG FORECASTS (2005 AND 2035)

Criterion	2005 Existing Conditions	2035 No Project Scenario	2009 CTP 2035 Conditions	Change 2005 to 2035	
				Numerical	Percentage
Daily Vehicle Miles of Travel (VMT)	11,441,811	14,768,411	14,417,956	+2,976,144	+26.0%
Daily Vehicle Miles Traveled per Capita	23.1	26.0	25.3	+2.2	+9.5%
Fuel Economy (miles per gallon)	19.86	32.15	32.15	+12.29	+61.9%
Carbon Dioxide Equivalent emissions (CO_2e ~~pounds per day~~ tons per year)	2,549,042	2,048,185	1,999,582	-549,460	-21.6%

Source: Sonoma County Transportation Authority; Sonoma County Transportation Model and Clean Air and Climate Protection Software 5, 2008.

Response 2-37: Appendix A of the CTP, List of Projects, iv. Strategic Projects, identifies various projects within the CTP and includes cost and benefit columns for comparative purposes. The commenter should also note that the List includes the implementing party and what resources are needed to implement the List of Strategic Projects.

The suggested explanation of each mitigation measure to the extent requested by the commenting party is beyond the scope of this Program EIR. The mitigation measures identified in the Draft EIR would be in addition to those measures included in the CTP. CEQA does not require EIRs to address economic or social effects of projects or mitigation measures (State CEQA Guidelines Section 15131. The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 2-38: A complete version of Draft EIR Appendix A was made available in CD and hard copies of the Draft EIR are available at the SCTA offices. The SCTA website has been corrected to contain the entire contents of Appendix A.

Response 2-39: The commenter is referred to Response to Comment 2-27.

Response 2-40: This updated information has been provided in Section 4.0 of this document.

Response 2-41: The proposed project is the adoption and implementation of the updated CTP, which is anticipated to be fully implemented by year 2035. The Draft EIR is required to evaluate the environmental effects of the full implementation of the proposed CTP, while consideration of year 2015 condition would not fully evaluate the impact of the proposed CTP.

Response 2-42: The Appendix E analysis of fuel consumption from the countywide vehicle fleet has been reformatted to better clarify and illustrate the relationship between VMT, fuel economy assumptions, and overall fuel consumption. This updated information has been provided in Section 4.0 of this document.

Response 2-43: The commenter is referred to Response to Comment 2-27.

Response 2-44: Appendix F has been reformatted to better clarify and illustrate the GHG emissions anticipated from the CTP's implementation. This includes an analysis of the typical GHG emissions from a one-acre hypothetical construction site. The GHG emissions from the vehicle activity anticipated from each of the five CTP alternatives were derived from SCTA's use of the ICLEI CACP software. This updated information has been provided in Section 4.0 of this document.

- Draft EIR page 5.0-, 21, Table 5.0-3 Motor Vehicle Fleet Travel and GHG Forecasts (2005 and 2035) is updated below:

TABLE 5.0-3
MOTOR VEHICLE FLEET TRAVEL AND GHG FORECASTS (2005 AND 2035)

Criterion	2005 Existing Conditions	2035 No Project Scenario	2009 CTP 2035 Conditions	Change 2005 to 2035	
				Numerical	Percentage
Daily Vehicle Miles of Travel (VMT)	11,441,811	14,768,411	14,417,956	+2,976,144	+26.0%
Daily Vehicle Miles Traveled per Capita	23.1	26.0	25.3	+2.2	+9.5%
Fuel Economy (miles per gallon)	19.86	32.15	32.15	+12.29	+61.9%
Carbon Dioxide Equivalent emissions (CO_2e tons per ~~day~~ year)	2,549,042	2,048,185	1,999,582	-549,460	-21.6%

Source: Sonoma County Transportation Authority; Sonoma County Transportation Model and Clean Air and Climate Protection Software 5, 2008.

Response 2-45: This adjustment has been made to the re-formatting of Appendix F. This updated information has been provided in Section 4.0 of this document.

Response 2-46: This adjustment has been made to the re-formatting of Appendix F. This updated information has been provided in Section 4.0 of this document.

Response 2-47: The commenter notes lack of reference to Appendix F and G in the Draft EIR. The following text changes are made to the Draft EIR:

- Draft EIR page 5.0-20, the following sentence is added after the last paragraph under "Methodology""

  "**Appendix F** provides a summary of greenhouse gas emission modeling results for the proposed CTP as well as the Draft EIR alternatives evaluated in Section 6.0 (Project Alternatives). "

- Draft EIR page 6.0-1, the following text change is made to the last sentence on the page:

  "A complete listing of projects by alternative is provided in Appendix G ~~F of the 2008 CTP~~."

Letter 3

Transportation Solutions Defense and Education Fund

P.O. Box 151439 San Rafael, CA 94915 415-331-1982

June 20, 2009
By E-Mail

Mike Kerns, Chair
Sonoma County Transportation Authority
490 Mendocino Avenue, Suite 206
Santa Rosa, CA 95401

Re: Comprehensive Transportation Plan Draft EIR Comments

Dear Supervisor Kerns:

TRANSDEF, the Transportation Solutions Defense and Education Fund, is a Marin-based environmental organization focused on climate change and the regional planning of transportation, land use and air quality in the San Francisco Bay Area. For the past 15 years, we have participated in MTC's development of Regional Transportation Plans and BAAQMD's development of Clean Air Plans.

From that experience base, we seek to offer our comments first on the merits of the Comprehensive Transportation Plan (Plan, or CTP), and then on its faulty analysis in the Draft Environmental Impact Report (DEIR). The improper framing of the No Project Alternative hides the impacts of the CTP, thereby depriving decisionmakers of the information they need to make sound policy choices for Sonoma County, and preventing the identification of adequate mitigations for those impacts. TRANSDEF will identify in this comment letter the full set of reasons why the DEIR is inadequate.

<u>Excessive VMT Growth--Merits of the CTP</u>
The DEIR reveals a Business-as-Usual plan that is unresponsive to the challenges of climate change. Rapidly developing science points to the need to urgently reduce greenhouse gas (GHG) emissions in the near-term. Just last week, government scientists released a report detailing how global warming is already having harmful effects. Its message for decisionmakers was:

> Reducing emissions of carbon dioxide would lessen warming over this century and beyond. Sizable early cuts in emissions would significantly reduce the pace and the overall amount of climate change. Earlier cuts in emissions would have a greater effect in reducing climate change than comparable reductions made later. (*Global Climate Change Impacts in the United States*, p. 9. (attached)) 3-1

TRANSDEF 6/20/2009 page 2

Because motor vehicles emit roughly 60% of the GHG emissions from Sonoma County, the CTP carries a heavy burden to accomplish actual emissons reductions. The DEIR asserts that by adopting the CTP, GHGs will decrease by 21.6% from existing conditions by 2035. This projection may be grossly in error, as it conflicts with the DEIR's finding that gasoline consumption will increase by 25% over the same time period. Even if this result turns out to be valid, this reduction can be entirely attributed to an increase in fuel economy of 61.9%, rather than anything specific to the CTP itself. 3-1

The CTP has failed to accomplish its goal of reducing transportation-related GHGs by 2015 to 25% below 1990 levels, and by 2035 to 40% below 1990 levels. It is clear to TRANSDEF that the problem is that the CTP has failed to significantly reduce the growth in VMT. The DEIR projects a 26% increase in VMT by 2035, despite the CTP's Objective 3A, "Reduce VMT per capita by 10% below 2005 levels by 2035." 3-2

Acknowledging that the Plan does not accomplish its goals is the crucial step in changing course. The question then is whether those goals are important enough to warrant making substantial changes to the Plan--to attempt practices that are uncomfortable, unfamiliar and/or uncommon. Accomplishing those goals will require the courage to innovate. There is no easy way to achieve those goals.

We see this Plan's principal focus as the improvement of travel conditions for single-occupant vehicles. That's the policy-neutral way of saying "congestion relief." It's why we called this CTP a business-as-usual plan. This is the approach to transportation seen across most of America. While SCTA's state mandate to reduce congestion has not yet been broadened in response to the current realities of climate change, Caltrans is moving forward with an entirely new approach that brings together land use and transportation planning in the era of SB 375 that it calls the Smart Mobility Framework.[1] We urge decisionmakers to consider the far-reaching critique of congestion relief accomplished by means of conventional widening projects in *Smart Congestion Reductions--Reevaluating The Role Of Highway Expansion For Improving Urban Transportation [aka Smart Transportation Investments]* (attached). 3-3

We don't believe the Plan's goals are achievable while pursing the business-as-usual approach to congestion relief. We instead recommend relying on alternative approaches, such as are described in *Win-Win Emission Reduction Strategies* (attached). One of the key strategies is road pricing. TRANSDEF urges SCTA to adopt a CTP Alternative that includes road pricing. Recognizing that the County cannot undertake pricing all by itself, and that pricing needs to be a regional effort, we recommend that the CTP commit to advocate at the regional, state and federal levels to secure authorization to increase the cost of driving, through such methods as road pricing, congestion pricing, and parking fees on all commercial parking spaces (including privately owned spaces).

[1] http://dot.ca.gov/hq/tpp/offices/ocp/smf.html

TRANSDEF 6/20/2009 page 3

Current literature, including the recent report *Cost-Effective GHG Reductions through Smart Growth & Improved Transportation Choices* (attached) identify approaches to VMT Reduction that go beyond what has been included in the CTP. MTC's analysis of the Scenario Assessment component of the 2009 RTP process concluded that the joint implementation of pricing and compact land use was necessary to enable the region to reach AB 32 goals. To attain its own goals, SCTA's preferred Alternative should utilize both approaches. 3-4

The 26% increase in VMT is clearly related to the CTP's inclusion of widening projects that increase the lane-miles of highways and roadways. Current research has determined that a 10% increase in lane-miles will increase VMT by 5.5%. (*Growing Cooler*, p. 12 (attached).)

> The most-effective policy sets combine land use policies, such as compact growth, with strong transit provision and **not expanding highway capacity**. The addition of auto pricing policies, such as fuel taxes, work trip parking charges, or all-day tolls increases the effectiveness of the land use and transit policies. Peak-period tolls, by themselves, increase travel. Expanding road capacity, along with transit capacity, but without changing market incentives to encourage more efficient use of existing roads and parking, results in expensive transit systems with low ridership. *(Review of U.S. and European Regional Modeling Studies of Policies Intended to Reduce Motorized Travel, Fuel Use and Emissions,* p. 1. (attached) (emphasis added.)) 3-5

Based on that review and *Smart Congestion Reductions* (mentioned above), SCTA should eliminate some or all of its highway and roadway widening projects while instituting more transit service, parking charges and all-day tolls. The most obvious expansion project to eliminate would be the Marin-Sonoma Narrows HOV/HOT lanes, since that project will encourage more long-distance driving in a corridor that will soon have an excellent transit alternative. That widening project contradicts the County's policy of discouraging the creation of bedroom communities for adjoining counties.

<u>No Project Alternative</u>

The No Project Alternative assumes that in 2035, everything contained in past CTPs has been built. Instead, the Alternative should have represented the existing transportation network as it would function with 2035 population and land use. It improperly includes transportation projects from past plans that have not yet been built. This sleight-of-hand hides the impacts of most of the transportation investments in the CTP by including them in the 2035 baseline, thus making the CTP appear far more benign than is justified. The DEIR defines the No Project Alternative: 3-6

TRANSDEF 6/20/2009 page 4

> The No Project/No Action alternative addresses the effect of not implementing the 2009 CTP. This includes a set of transportation projects and programs that are in advanced planning stages and assumes that all reasonably foreseeable projects and programs (i.e., projects that are fully funded, programmed and/or have cleared the environmental phase) from the adopted 2004 CTP and 2009 Regional Transportation Improvement Program are implemented, but that all other projects and programs do not proceed forward. (p. 6.0-2. (Unless otherwise noted, all page references are to the CTP DEIR.))

This is not a new issue. In a letter addressing this precise topic, the California Attorney General commented to MTC that 3-6

> CEQA requires that an EIR evaluate the potential environmental impacts of an entire project, which in this context we believe represents the entire $223 billion of authorized expenditures – not just the $31.6 billion for projects MTC identifies as 'discretionary,' but also the $191 billion for projects identified as 'committed,' projects included in the prior Transportation Plan but not yet constructed. (Letter to MTC, Oct. 1, 2008, at 5. (attached))

The "entire project" must be compared to a "No Project" alternative that represents 2035 conditions without the expansion projects approved previously, but not yet constructed. Instead of comparing the new Plan with existing conditions, the DEIR improperly compares the new CTP with the old CTP. As a result, the DEIR fails to properly examine project impacts.

The CEQA Guidelines clearly distinguish conventional physical projects from land use plans and regulatory plans. A CTP should be treated as a collection of actual physical projects, which bear no resemblance to the mere concepts that make up the content of a land use plan. A CTP's No Project Alternative should be seen as a no build alternative, viewed at an analysis point decades hence:

> If the project is other than a land use or regulatory plan, for example a development project on identifiable property, the "no project" alternative is the circumstance under which the project does not proceed. Here the discussion would compare the environmental effects of the property remaining in its existing state against environmental effects which would occur if the project is approved. ... In certain instances, the no project alternative means "no build" wherein the existing environmental setting is maintained. However, where failure to proceed with the project will not 3-7

TRANSDEF 6/20/2009 page 5

> result in preservation of existing environmental conditions, the analysis should identify the practical result of the project's non-approval and not create and analyze a set of artificial assumptions that would be required to preserve the existing physical environment. (Section 15126.6(e)(3)(B))

On the basis of this Guideline, the inclusion of previously approved but unconstructed projects in the No Project Alternative is improper. Those projects must be instead included in the Build alternatives. 3-7

New Project Alternative

Even though the project list for the No Project Alternative is highly flawed (see above), it is still instructive as to the VMT impacts of highway widening. The only difference we can find in freeway projects when comparing the No Project Alternative to the CTP is that the latter adds a capacity increase to the Marin-Sonoma Narrows (the project was not fully funded in 2004--only safety improvements were funded back then.)

A careful viewing of Table 6.0-2 on page 6.0-32 indicates that the CTP results in a 3% increase in freeway VMT. This represents a 1% increase in countywide VMT! What else can that be other than an increase in long distance driving through the Narrows? Unfortunately, the DEIR alternatives analysis gives no information about transit mode share. Was SMART ridership higher for the No Project Alternative? 3-8

Given how difficult it is to reduce VMT, this observation offers a golden opportunity to consider approaches that might attain Plan Objective 3A, the 2035 reduction of per capita VMT to a level 10% below 2005 levels. We urge SCTA to construct a variant of DEIR Alternative 3, in which funding for the capacity expansion of the Marin-Sonoma Narrows is transferred to SMART and the bus system, to maximize transit availability. Add to this alternative the pricing elements of Alternative 4. Eliminate the widening of local roads, to test whether demand management via pricing and travel choice can reduce the impacts of growth enough to make it possible to postpone those widenings. 3-9

Comments on DEIR Text (keyed to DEIR page numbers)

3.0-16: The assumed 2035 gasoline price of $7.47 in today's dollars indicates the presence of a carbon tax (as disclosed on p. 6.0-17). Was it the intention of the EIR preparer to have a carbon tax for all alternatives, or was it supposed to be only associated with Alternative 4, the Pricing Alternative? What was the basis for assuming this particular level of carbon tax? 3-10

4.2-6: While it is literally true that "The ozone designation is nonattainment/transitional, denoting that the area is close to attaining the standard" it is widely recognized that higher local temperatures resulting from global warming will worsen ground level ozone concentrations. Because of this trend, there is no evidence that the area is close to attainment, or that it could remain in attainment. 3-11

TRANSDEF 6/20/2009 page 6

4.2-7: The mobile sources contribution to PM emissions in Table 4.2-5 appears to be in error. Automobiles are known to emit about 10 mg. of PM per mile.[2] With a 2005 VMT of roughly 11 million miles, this should have resulted in a combined total PM of at least 46 tons/year, not 3.6. 3-12

4.2-13: After checking directly with BAAQMD, TRANSDEF is clear that there is no evidentiary basis for the assertion that "However, this criterion is applied to general plans that induce growth, not to transportation plans that manage planned growth." This notion was apparently concocted by the EIR preparer to avoid having to acknowledge significant impacts in the air quality area. It must be deleted, and Impact 4.2-1 be corrected to indicate an inconsistency. Table 4.2-8 clearly indicates that VMT is projected to grow faster than population, thereby generating a significant impact according to the 1999 BAAQMD CEQA Guidelines. Mitigation is required. 3-13

4.2-17: There is no evidence in the DEIR to support the statement: "As noted in Impact 4.2-1, the CTP would reduce the rate of growth of VMT over existing conditions to a rate closer to the projected population growth rate." There is neither any data on the existing rate of VMT growth, nor any justification for a claimed causal relationship between a reduction in that rate and the CTP. Delete this statement. 3-14

4.2-17: The reduction of ozone precursors between 2008 and 2035 is almost entirely due to factors unrelated to the CTP--tightened state tailpipe emissions standards being the most important. It is fallacious to claim that "The decrease in emissions results from a number of factors, including the CTP's reductions in travel activity ..." when Table 4.2-8 clearly indicates that VMT is projected to increase dramatically during that period. 3-15

4.2-17 & -18: It is grossly inaccurate for the DEIR to claim that "These mobility and air quality benefits would help the county achieve its four transportation and air quality benchmarks" when Policy 3 goals have not been achieved. 3-16

4.2-18: There is no evidence in the DEIR to support the assertion that "the proposed CTP would not cause increases in emissions from the transportation sector ...." In fact, the incorrect and illegal framing of the No Project Alternative (see above) prevents the reader of the DEIR from determining the full impacts of the CTP. In the absence of a No Project Alternative that contains no projects other than the ones currently under construction contract, it is impossible to accurately determine the impacts of the full set of projects listed in the CTP. More than likely, the increased highway and roadway capacity of the projects in the CTP are directly responsible for an increase in emissions 3-17

[2] W.R. Pierson, A.W. Gertler, N.F. Robinson, J.C. Sagebiel, B. Zielinska, G. Bishop, D.H. Stedman, R.B. Zweidinger, and W.D. Ray (1996). Real-world automotive emissions – summary of studies in the Fort McHenry and Tuscarora Mountain Tunnels *Atmos. Env.* **30**, 2233-2256.
A.W. Gertler (2005) Diesel vs. gasoline emissions: Does PM from diesel or gasoline vehicles dominate in the US? *Atmos. Env.* **39** 2349-2355.
M. Abu-Allaban, J.A. Gillies, and A.W. Gertler (2003) Application of a multi-lag regression approach to determine onroad PM_{10} and $PM_{2.5}$ emission rates. *Atmos. Environ.* **37**, 5157-5164.

TRANSDEF 6/20/2009 page 7

from the transportation sector. Current research has determined that a 10% increase in lane-miles will increase VMT by 5.5%. (*Growing Cooler*, p. 12 (attached).)
4.2-18: Table 4.2-3 indicates that the Bay Area has a non-attainment status for the State standards for PM10 and PM2.5, along with non-attainment of the Federal PM 2.5 standard. Thus, because the region is already violating air quality standards, and because the increase in PM emissions acknowleged in Impact 4.2-3 can only delay attainment, the following misstatement must be deleted from the EIR: "However, these emissions would not lead to any violation of air quality standards, contribute to an existing or projected air quality violation, or result in a cumulatively considerable net increase of emissions of PM_{10} and $PM_{2.5}$, as these emissions are factored into the BAAQMD's plan to attain federal and state particulate standards." TRANSDEF has been actively involved in all of BAAQMD's plans to attain federal and state standards since the 1990's. If there was an Implementation Schedule for particulates, it was not adopted with any kind of public outreach process. TRANSDEF has never seen it, and it is not available on BAAQMD's new website. However, based on years of experience, we strongly suspect that the so-called Schedule does not constitute a valid "plan to attain federal and state particulate standards." It is certainly not a SIP. Please note that MTC's FEIR for the 2009 RTP acknowledged a significant cumulative impact of increased emissions of PM10 and PM 2.5 over existing conditions. (DEIR p. 2.2-21.) Impact 4.2-3 must be revised to acknowledge a significant and unavoidable impact, for which mitigation must be offered. **3-17**

4.2-18: The following sentence asserts that something entirely irrelevant to an analysis of PM emissions, namely the Ozone Strategy, has a bearing on evaluating the significance of PM emissions: "Because the CTP is consistent with BAAQMD's 2005 Ozone Strategy (see Impact 4.2-1), it would not result in a cumulatively considerable net increase in emissions of PM10 and PM2.5." Because the logic of that sentence is nonexistent, it must be deleted. Instead, the increase in emissions of PM 10 and PM2.5 must be found to be cumulatively considerable. **3-18**

4.2-19: Because Diesel PM is a Toxic Air Contaminant, add the following to MM 4.2-4: The utilization of on-road or off-road diesel equipment for more than a de minimus amount of time triggers the requirement to implement T-BACT, the Best Available Control Technology for Toxics, which is defined as meeting the latest CARB regulations for diesel engines. **3-19**

4.3-27: "As such, the proposed CTP will result in significant impacts, given the extent of projected growth throughout the county and region. As noted earlier, the majority of these impacts are directly linked to the planned growth reflected in General Plans throughout Sonoma County and would occur even in the absence of the proposed CTP." This assertion is not supported by any evidence. Because of the flawed selection of the No Project Alternative (see above) and the failure to test an representative alternative, it impossible to determine whether a CTP designed to reduce VMT would in fact have similarly significant impacts. **3-20**

TRANSDEF 6/20/2009 page 8

4.3-29: The DEIR provides no evidence to support its assertion that: Implementation of the 2009 CTP would not directly cause increases in traffic or vehicle miles traveled." On the contrary, this letter provides expert evidence that the expansion of road capacity is correlated with increases in VMT. See *Growing Cooler*, p. 12. (attached) Furthermore, had 2035 conditions been compared to a valid No Project Alternative (see above), the increase in VMT attributable to the CTP would have been evident. 3-21

4.3-30: Impact 4.3-2 should refer twice to vehicle hours travelled--Vehicle Miles Travelled is a typo. All the above comments directed towards the discussion of VMT on the previous DEIR page are equally applicable to VHT. 3-22

4.3-32: Again, the reduction in average daily vehicle speeds is not the inevitable result of population growth--it is the inevitable result of the CTP's auto-centric growth, in which the vast bulk of transportation funding is used to make driving more convenient for single-occupant vehicles. Again, no valid conclusions can be drawn from the comparison with the No Project Alterrnative. 3-23

4.4-30: The analysis for Impact 4.4-7 appears mistaken. The Port Sonoma Ferry Terminal is proposed in an area surrounded by habitat restoration projects. In addition, the rest of the entire surrounding area is zoned for agriculture, and protected from urban development. Please identify precisely what plans are currently in force in that sensitive vicinity, and evaluate their consistency with a proposed ferry terminal. Please re-evaluate the other biological impact areas for this project, because the site may well be the most sensitive habitat of any project in the CTP. 3-24

4.3-33: The first sentence of Impact 4.3-4 should read "Implementation of the 2009 CTP would not directly increase PHD or PHT on the county's roadway system." All comments pertaining to VMT on page 4.3-29 apply equally to PHD and PHT. Given the projected near quadrupling of PHD, we urgently re-refer the reader to *Smart Congestion Reductions--Reevaluating The Role Of Highway Expansion For Improving Urban Transportation [aka Smart Transportation Investments]* (attached) for the reasons why chasing after congestion is a fruitless task, and why other approaches are cheaper, faster and will result in substantial GHG emissions reductions. 3-25

4.3-35: The discussion of Impact 4.3-7 includes the quote "First, the CTP does not mandate such smart growth strategies." Given the other Smart Growth policies of the CTP, and given all the evidence in reports attached to these comments, the failure to achieve the CTP's goals should result in a mitigation program that includes all feasible measures, including mandating smart growth strategies. 3-26

4.8-19: It is unclear to us whether Table 4.8-2 is accurate in regards to the Petaluma Rainier Avenue Crosstown Connector and Interchange. This area has been notorious for flooding. We suspect this project will have a significant impact by "expos[ing] people or structures to a significant risk of loss, injury, or death involving flooding." Would this project be going forward if it did not provide access to cheap land in a floodplain? Many 3-27 believe the area should never be developed, especially given a future of sea level rise. The most appropriate mitigation for this impact would be avoidance--delete the project. 4.13-11: The rate of increase in VMT in Table 4.13-3 is almost exactly equal to the rate of increase in gasoline consumption between 2008 and 2035. This indicates a stunning failure to achieve any motor vehicle fuel economies over that period. This conflicts with the statement on page 4.13-13 that "Yet, the SCTA estimates that this price increase will generally be offset by increases in future vehicle fuel economies, which are expected to increase from 19.86 miles per gallon to 32.15 miles per gallon in 2035." If those assumptions had been correctly entered into the model, gasoline consumption would have decreased, rather than increased. 3-27

4.13-13 & -14: The word "accommodate" is used in the following sentence as if the CTP is environmentally beneficial. "If these trends continue, implementation of the proposed projects in the 2009 CTP would accommodate the increased use of petroleum fuels between the current conditions and 2035." Where is the evaluation of the environmental impacts of the increased use of petroleum fuels? 3-28

4.13-14: MM 4.13-1c does not qualify as a mitigation measure. "[C]onsider[ing] investments in alternative fuel buses and rolling stock" will not result in a reduced impact. The impact will be reduced only if such investments are actually made. The measure needs to be rewritten with mandatory language. 3-29

5.0-3: The text of Section 5.2, Cumulative Air Quality Impacts, must be revised consistent with the comments on Section 4.2, above. 3-30

5.0-3: The text of Section 5.3, Cumulative Transportation and Circulation Impacts, must be revised consistent with the comments on Section 4.3, above. 3-31

5.0-21: Table 5.0-3 is inconsistent with Table 4.13-3, in that gasoline consumption should be proportional to GHG emissions. Table 5.0-3 shows a 21.6% reduction in GHG emissions, while Table 4.13-3 shows a 25% increase in gasoline consumption. These tables can't both be correct. 3-32

5.0-22: The DEIR is able to show the CTP reducing 2035 GHG emissions compared with the No Project Alternative only because it defines the No Project Alternative in such a way as to hide most of the impacts. (See above.) A legitimate analysis of the subject would reveal that the CTP's increase in road capacity significantly increases VMT and GHG emissions. (See lane-mile elasticity of 0.55 in Growing Cooler, p. 12. (attached)) 3-33

5.0-23: None of the proposed Mitigation Measures on this page, or on pages 5.0-25 & -26 qualify as legitimate mitigation measures. "An EIR shall describe feasible measures which could minimize significant adverse impacts ...." CEQA Guidelines Section 15126.4(a)(1). The verbs "consider" "work with" and "encourage" do not create mandatory requirements and concrete commitments that would or could result in minimizing impacts. (While MM 5.0-1g contains the mandatory language "shall include" 3-34

TRANSDEF 6/20/2009 page 10

it fails to identify what must be included. The CEQA Guidelines call for adopting a performance measure in situations where the final mitigations have not been adopted.) 3-34

> Where several measures are available to mitigate an impact, each should be discussed and the basis for selecting a particular measure should be identified. Formulation of mitigation measures should not be deferred until some future time. However, measures may specify performance standards which would mitigate the significant effect of the project and which may be accomplished in more than one specified way. CEQA Guidelines Section 15126.4(a)(1)(B).

6.0-3: Alternatives 1, 2, 3, 4 and 5 explicity state that the assumed 2035 gasoline price is $7.47 in today's dollars, indicating the presence of a carbon tax. Was that price scenario actually intended for only the Pricing Alternative, Alternative 4, or was it intended for all the alternatives? 3-35

6.0-5: It is unnecessarily difficult to read through the project Alternatives, including the CTP, to compare their components. Please provide a matrix similar to the one contained in MTC's RTP DEIR, which used check marks to indicate which alternatives contained a particular project. This would save large amounts of paper, while making the DEIR more usable. While doing so, it would be helpful to identify the total cost of each alternative. Although Alternatives 2 and 5 are explicitly identified as fiscally unconstrained, it is not at all clear that the rest of the alternatives <u>are</u> constrained. 3-36

6.0-12: It is not clear what "improvements" are referred to in the Land Use and Pricing Assumptions section "Additional improvements included in this alternative are the same as Alternative 2." 3-37

6.0-38: It is not true that "It [the Alternative] shifts the focus from roadway improvements toward additional transit expansion, such as reduced headway for SMART rail service and Sonoma County Transit bus service." Vastly more dollars would be spent on roadway improvements in this Alternative. Transit expansion, while desirable, is only an add-on to an auto-centric Plan. As a result, there is little mode shift to transit. 3-38

6.0-42: It is important to not take the following finding out of context: "Taken as a whole, this alternative would potentially have more impacts on population and housing than the proposed 2009 CTP, based largely on its potential to induce growth in the urbanized areas of the county." The impacts described are experienced primarily at the political level, rather than on the environment itself. As noted below, inducement of growth near transit areas is a net environmental benefit. 3-39

6.0-51: Although the Alternatives Analysis did not calculate the percentage changes in VMT and VHT, it is interesting to note that Alternative 3 had a slightly greater percentage reduction in VHT than Alternative 4, while Alternative 4, the Pricing 3-40

TRANSDEF 6/20/2009 page 11

Alternative, had a much greater reduction in VMT than Alternative 3, the Compact Land Use Alternative. Any hypothesis for these results? Based on this analysis demonstrating efficacy in VMT reduction, the Environmentally Superior Alternative should be a hybrid of Alternatives 3 and 4. There is no good reason not to combine them when it comes to developing policy. 3-40

6.0-51: There is no evidentiary basis for finding that increased SMART headways would create "more adverse impacts on noise" given that the basic service has a less than significant impact. (p. 4.10-19.) Inducement of growth near transit areas, when evaluating the overall environmental impacts of a project, is a significant benefit, not an impact, because of the reduction in sprawl-associated environmental impacts, including conversion of agricultural lands, habitat lands and open space to urban uses, increased air emissions, polluted run-off and increased water consumption. 3-41

6.0-52: Table 6.0-21, the summary of Alternatives Comparison, should contain the Air Quality element. 3-42

Recirculation

As a result of the disclosure of new and significant impacts, along with the correction of crucial facts and findings, such as whether the Plan achieves its GHG emissions reduction goal, a revised DEIR will need to be recirculated before it can be certified as adequate. CEQA Guidelines Section 15088.5(a). 3-43

TRANSDEF appreciates this opportunity to comment on the CTP DEIR. We urge SCTA to exhibit leadership in the area of climate change by taking the CTP past the level of business-as-usual, and show the rest of the United States what a motivated agency can accomplish. If Sonoma County becomes a national model for GHG emissions reductions, that could affect the sensitive discussions between the U.S. and China, which recently became the world's largest emitter of GHGs. While it is difficult and scary to be a pioneer, the people of Sonoma County deserve no less. We stand ready to assist SCTA in further refining the Comprehensive Transportation Plan.

Sincerely,

/s/ DAVID SCHONBRUNN

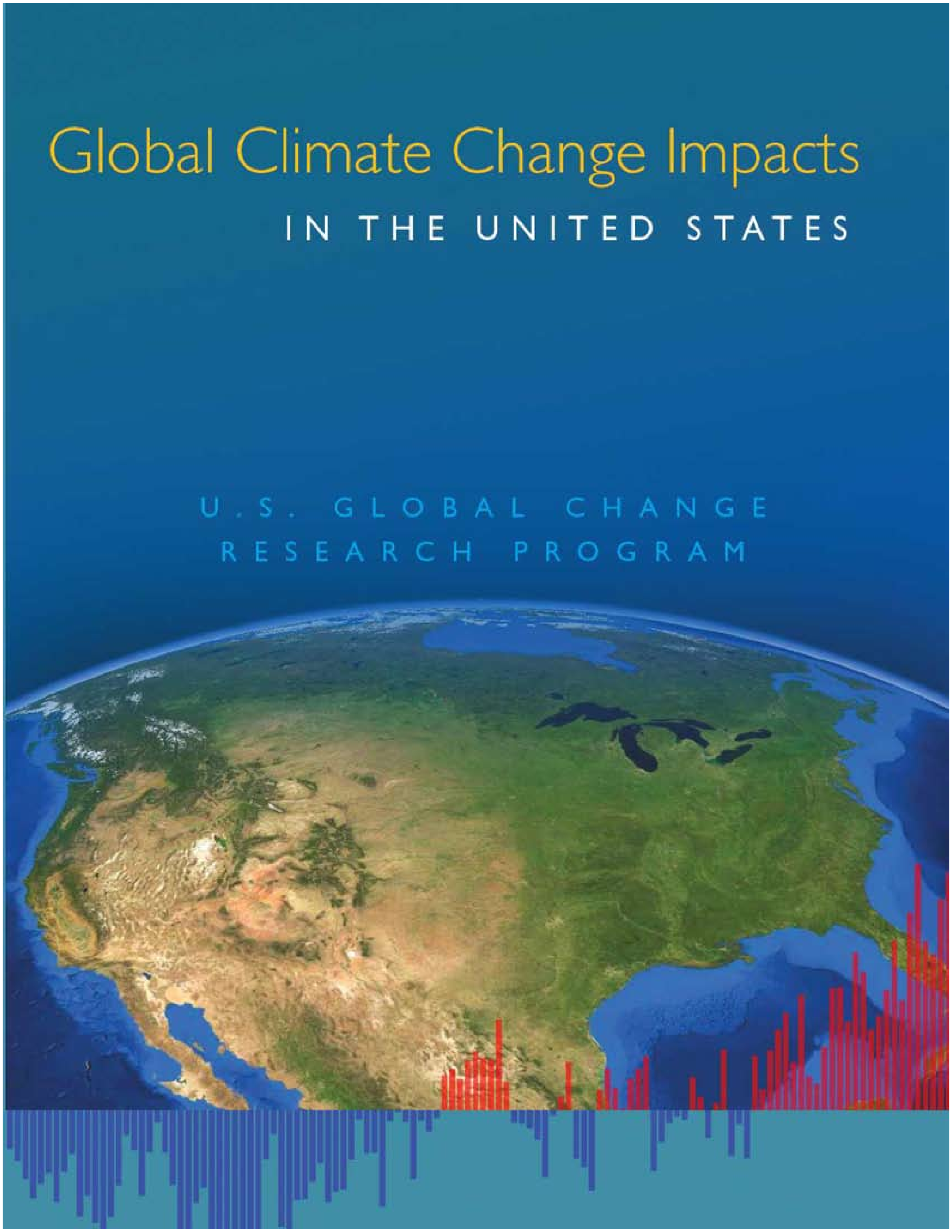
David Schonbrunn,
President

Attachments: (See next page)

TRANSDEF 6/20/2009 page 12

Attachments:
Global Climate Change Impacts in the United States
Cost-Effective GHG Reductions through
Smart Growth & Improved Transportation Choices
Growing Cooler (Chapter 1)
Attorney General's 10/1/08 letter to MTC
Win-Win Emission Reduction Strategies
Smart Congestion Reductions--Reevaluating The Role Of Highway Expansion For Improving Urban Transportation [aka Smart Transportation Investments]
Review of U.S. and European Regional Modeling Studies of Policies Intended to Reduce Motorized Travel, Fuel Use, and Emissions

which are also available at:
http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf
http://www.ccap.org/docs/resources/677/CCAP%20Smart%20Growth%20-$%20per%20ton%20CO2%20_June%202009_%20FINAL.pdf
http://www.smartgrowthamerica.org/gcindex.html
http://ag.ca.gov/globalwarming/ceqa/comments.php
http://www.vtpi.org/documents/innovative.php
http://www.vtpi.org/documents/evaluation.php


Global Climate Change Impacts
IN THE UNITED STATES
U.S. GLOBAL CHANGE
RESEARCH PROGRAM


Global Climate Change
Impacts in the United States
A State of Knowledge Report from the
U.S. Global Change Research Program

The full report can be found online at www.globalchange.gov/usimpacts

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The bars at the bottom of the front cover show the global annual average temperature from 1900-2008, see page 17

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This report on Global Climate Change Impacts in the United States was prepared in accordance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and the information quality act guidelines issued by the Department of Commerce and NOAA pursuant to Section 515 <http://www.noaanews.noaa.gov/stories/iq.htm>.

June 2009

Members of Congress:

On behalf of the National Science and Technology Council, the U.S. Global Change Research Program is pleased to transmit to the President and the Congress this state of knowledge report: "*Global Climate Change Impacts in the United States*." This report summarizes the science of climate change and the impacts of climate change on the United States, now and in the future.

As our nation strives to develop effective policies to respond to climate change, it is critical to have the latest and best scientific information to inform decision making. More than a year in the making, this report provides that information. It is the first report in almost a decade to provide an extensive evaluation of climate change impacts on the United States at the regional level.

An expert team of scientists operating under the authority of the Federal Advisory Committee Act, assisted by communication specialists, wrote the document. The report was reviewed and revised based on comments from experts and the public in accordance with the Information Quality Act guidelines issued by the Department of Commerce and the National Oceanic and Atmospheric Administration.

We highly commend the authors and support personnel of both this report and the underlying Synthesis and Assessment Products for the outstanding quality of their work in providing sound and thorough science-based information for policy formulation and climate change research priority setting. We intend to use the essential information contained in this report as we make policies and decisions about the future, and we recommend others do the same.

Sincerely,

Dr. John Holdren
Director,
Office of Science and Technology Policy

Dr. Jane Lubchenco
Administrator,
National Oceanic and Atmospheric Administration

CONTENTS




Climate Change Impacts by Sector







CONTENTS

Regional Climate Change Impacts

About this Report

What is this report?

This report summarizes the science of climate change and the impacts of climate change on the United States, now and in the future. It is largely based on results of the U.S. Global Change Research Program (USGCRP),[a] and integrates those results with related research from around the world. This report discusses climate-related impacts for various societal and environmental sectors and regions across the nation. It is an authoritative scientific report written in plain language, with the goal of better informing public and private decision making at all levels.

Who called for it, who wrote it, and who approved it?

The USGCRP called for this report. An expert team of scientists operating under the authority of the Federal Advisory Committee Act, assisted by communication specialists, wrote the document. The report was extensively reviewed and revised based on comments from experts and the public. The report was approved by its lead USGCRP Agency, the National Oceanic and Atmospheric Administration, the other USGCRP agencies, and the Committee on the Environment and Natural Resources on behalf of the National Science and Technology Council.[b] This report meets all Federal requirements associated with the Information Quality Act, including those pertaining to public comment and transparency.

What are its sources?

The report draws from a large body of scientific information. The foundation of this report is a set of 21 Synthesis and Assessment Products (SAPs), which were designed to address key policy-relevant issues in climate science (see page 161); several of these were also summarized in the *Scientific Assessment of the Effects of Climate Change on the United States* published in 2008. In addition, other peer-reviewed scientific assessments were used, including those of the Intergovernmental Panel on Climate Change, the U.S. National Assessment of the Consequences of Climate Variability and Change, the Arctic Climate Impact Assessment, the National Research Council's Transportation Research Board report on the Potential Impacts of Climate Change on U.S. Transportation, and a variety of regional climate impact assessments. These assessments were augmented with government statistics as necessary (such as population census and energy usage) as well as publicly available observations and peer-reviewed research published through the end of 2008. This new work was carefully selected by the author team with advice from expert reviewers to update key aspects of climate change science relevant to this report. The icons on the bottom of this page represent some of the major sources drawn upon for this synthesis report.

On the first page of each major section, the sources primarily drawn upon for that section are shown using these icons. Endnotes, indicated by superscript numbers and compiled at the end of the book, are used for specific references throughout the report.

See page 161 for descriptions of these sources.

[a] The U.S. Global Change Research Program (USGCRP), which was established in 1990 by the Global Change Research Act, encompasses the Climate Change Science Program (CCSP).

[b] A description of the National Science and Technology Council (NSTC) can be found at www.ostp.gov/cs/nstc.

Does this report deal with options for responding to climate change?

While the primary focus of this report is on the impacts of climate change in the United States, it also deals with some of the actions society is already taking or can take to respond to the climate challenge. Responses to climate change fall into two broad categories. The first involves "mitigation" measures to reduce climate change by, for example, reducing emissions of heat-trapping gases and particles, or increasing removal of heat-trapping gases from the atmosphere. The second involves "adaptation" measures to improve our ability to cope with or avoid harmful impacts and take advantage of beneficial ones, now and in the future. Both of these are necessary elements of an effective response strategy. These two types of responses are linked in that more effective mitigation measures reduce the amount of climate change, and therefore the need for adaptation.

This report underscores the importance of mitigation by comparing impacts resulting from higher versus lower emissions scenarios. The report shows that choices made about emissions in the next few decades will have far-reaching consequences for climate change impacts. Over the long term, lower emissions will lessen both the magnitude of climate change impacts and the rate at which they appear.

While the report underscores the importance of mitigation as an essential part of the nation's climate change strategy, it does not evaluate mitigation technologies or undertake an analysis of the effectiveness of various approaches. These issues are the subject of ongoing studies by the U.S. Government's Climate Change Technology Program and several federal agencies including the Department of Energy, Environmental Protection Agency, National Oceanic and Atmospheric Administration, Department of Transportation, and Department of Agriculture. The range of mitigation responses being studied includes more efficient production and use of energy, increased use of non-carbon-emitting energy sources, and carbon capture and storage.

Adaptation options also have the potential to moderate harmful impacts of current and future climate variability and change. While this report does address adaptation, it does not do so comprehensively. Rather, in the context of impacts, this report identifies examples of actions currently being pursued in various sectors and regions to address climate change, as well as other environmental problems that could be exacerbated by climate change such as urban air pollution and heat waves. In most cases, there is currently insufficient peer-reviewed information to evaluate the practicality, effectiveness, costs, or benefits of these measures, highlighting a need for research in this area. Thus, the discussion of various public and private adaptation examples should not be viewed as an endorsement of any particular option, but rather as illustrative examples of approaches being tried.

How is the likelihood of various outcomes expressed given that the future is not certain?

When it is considered necessary to express a range of possible outcomes and identify the likelihood of particular impacts, this report takes a plain-language approach to expressing the expert judgment of the author team based on the best available evidence. For example, an outcome termed "likely" has at least a two-thirds chance of occurring; an outcome termed "very likely," at least a 90 percent chance.[1] In using these terms, the Federal Advisory Committee has taken into consideration a wide range of information, including the strength and consistency of the observed evidence, the range and consistency of model projections, the reliability of particular models as tested by various methods, and most importantly, the body of work addressed in earlier synthesis and assessment reports. Key sources of information used to develop these characterizations of uncertainty are referenced in endnotes.

How does this report address incomplete scientific understanding?

This assessment identifies areas in which scientific uncertainty limits our ability to estimate future climate change and its impacts. The section on *An Agenda for Climate Impacts Science* at the end of this report highlights some of these areas.

Executive Summary

Observations show that warming of the climate is unequivocal. The global warming observed over the past 50 years is due primarily to human-induced emissions of heat-trapping gases. These emissions come mainly from the burning of fossil fuels (coal, oil, and gas), with important contributions from the clearing of forests, agricultural practices, and other activities.

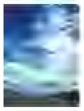
Warming over this century is projected to be considerably greater than over the last century. The global average temperature since 1900 has risen by about 1.5°F. By 2100, it is projected to rise another 2 to 11.5°F. The U.S. average temperature has risen by a comparable amount and is very likely to rise more than the global average over this century, with some variation from place to place. Several factors will determine future temperature increases. Increases at the lower end of this range are more likely if global heat-trapping gas emissions are cut substantially. If emissions continue to rise at or near current rates, temperature increases are more likely to be near the upper end of the range. Volcanic eruptions or other natural variations could temporarily counteract some of the human-induced warming, slowing the rise in global temperature, but these effects would only last a few years.

Reducing emissions of carbon dioxide would lessen warming over this century and beyond. Sizable early cuts in emissions would significantly reduce the pace and the overall amount of climate change. Earlier cuts in emissions would have a greater effect in reducing climate change than comparable reductions made later. In addition, reducing emissions of some shorter-lived heat-trapping gases, such as methane, and some types of particles, such as soot, would begin to reduce warming within weeks to decades.

Climate-related changes have already been observed globally and in the United States. These include increases in air and water temperatures, reduced frost days, increased frequency and intensity of heavy downpours, a rise in sea level, and reduced snow cover, glaciers, permafrost, and sea ice. A longer ice-free period on lakes and rivers, lengthening of the growing season, and increased water vapor in the atmosphere have also been observed. Over the past 30 years, temperatures have risen faster in winter than in any other season, with average winter temperatures in the Midwest and northern Great Plains increasing more than 7°F. Some of the changes have been faster than previous assessments had suggested.

These climate-related changes are expected to continue while new ones develop. Likely future changes for the United States and surrounding coastal waters include more intense hurricanes with related increases in wind, rain, and storm surges (but not necessarily an increase in the number of these storms that make landfall), as well as drier conditions in the Southwest and Caribbean. These changes will affect human health, water supply, agriculture, coastal areas, and many other aspects of society and the natural environment.

This report synthesizes information from a wide variety of scientific assessments (see page 7) and recently published research to summarize what is known about the observed and projected consequences of climate change on the United States. It combines analysis of impacts on various sectors



such as energy, water, and transportation at the national level with an assessment of key impacts on specific regions of the United States. For example, sea-level rise will increase risks of erosion, storm surge damage, and flooding for coastal communities, especially in the Southeast and parts of Alaska. Reduced snowpack and earlier snow melt will alter the timing and amount of water supplies, posing significant challenges for water resource management in the West.

Society and ecosystems can adjust to some climatic changes, but this takes time. The projected rapid rate and large amount of climate change over this century will challenge the ability of society and natural systems to adapt. For example, it is difficult and expensive to alter or replace infrastructure designed to last for decades (such as buildings, bridges, roads, airports, reservoirs, and ports) in response to continuous and/or abrupt climate change.

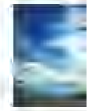
Impacts are expected to become increasingly severe for more people and places as the amount of warming increases. Rapid rates of warming would lead to particularly large impacts on natural ecosystems and the benefits they provide to humanity. Some of the impacts of climate change will be irreversible, such as species extinctions and coastal land lost to rising seas.

Unanticipated impacts of increasing carbon dioxide and climate change have already occurred and more are possible in the future. For example, it has recently been observed that the increase in atmospheric carbon dioxide concentration is causing an increase in ocean acidity. This reduces the ability of corals and other sea life to build shells and skeletons out of calcium carbonate. Additional impacts in the future might stem from unforeseen changes in the climate system, such as major alterations in oceans, ice, or storms; and unexpected consequences of ecological changes, such as massive dislocations of species or pest outbreaks. Unexpected social or economic changes, including major shifts in wealth, technology, or societal priorities would also affect our ability to respond to climate change. Both anticipated and unanticipated impacts become more challenging with increased warming.

Projections of future climate change come from careful analyses of outputs from global climate models run on the world's most advanced computers. The model simulations analyzed in this report used plausible scenarios of human activity that generally lead to further increases in heat-trapping emissions. None of the scenarios used in this report assumes adoption of policies explicitly designed to address climate change. However, the level of emissions varies among scenarios because of differences in assumptions about population, economic activity, choice of energy technologies, and other factors. Scenarios cover a range of emissions of heat-trapping gases, and the associated climate projections illustrate that lower emissions result in less climate change and thus reduced impacts over this century and beyond. Under all scenarios considered in this report, however, relatively large and sustained changes in many aspects of climate are projected by the middle of this century, with even larger changes by the end of this century, especially under higher emissions scenarios.

In projecting future conditions, there is always some level of uncertainty. For example, there is a high degree of confidence in projections that future temperature increases will be greatest in the Arctic and in the middle of continents. For precipitation, there is high confidence in projections of continued increases in the Arctic and sub-Arctic (including Alaska) and decreases in the regions just outside the tropics, but the precise location of the transition between these is less certain. At local to regional scales and on time frames up to a few years, natural climate variations can be relatively large and can temporarily mask the progressive nature of global climate change. However, the science of making skillful projections at these scales has progressed considerably, allowing useful information to be drawn from regional climate studies such as those highlighted in this report.

This report focuses on observed and projected climate change and its impacts on the United States. However, a discussion of these issues would be incomplete without mentioning some of the actions society can take to respond to the climate challenge. The two major categories are "mitigation" and "adaptation." Mitigation refers to options for limiting climate change by, for example, reducing



heat-trapping emissions such as carbon dioxide, methane, nitrous oxide, and halocarbons, or removing some of the heat-trapping gases from the atmosphere. Adaptation refers to changes made to better respond to present or future climatic and other environmental conditions, thereby reducing harm or taking advantage of opportunity. Effective mitigation measures reduce the need for adaptation. Mitigation and adaptation are both essential parts of a comprehensive climate change response strategy.

Carbon dioxide emissions are a primary focus of mitigation strategies. These include improving energy efficiency, using energy sources that do not produce carbon dioxide or produce less of it, capturing and storing carbon dioxide from fossil fuel use, and so on. Choices made about emissions reductions now and over the next few decades will have far-reaching consequences for climate-change impacts. The importance of mitigation is clear in comparisons of impacts resulting from higher versus lower emissions scenarios considered in this report. Over the long term, lower emissions will lessen both the magnitude of climate-change impacts and the rate at which they appear. Smaller climate changes that come more slowly make the adaptation challenge more tractable.

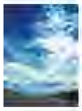
However, no matter how aggressively heat-trapping emissions are reduced, some amount of climate change and resulting impacts will continue due to the effects of gases that have already been released. This is true for several reasons. First, some of these gases are very long-lived and the levels of atmospheric heat-trapping gases will remain elevated for hundreds of years or more. Second, the Earth's vast oceans have absorbed much of the heat added to the climate system due to the increase in heat-trapping gases, and will retain that heat for many decades. In addition, the factors that determine emissions, such as energy-supply systems, cannot be changed overnight. Consequently, there is also a need for adaptation.

Adaptation can include a wide range of activities. Examples include a farmer switching to growing a different crop variety better suited to warmer or drier conditions; a company relocating key business centers away from coastal areas vulnerable to sea-level rise and hurricanes; and a community altering its zoning and building codes to place fewer structures in harm's way and making buildings less vulnerable to damage from floods, fires, and other extreme events. Some adaptation options that are currently being pursued in various regions and sectors to deal with climate change and/or other environmental issues are identified in this report. However, it is clear that there are limits to how much adaptation can achieve.

Humans have adapted to changing climatic conditions in the past, but in the future, adaptations will be particularly challenging because society won't be adapting to a new steady state but rather to a rapidly moving target. Climate will be continually changing, moving at a relatively rapid rate, outside the range to which society has adapted in the past. The precise amounts and timing of these changes will not be known with certainty.

In an increasingly interdependent world, U.S. vulnerability to climate change is linked to the fates of other nations. For example, conflicts or mass migrations of people resulting from food scarcity and other resource limits, health impacts, or environmental stresses in other parts of the world could threaten U.S. national security. It is thus difficult to fully evaluate the impacts of climate change on the United States without considering the consequences of climate change elsewhere. However, such analysis is beyond the scope of this report.

Finally, this report identifies a number of areas in which inadequate information or understanding hampers our ability to estimate future climate change and its impacts. For example, our knowledge of changes in tornadoes, hail, and ice storms is quite limited, making it difficult to know if and how such events have changed as climate has warmed, and how they might change in the future. Research on ecological responses to climate change is also limited, as is our understanding of social responses. The section titled *An Agenda for Climate Impacts Science* at the end of this report offers some thoughts on the most important ways to improve our knowledge. Results from such efforts would inform future assessments that continue building our understanding of humanity's impacts on climate, and climate's impacts on us.



Key Findings

1. Global warming is unequivocal and primarily human-induced.
Global temperature has increased over the past 50 years. This observed increase is due primarily to human-induced emissions of heat-trapping gases. (p. 13)

2. Climate changes are underway in the United States and are projected to grow.
Climate-related changes are already observed in the United States and its coastal waters. These include increases in heavy downpours, rising temperature and sea level, rapidly retreating glaciers, thawing permafrost, lengthening growing seasons, lengthening ice-free seasons in the ocean and on lakes and rivers, earlier snowmelt, and alterations in river flows. These changes are projected to grow. (p. 27)

3. Widespread climate-related impacts are occurring now and are expected to increase.
Climate changes are already affecting water, energy, transportation, agriculture, ecosystems, and health. These impacts are different from region to region and will grow under projected climate change. (p. 41-106, 107-152)

4. Climate change will stress water resources.
Water is an issue in every region, but the nature of the potential impacts varies. Drought, related to reduced precipitation, increased evaporation, and increased water loss from plants, is an important issue in many regions, especially in the West. Floods and water quality problems are likely to be amplified by climate change in most regions. Declines in mountain snowpack are important in the West and Alaska where snowpack provides vital natural water storage. (p. 41, 129, 135, 139)

5. Crop and livestock production will be increasingly challenged.
Many crops show positive responses to elevated carbon dioxide and low levels of warming, but higher levels of warming often negatively affect growth and yields. Increased pests, water stress, diseases, and weather extremes will pose adaptation challenges for crop and livestock production. (p. 71)

6. Coastal areas are at increasing risk from sea-level rise and storm surge.
Sea-level rise and storm surge place many U.S. coastal areas at increasing risk of erosion and flooding, especially along the Atlantic and Gulf Coasts, Pacific Islands, and parts of Alaska. Energy and transportation infrastructure and other property in coastal areas are very likely to be adversely affected. (p. 111, 139, 145, 149)

7. Risks to human health will increase.
Harmful health impacts of climate change are related to increasing heat stress, waterborne diseases, poor air quality, extreme weather events, and diseases transmitted by insects and rodents. Reduced cold stress provides some benefits. Robust public health infrastructure can reduce the potential for negative impacts. (p. 89)

8. Climate change will interact with many social and environmental stresses.
Climate change will combine with pollution, population growth, overuse of resources, urbanization, and other social, economic, and environmental stresses to create larger impacts than from any of these factors alone. (p. 99)

9. Thresholds will be crossed, leading to large changes in climate and ecosystems.
There are a variety of thresholds in the climate system and ecosystems. These thresholds determine, for example, the presence of sea ice and permafrost, and the survival of species, from fish to insect pests, with implications for society. With further climate change, the crossing of additional thresholds is expected. (p. 76, 82, 115, 137, 142)

10. Future climate change and its impacts depend on choices made today.
The amount and rate of future climate change depend primarily on current and future human-caused emissions of heat-trapping gases and airborne particles. Responses involve reducing emissions to limit future warming, and adapting to the changes that are unavoidable. (p. 25, 29)

Global Climate Change

Key Messages:

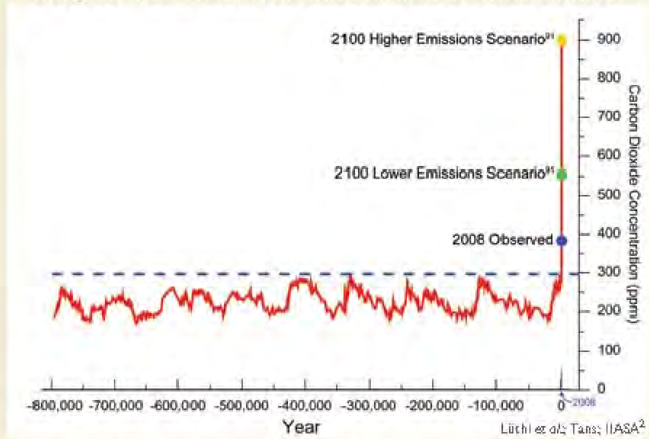
- Human activities have led to large increases in heat-trapping gases over the past century.
- Global average temperature and sea level have increased, and precipitation patterns have changed.
- The global warming of the past 50 years is due primarily to human-induced increases in heat-trapping gases. Human "fingerprints" also have been identified in many other aspects of the climate system, including changes in ocean heat content, precipitation, atmospheric moisture, and Arctic sea ice.
- Global temperatures are projected to continue to rise over this century; by how much and for how long depends on a number of factors, including the amount of heat-trapping gas emissions and how sensitive the climate is to those emissions.

Key Sources

This introduction to global climate change explains very briefly what has been happening to the world's climate and why, and what is projected to happen in the future. While this report focuses on climate change impacts in the United States, understanding these changes and their impacts requires an understanding of the global climate system.

Many changes have been observed in global climate over the past century. The nature and causes of these changes have been comprehensively chronicled in a variety of recent reports, such as those by the Intergovernmental Panel on Climate Change (IPCC) and the U.S. Climate Change Science Program (CCSP). This section does not intend to duplicate these comprehensive efforts, but rather to provide a brief synthesis, and to integrate more recent work with the assessments of the IPCC, CCSP, and others.

800,000 Year Record of Carbon Dioxide Concentration



Analysis of air bubbles trapped in an Antarctic ice core extending back 800,000 years documents the Earth's changing carbon dioxide concentration. Over this long period, natural factors have caused the atmospheric carbon dioxide concentration to vary within a range of about 170 to 300 parts per million (ppm). Temperature-related data make clear that these variations have played a central role in determining the global climate. As a result of human activities, the present carbon dioxide concentration of about 385 ppm is about 30 percent above its highest level over at least the last 800,000 years. In the absence of strong control measures, emissions projected for this century would result in the carbon dioxide concentration increasing to a level that is roughly 2 to 3 times the highest level occurring over the glacial-interglacial era that spans the last 800,000 or more years.

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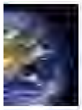
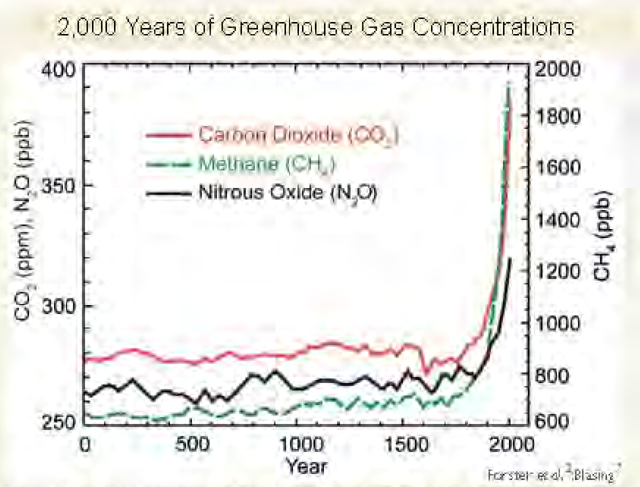


Human activities have led to large increases in heat-trapping gases over the past century.

The Earth's climate depends on the functioning of a natural "greenhouse effect." This effect is the result of heat-trapping gases (also known as greenhouse gases) like water vapor, carbon dioxide, ozone, methane, and nitrous oxide, which absorb heat radiated from the Earth's surface and lower atmosphere and then radiate much of the energy back toward the surface. Without this natural greenhouse effect, the average surface temperature of the Earth would be about 60°F colder. However, human activities have been releasing additional heat-trapping gases, intensifying the natural greenhouse effect, thereby changing the Earth's climate.

Climate is influenced by a variety of factors, both human-induced and natural. The increase in the carbon dioxide concentration has been the principal factor causing warming over the past 50 years. Its concentration has been building up in the Earth's atmosphere since the beginning of the industrial era in the mid-1700s, primarily due to the burning of fossil fuels (coal, oil, and natural gas) and the clearing of forests. Human activities have also increased the emissions of other greenhouse gases, such as methane, nitrous oxide, and halocarbons.[3]



Increases in concentrations of these gases since 1750 are due to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion molecules of air.

These emissions are thickening the blanket of heat-trapping gases in Earth's atmosphere, causing surface temperatures to rise.

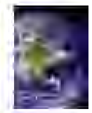
Heat-trapping gases

Carbon dioxide concentration has increased due to the use of fossil fuels in electricity generation, transportation, and industrial and household uses. It is also produced as a by-product during the manufacturing of cement. Deforestation provides a source of carbon dioxide and reduces its uptake by trees and other plants. Globally, over the past several decades, about 80 percent of human-induced carbon dioxide emissions came from the burning of fossil fuels, while about 20 percent resulted from deforestation and associated agricultural practices. The concentration of carbon dioxide in the atmosphere has increased by roughly 35 percent since the start of the industrial revolution.[3]

Methane concentration has increased mainly as a result of agriculture; raising livestock (which produce methane in their digestive tracts); mining, transportation, and use of certain fossil fuels; sewage; and decomposing garbage in landfills. About 70 percent of the emissions of atmospheric methane are now related to human activities.[4]

Nitrous oxide concentration is increasing as a result of fertilizer use and fossil fuel burning.

Halocarbon emissions come from the release of certain manufactured chemicals to the atmosphere. Examples include chlorofluorocarbons (CFCs), which were used extensively in refrigeration and for other industrial processes before their presence in the atmosphere was found to cause stratospheric ozone depletion. The abundance of these gases in the atmosphere is now decreasing as a result of international regulations designed to protect the ozone layer. Continued decreases in ozone-depleting halocarbon emissions are expected to reduce their relative influence on climate change in the future.[3,5] Many halocarbon replacements, however, are potent greenhouse gases, and their concentrations are increasing.[6]



Ozone is a greenhouse gas, and is continually produced and destroyed in the atmosphere by chemical reactions. In the troposphere, the lowest 5 to 10 miles of the atmosphere near the surface, human activities have increased the ozone concentration through the release of gases such as carbon monoxide, hydrocarbons, and nitrogen oxides. These gases undergo chemical reactions to produce ozone in the presence of sunlight. In addition to trapping heat, excess ozone in the troposphere causes respiratory illnesses and other human health problems.

In the stratosphere, the layer above the troposphere, ozone exists naturally and protects life on Earth from exposure to excessive ultraviolet radiation from the Sun. As mentioned previously, halocarbons released by human activities destroy ozone in the stratosphere and have caused the ozone hole over Antarctica.[8] Changes in the stratospheric ozone layer have contributed to changes in wind patterns and regional climates in Antarctica.[9]

Water vapor is the most important and abundant greenhouse gas in the atmosphere. Human activities produce only a very small increase in water vapor through irrigation and combustion processes.[3] However, the surface warming caused by human-produced increases in other greenhouse gases leads to an increase in atmospheric water vapor, since a warmer climate increases evaporation and allows the atmosphere to hold more moisture. This creates an amplifying "feedback loop," leading to more warming.

Other human influences

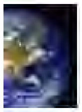
In addition to the global-scale climate effects of heat-trapping gases, human activities also produce additional local and regional effects. Some of these activities partially offset the warming caused by greenhouse gases, while others increase the warming. One such influence on climate is caused by tiny particles called "aerosols" (not to be confused with aerosol spray cans). For example, the burning of coal produces emissions of sulfur-containing compounds. These compounds form "sulfate aerosol" particles, which reflect some of the incoming sunlight away from the Earth, causing a cooling influence at the surface. Sulfate aerosols also tend to make clouds more efficient at reflecting sunlight, causing an additional indirect cooling effect. Another type of aerosol, often referred to as soot or black carbon, absorbs incoming sunlight and traps heat in the atmosphere. Thus, depending on their type, aerosols can either mask or increase the warming caused by increased levels of greenhouse gases.[13] On a globally averaged basis, the sum of these aerosol effects offsets some of the warming caused by heat-trapping gases.[10]

The effects of various greenhouse gases and aerosol particles on Earth's climate depend in part on how long these gases and particles remain in the atmosphere. After emission, the atmospheric concentration of carbon dioxide remains elevated for thousands of years, and that of methane for decades, while the elevated concentrations of aerosols only persist for days to weeks.[11,12] The climate effects of reductions in emissions of carbon dioxide and other long-lived gases do not become apparent for at least several decades. In contrast, reductions in emissions of short-lived compounds can have a rapid, but complex effect since the geographic patterns of their climatic influence and the resulting surface temperature responses are quite different. One modeling study found that while the greatest emissions of short-lived pollutants in summertime by late this century are projected to come from Asia, the strongest climate response is projected to be over the central United States.[13]

Human activities have also changed the land surface in ways that alter how much heat is reflected or absorbed by the surface. Such changes include the cutting and burning of forests, the replacement of other areas of natural vegetation with agriculture and cities, and large-scale irrigation. These transformations of the land surface can cause local (and even regional) warming or cooling. Globally, the net effect of these changes has probably been a slight cooling of the Earth's surface over the past 100 years.[14,15]

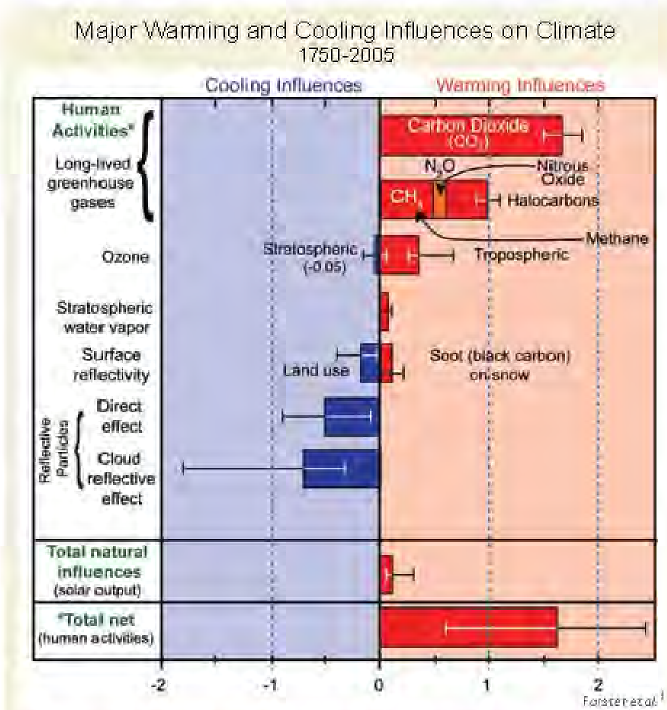
Natural influences

Two important natural factors also influence climate: the Sun and volcanic eruptions. Over the past three decades, human influences on climate have become increasingly obvious, and global temperatures have risen sharply. During the same period, the Sun's energy output (as measured by satellites since 1979) has followed its historical 11-year cycle



of small ups and downs, but with no net increase (see figure page 20).[16] The two major volcanic eruptions of the past 30 years have had short-term cooling effects on climate, lasting 2 to 3 years.[17] Thus, these natural factors cannot explain the warming of recent decades; in fact, their net effect on climate has probably been a slight cooling influence over this period. Slow changes in Earth's orbit around the Sun and its tilt toward or away from the Sun are also a purely natural influence on climate, but are only important on timescales from thousands to many tens of thousands of years.

The climate changes that have occurred over the last century are not solely caused by the human and natural factors described above. In addition to these influences, there are also fluctuations in climate that occur even in the absence of changes in human activities, the Sun, or volcanoes. One example is the El Niño phenomenon, which has important influences on many aspects of regional and global climate. Many other modes of variability have been identified by climate scientists and their effects on climate occur at the same time as the effects of human activities, the Sun, and volcanoes.



The figure above shows the amount of warming influence (red bars) or cooling influence (blue bars) that different factors have had on Earth's climate over the industrial age (from about 1750 to the present). Results are in watts per square meter. The longer the bar, the greater the influence on climate. The top part of the box includes all the major human-induced factors, while the second part of the box includes the Sun, the only major natural factor with a long-term effect on climate. The cooling effect of individual volcanoes is also natural, but is relatively short-lived (2 to 3 years), thus their influence is not included in this figure. The bottom part of the box shows that the total net effect (warming influences minus cooling influences) of human activities is a strong warming influence. The thin lines on each bar provide an estimate of the range of uncertainty.

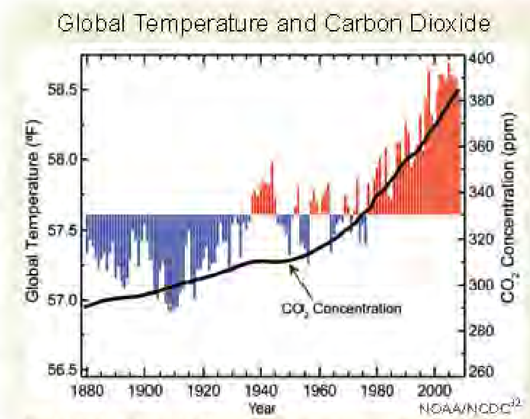
Carbon release and uptake

Once carbon dioxide is emitted to the atmosphere, some of it is absorbed by the oceans and taken up by vegetation, although this storage may be temporary. About 45 percent of the carbon dioxide emitted by human activities in the last 50 years is now stored in the oceans and vegetation. The rest has remained in the air, increasing the atmospheric concentration.[2,3,18] It is thus important to understand not only how much carbon dioxide is emitted, but also how much is taken up, over what time scales, and how these sources and "sinks" of carbon dioxide might change as climate continues to warm. For example, it is known from long records of Earth's climate history that under warmer conditions, carbon tends to be released, for instance, from thawing permafrost, initiating a feedback loop in which more carbon release leads to more warming which leads to further release, and so on.[19,20]

Global emissions of carbon dioxide have been accelerating. The growth rate increased from 1.3 percent per year in the 1990s to 3.3 percent per year between 2000 and 2006.[21] The increasing emissions of carbon dioxide are the primary cause of the increased concentration of carbon dioxide observed in the atmosphere. There is also evidence that a smaller fraction of the annual human-induced emissions is now being taken up than in the past, leading to a greater fraction remaining in the atmosphere and an accelerating rate of increase in the carbon dioxide concentration.[21]

Ocean acidification

As the ocean absorbs carbon dioxide from the atmosphere, seawater is becoming less alkaline (its pH is decreasing) through a process generally referred to as ocean acidification. The pH of seawater has decreased significantly since 1750,[22,23] and is projected to drop much more dramatically by the end of the century if carbon dioxide concentrations continue to increase.[24] Such ocean acidification is essentially irreversible over a time scale of centuries. As discussed in the *Ecosystems* sector and *Coasts* region, ocean acidification affects the process of calcification by which living things create shells and skeletons, with substantial negative consequences for coral reefs, mollusks, and some plankton species important to ocean food chains.[25]



Global annual average temperature (as measured over both land and oceans). Red bars indicate temperatures above and blue bars indicate temperatures below the average temperature for the period 1901-2000. The black line shows atmospheric carbon dioxide (CO_2) concentration in parts per million (ppm). While there is a clear long-term global warming trend, each individual year does not show a temperature increase relative to the previous year, and some years show greater changes than others.[22] These year-to-year fluctuations in temperature are due to natural processes, such as the effects of El Niños, La Niñas, and the eruption of large volcanoes.

Global average temperature and sea level have increased, and precipitation patterns have changed.

Temperatures are rising

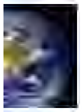
Global average surface air temperature has increased substantially since 1970.[26] The estimated change in the average temperature of Earth's surface is based on measurements from thousands of weather stations, ships, and buoys around the world, as well as from satellites. These measurements are independently compiled, analyzed, and processed by different research groups. There are a number of important steps in the data processing. These include identifying and adjusting for the effects of changes in the instruments used to measure temperature, the measurement times and locations, the local environment around the measuring site, and such factors as satellite orbital drift. For instance, the growth of cities can cause localized "urban heat island" effects.

A number of research groups around the world have produced estimates of global-scale changes in surface temperature. The warming trend that is apparent in all of these temperature records is confirmed by other independent observations, such as the melting of Arctic sea ice, the retreat of mountain glaciers on every continent,[27] reductions in the extent of snow cover, earlier blooming of plants in spring, and increased melting of the Greenland and Antarctic ice sheets.[28,29] Because snow and ice reflect the Sun's heat, this melting causes more heat to be absorbed, which causes more melting, resulting in another feedback loop.[20]

Additionally, temperature measurements above the surface have been made by weather balloons since the late 1940s, and from satellites since 1979. These measurements show warming of the troposphere, consistent with the surface warming.[30,31] They also reveal cooling in the stratosphere.[30] This pattern of tropospheric warming and stratospheric cooling agrees with our understanding of how atmospheric temperature would be expected to change in response to increasing greenhouse gas concentrations and the observed depletion of stratospheric ozone.[14]

Precipitation patterns are changing

Precipitation is not distributed evenly over the globe. Its average distribution is governed primarily by atmospheric circulation patterns, the availability of moisture, and surface terrain effects. The first two of these factors are influenced by temperature. Thus, human-caused changes in temperature are expected to alter precipitation patterns.



Observations show that such shifts are occurring. Changes have been observed in the amount, intensity, frequency, and type of precipitation. Pronounced increases in precipitation over the past 100 years have been observed in eastern North America, southern South America, and northern Europe. Decreases have been seen in the Mediterranean, most of Africa, and southern Asia. Changes in the geographical distribution of droughts and flooding have been complex. In some regions, there have been increases in the occurrences of both droughts and floods.[28] As the world warms, northern regions and mountainous areas are experiencing more precipitation falling as rain rather than snow.[34] Widespread increases in heavy precipitation events have occurred, even in places where total rain amounts have decreased. These changes are associated with the fact that warmer air holds more water vapor evaporating from the world's oceans and land surface.[31] This increase in atmospheric water vapor has been observed from satellites, and is primarily due to human influences.[35,36]

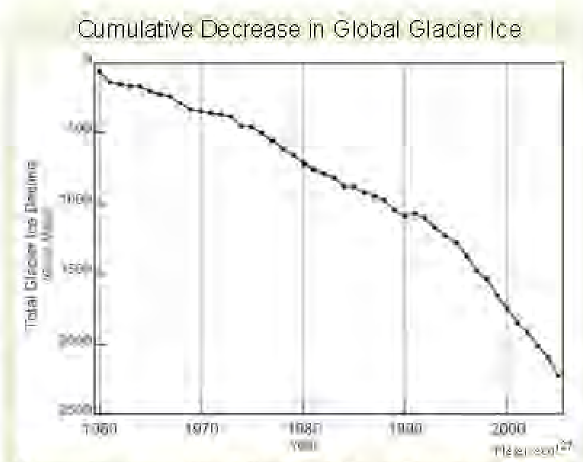
Sea level is rising

After at least 2,000 years of little change, sea level rose by roughly 8 inches over the past century. Satellite data available over the past 15 years show sea level rising at a rate roughly double the rate observed over the past century.[37]

There are two principal ways in which global warming causes sea level to rise. First, ocean water expands as it warms, and therefore takes up more space. Warming has been observed in each of the world's major ocean basins, and has been directly linked to human influences.[38,39]

Second, warming leads to the melting of glaciers and ice sheets, which raises sea level by adding water to the oceans. Glaciers have been retreating worldwide for at least the last century, and the rate of retreat has increased in the past decade.[29,40] Only a few glaciers are actually advancing (in locations that were well below freezing, and where increased precipitation has outpaced melting). The total volume of glaciers on Earth is declining sharply. The progressive disappearance of glaciers has implications not only for the rise in global sea level, but also for water supplies in certain densely populated regions of Asia and South America.

The Earth has major ice sheets on Greenland and Antarctica. These ice sheets are currently losing ice volume by increased melting and calving of icebergs, contributing to sea-level rise. The Greenland Ice Sheet has also been experiencing record amounts of surface melting, and a large increase in the rate of mass loss in the past decade.[41] If the entire Greenland Ice Sheet melted, it would raise sea level by about 20 feet. The Antarctic Ice Sheet consists of two portions, the West Antarctic Ice Sheet and the East Antarctic Ice Sheet. The West Antarctic Ice Sheet, the more vulnerable to melting of the two, contains enough water to raise global sea levels by about 16 to 20 feet.[29] If the East Antarctic Ice Sheet melted entirely, it would raise global sea level by about 200 feet. Complete melting of these ice sheets over this century or the next is thought to be virtually impossible, although past climate records provide precedent for very significant decreases in ice volume, and therefore increases in sea level.[42,43]



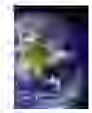
As temperatures have risen, glaciers around the world have shrunk. The graph shows the cumulative decline in glacier ice worldwide.

The global warming of the past 50 years is due primarily to human-induced increases in heat-trapping gases. Human "fingerprints" also have been identified in many other aspects of the climate system, including changes in ocean heat content, precipitation, atmospheric moisture, and Arctic sea ice.

In 1996, the IPCC Second Assessment Report[44] cautiously concluded that "the balance of evidence suggests a discernible human influence on global climate." Since then, a number of national and international assessments have come to much stronger conclusions about the reality of human effects on climate. Recent scientific assessments find that most of the warming of the Earth's surface over the past 50 years has been caused by human activities.[45,46]

This conclusion rests on multiple lines of evidence. Like the warming "signal" that has gradually emerged from the "noise" of natural climate variability, the scientific evidence for a human influence on global climate has accumulated over the past several decades, from many hundreds of studies. No single study is a "smoking gun." Nor has any single study or combination of studies undermined the large body of evidence supporting the conclusion that human activity is the primary driver of recent warming.

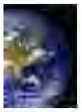
The first line of evidence is our basic physical understanding of how greenhouse gases trap heat, how the climate system responds to increases in greenhouse gases, and how other human and natural factors influence climate. The second line of evidence is from indirect estimates of climate changes over the last 1,000 to 2,000 years. These records are obtained from living things and their remains (like tree rings and corals) and from physical quantities (like the ratio between lighter and heavier isotopes of oxygen in ice cores) which change in measurable ways as climate changes. The lesson from these data is that global surface temperatures over the last several decades are clearly unusual, in that they were higher than at any time during at least the past 400 years.[47] For the Northern Hemisphere, the recent temperature rise is clearly unusual in at least the last 1,000 years.[47,48]

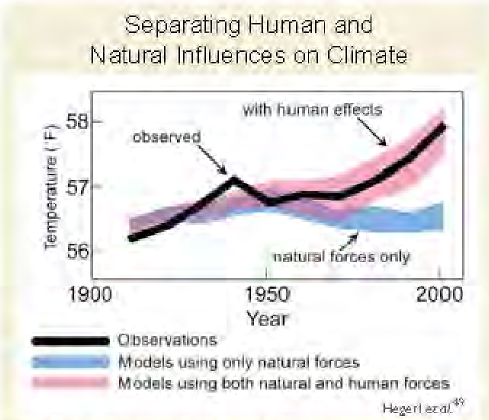


The third line of evidence is based on the broad, qualitative consistency between observed changes in climate and the computer model simulations of how climate would be expected to change in response to human activities. For example, when climate models are run with historical increases in greenhouse gases, they show gradual warming of the Earth and ocean surface, increases in ocean heat content and the temperature of the lower atmosphere, a rise in global sea level, retreat of sea ice and snow cover, cooling of the stratosphere, an increase in the amount of atmospheric water vapor, and changes in large-scale precipitation and pressure patterns. These and other aspects of modeled climate change are in agreement with observations.[14,49]

Finally, there is extensive statistical evidence from so-called "fingerprint" studies. Each factor that affects climate produces a unique pattern of climate response, much as each person has a unique fingerprint. Fingerprint studies exploit these unique signatures, and allow detailed comparisons of modeled and observed climate change patterns.[44] Scientists rely on such studies to attribute observed changes in climate to a particular cause or set of causes. In the real world, the climate changes that have occurred since the start of the Industrial Revolution are due to a complex mixture of human and natural causes. The importance of each individual influence in this mixture changes over time. Of course, there are not multiple Earths, which would allow an experimenter to change one factor at a time on each Earth, thus helping to isolate different fingerprints. Therefore, climate models are used to study how individual factors affect climate. For example, a single factor (like greenhouse gases) or a set of factors can be varied, and the response of the modeled climate system to these individual or combined changes can thus be studied.[50]

For example, when climate model simulations of the last century include all of the major influences on climate, both human-induced and natural, they can reproduce many important features of observed climate change patterns. When human influences are removed from the model experiments, results suggest that the surface of the Earth would actually have cooled slightly over the last 50 years. The clear message from fingerprint studies is that the





The blue band shows how global average temperatures would have changed due to natural forces only, as simulated by climate models. The red band shows model projections of the effects of human and natural forces combined. The black line shows actual observed global average temperatures. As the blue band indicates, without human influences, temperature over the past century would actually have first warmed and then cooled slightly over recent decades.[38]

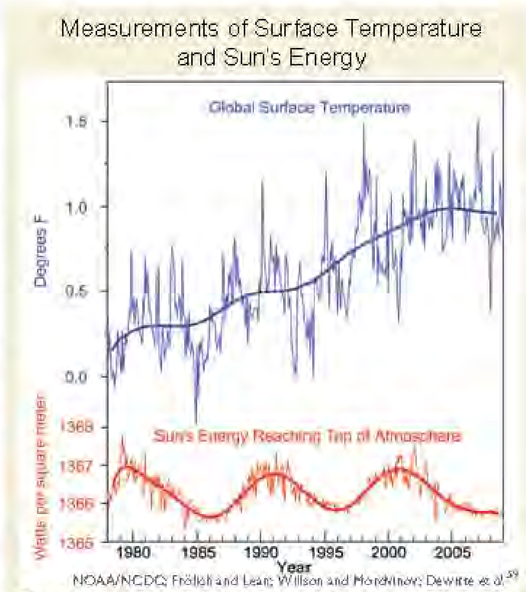
observed warming over the last half-century cannot be explained by natural factors, and is instead caused primarily by human factors.[14,50]

Another fingerprint of human effects on climate has been identified by looking at a slice through the layers of the atmosphere, and studying the pattern of temperature changes from the surface up through the stratosphere. In all climate models, increases in carbon dioxide cause warming at the surface and in the troposphere, but lead to cooling of the stratosphere. For straightforward physical reasons, models also calculate that the human-caused depletion of stratospheric ozone has had a strong cooling effect in the stratosphere. There is a good match between the model fingerprint in response to combined carbon dioxide and ozone changes and the observed pattern of tropospheric warming and stratospheric cooling (see figure on next page).[14]

In contrast, if most of the observed temperature change had been due to an increase in solar output rather than an increase in greenhouse gases, Earth's atmosphere would have warmed throughout its full vertical extent, including the stratosphere.[9] The observed pattern of atmospheric temperature changes, with its pronounced cooling in the stratosphere, is therefore inconsistent with the hypothesis that changes in the Sun can explain the warming of recent decades. Moreover, direct satellite measurements of solar output show slight decreases during the recent period of warming.

The earliest fingerprint work[51] focused on changes in surface and atmospheric temperature. Scientists then applied fingerprint methods to a whole range of climate variables,[50,52] identifying human-caused climate signals in the heat content of the oceans,[38,39] the height of the tropopause[53] (the boundary between the troposphere and stratosphere, which has shifted upward by hundreds of feet in recent decades), the geographical patterns of precipitation,[54] drought,[55] surface pressure,[56] and the runoff from major river basins.[57]

Studies published after the appearance of the IPCC Fourth Assessment Report in 2007 have also found human fingerprints in the increased levels of atmospheric moisture[35,36] (both close to the surface and over the full extent of the atmosphere), in the



The Sun's energy received at the top of Earth's atmosphere has been measured by satellites since 1978. It has followed its natural 11-year cycle of small ups and downs, but with no net increase (bottom). Over the same period, global temperature has risen markedly (top).[40]

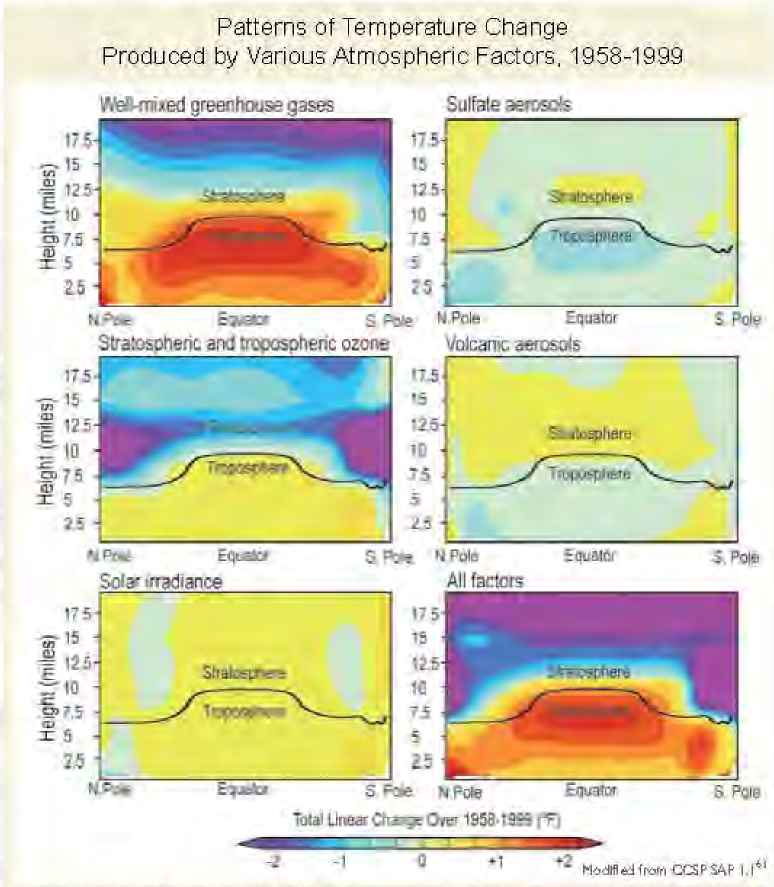
decline of Arctic sea ice extent,[61] and in the patterns of changes in Arctic and Antarctic surface temperatures.[62]

The message from this entire body of work is that the climate system is telling a consistent story of increasingly dominant human influence – the changes in temperature, ice extent, moisture, and circulation patterns fit together in a physically consistent way, like pieces in a complex puzzle.

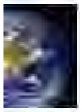
Increasingly, this type of fingerprint work is shifting its emphasis. As noted, clear and compelling scientific evidence supports the case for a pronounced human influence on global climate. Much of the recent attention is now on climate changes at continental and regional scales,[64,65] and on variables that can have large impacts on societies. For example, scientists have established causal links between human activities and the changes in snowpack, maximum and minimum temperature, and the seasonal timing of runoff over mountainous regions of the western United States.[34] Human activity is likely to have made a substantial contribution to ocean surface temperature changes in hurricane formation regions.[66-68] Researchers are also looking beyond the physical climate system, and are beginning to tie changes in the distribution and seasonal behavior of plant and animal species to human-caused changes in temperature and precipitation.[69,70]

For over a decade, one aspect of the climate change story seemed to show a significant difference between models and observations.[14]

In the tropics, all models predicted that with a rise in greenhouse gases, the troposphere would be expected to warm more rapidly than the surface. Observations from weather balloons, satellites, and surface thermometers seemed to show the opposite behavior (more rapid warming of the surface than the troposphere). This issue was a stumbling block in our understanding of the causes of climate change. It is now largely resolved.[71] Research showed that there were large uncertainties in the satellite and weather balloon data. When uncertainties in models and observations are properly accounted for, newer observational data sets (with better treatment of known problems) are in agreement with climate model results.[31,72-75]



Climate simulations of the vertical profile of temperature change due to various factors, and the effect due to all factors taken together. The panels above represent a cross-section of the atmosphere from the north pole to the south pole, and from the surface up into the stratosphere. The black lines show the location of the tropopause, the boundary between the lower atmosphere (troposphere) and the stratosphere.



This does not mean, however, that all remaining differences between models and observations have been resolved. The observed changes in some climate variables, such as Arctic sea ice,[61,76] some aspects of precipitation,[54,77] and patterns of surface pressure,[56] appear to be proceeding much more rapidly than models have projected. The reasons for these differences are not well understood. Nevertheless, the bottom-line conclusion from climate fingerprinting is that most of the observed changes studied to date are consistent with each other, and are also consistent with our scientific understanding of how the climate system would be expected to respond to the increase in heat-trapping gases resulting from human activities.[14,49]

Scientists are sometimes asked whether extreme weather events can be linked to human activities.[24] Scientific research has concluded that human influences on climate are indeed changing the likelihood of certain types of extreme events. For example, an analysis of the European summer heat wave of 2003 found that the risk of such a heat wave is now roughly four times greater than it would have been in the absence of human-induced climate change.[68,78]

Like fingerprint work, such analyses of human-caused changes in the risks of extreme events rely on information from climate models, and on our understanding of the physics of the climate system. All of the models used in this work have imperfections in their representation of the complexities of the "real world" climate system.[79,80] These are due to both limits in our understanding of the climate system, and in our ability to represent its complex behavior with available computer resources. Despite this, models are extremely useful, for a number of reasons.

First, despite remaining imperfections, the current generation of climate models accurately portrays many important aspects of today's weather patterns and climate.[79,80] Models are constantly being improved, and are routinely tested against many observations of Earth's climate system. Second, the fingerprint work shows that models capture not only our present-day climate, but also key features of the observed climate changes over the past century.[47] Third, many of the large-scale observed climate changes (such as the warming of the surface and troposphere, and the increase in the amount of moisture in the atmosphere) are driven by very basic physics, which is well-represented in models.[35] Fourth, climate models can be used to predict changes in climate that can be verified in the real world. Examples include the short-term global cooling subsequent to the eruption of Mount Pinatubo and the stratospheric cooling with increasing carbon dioxide. Finally, models are the only tools that exist for trying to understand the climate changes likely to be experienced over the course of this century. No period in Earth's geological history provides an exact analogue for the climate conditions that will unfold in the coming decades.[20]

Global temperatures are projected to continue to rise over this century; by how much and for how long depends on a number of factors, including the amount of heat-trapping gas emissions and how sensitive the climate is to those emissions.

Some continued warming of the planet is projected over the next few decades due to past emissions. Choices made now will influence the amount of future warming. Lower levels of heat-trapping emissions will yield less future warming, while higher levels will result in more warming, and more severe impacts on society and the natural world.

Emissions scenarios

The IPCC developed a set of scenarios in a Special Report on Emissions Scenarios (SRES).[81] These have been extensively used to explore the potential for future climate change. None of these scenarios, not even the one called "lower", includes implementation of policies to limit climate change or to stabilize atmospheric concentrations of heat-trapping gases. Rather, differences among these scenarios are due to different assumptions about changes in population, rate of adoption of new technologies, economic growth, and other factors.

The IPCC emission scenarios also do not encompass the full range of possible futures: emissions can change less than those scenarios imply, or they can change more. Recent carbon dioxide emissions are, in fact, above the highest emissions scenario developed by the IPCC[82] (see figure below). Whether this will continue is uncertain.

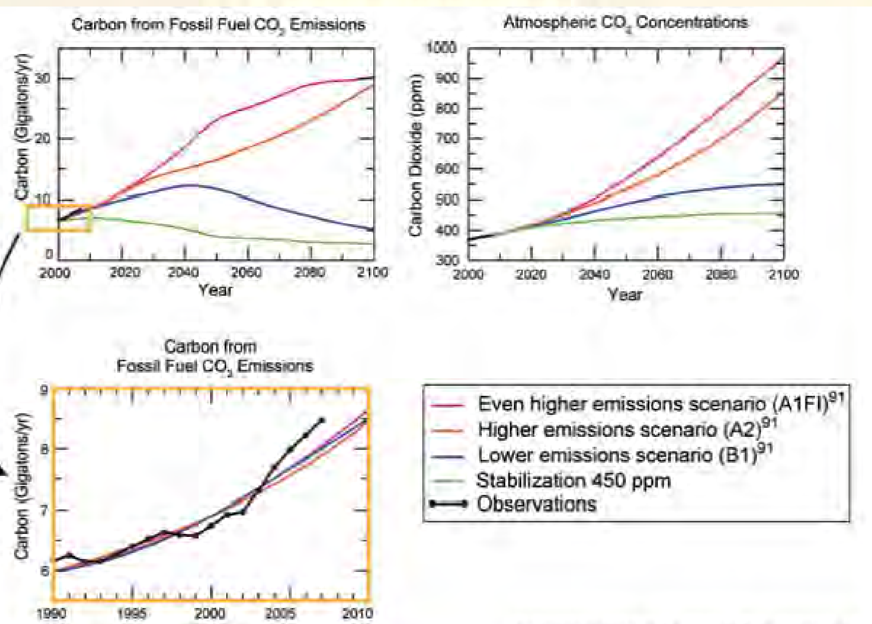
There are also lower possible emissions paths than those put forth by the IPCC. The Framework Convention on Climate Change, to which the United States and 191 other countries are signatories, calls for stabilizing concentrations of greenhouse gases in the atmosphere at a level that would avoid dangerous human interference with the climate system. What exactly constitutes such interference is subject to interpretation.

A variety of research studies suggest that a further 2°F increase (relative to the 1980-1999 period) would lead to severe, widespread, and irreversible impacts.[83-85] To have a good chance (but not a guarantee) of avoiding temperatures above those levels, it has been estimated that atmospheric concentration of carbon dioxide would need to stabilize in the long term at around today's levels.[86-89]

Reducing emissions of carbon dioxide would reduce warming over this century and beyond. Implementing sizable and sustained reductions in carbon dioxide emissions as soon as possible would significantly reduce the pace and the overall amount of climate change, and would be more effective than reductions of the same size initiated later. Reducing emissions of some shorter-lived greenhouse gases, such as methane, and some types of particles, such as soot, would begin to reduce the warming influence within weeks to decades.[13]

The graphs below show emissions scenarios and resulting carbon dioxide concentrations for three IPCC scenarios[90,91] and one stabilization scenario.[25]

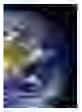
Scenarios of Future Carbon Dioxide
Global Emissions and Concentrations



Nakićenović and Swart; Clarke et al.; Marland et al.; Tans[92]

The graphs show recent and projected global emissions of carbon dioxide in gigatons of carbon, on the left, and atmospheric concentrations on the right under five emissions scenarios. The top three in the key are IPCC scenarios that assume no explicit climate policies (these are used in model projections that appear throughout this report). The bottom line is a "stabilization scenario," designed to stabilize atmospheric carbon dioxide concentration at 450 parts per million. The inset expanded below these charts shows emissions for 1990-2010 under the three IPCC scenarios along with actual emissions to 2007 (in black).

23



The stabilization scenario is aimed at stabilizing the atmospheric carbon dioxide concentration at roughly 450 parts per million (ppm); this is 70 ppm above the 2008 concentration of 385 ppm. Resulting temperature changes depend on atmospheric concentrations of greenhouse gases and particles and the climate's sensitivity to those concentrations.[87] Of those shown on the previous page, only the 450 ppm stabilization target has the potential to keep the global temperature rise at or below about 3.5°F from pre-industrial levels and 2°F above the current average temperature, a level beyond which many concerns have been raised about dangerous human interference with the climate system.[88,89] Scenarios that stabilize carbon dioxide below 450 ppm (not shown in the figure) offer an increased chance of avoiding dangerous climate change.[88,89]

Carbon dioxide is not the only greenhouse gas of concern. Concentrations of other heat-trapping gases like methane and nitrous oxide and particles like soot will also have to be stabilized at low enough levels to prevent global temperatures from rising higher than the level mentioned above. When these other gases are added, including the offsetting cooling effects of sulfate aerosol particles, analyses suggest that stabilizing concentrations around 400 parts per million of "equivalent carbon dioxide" would yield about an 80 percent chance of avoiding exceeding the 2°F above present temperature threshold. This would be true even if concentrations temporarily peaked as high as 475 parts per million and then stabilized at 400 parts per million roughly a century later.[72,88,89,93-95] Reductions in sulfate aerosol particles would necessitate lower equivalent carbon dioxide targets.

Rising global temperature

All climate models project that human-caused emissions of heat-trapping gases will cause further warming in the future. Based on scenarios that do not assume explicit climate policies to reduce greenhouse gas emissions, global average temperature is projected to rise by 2 to 11.5°F by the end of this century[90] (relative to the 1980-1999 time period). Whether the actual warming in 2100 will be closer to the low or the high end of this range depends primarily on two factors: first, the future level of emissions of heat-trapping gases, and second, how sensitive climate is to past and future emissions. The range of possible outcomes has been explored using a range of different emissions scenarios, and a variety of climate models that encompass the known range of climate sensitivity.

Changing precipitation patterns

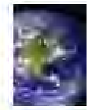
Projections of changes in precipitation largely follow recently observed patterns of change, with overall increases in the global average but substantial shifts in where and how precipitation falls.[90] Generally, higher latitudes are projected to receive more precipitation, while the dry belt that lies just outside the tropics expands further poleward,[96,97] and also receives less rain. Increases in tropical precipitation are projected during rainy seasons (such as monsoons), and especially over the tropical Pacific. Certain regions, including the U.S. West (especially the Southwest) and the Mediterranean, are expected to become drier. The widespread trend toward more heavy downpours is expected to continue, with precipitation becoming less frequent but more intense.[90] More precipitation is expected to fall as rain rather than snow.

Currently rare extreme events are becoming more common

In a warmer future climate, models project there will be an increased risk of more intense, more frequent, and longer-lasting heat waves.[90] The European heat wave of 2003 is an example of the type of extreme heat event that is likely to become much more common.[90] If greenhouse gas emissions continue to increase, by the 2040s more than half of European summers will be hotter than the summer of 2003, and by the end of this century, a summer as hot as that of 2003 will be considered unusually cool.[78]

Increased extremes of summer dryness and winter wetness are projected for much of the globe, meaning a generally greater risk of droughts and floods. This has already been observed,[55] and is projected to continue. In a warmer world, precipitation tends to be concentrated into heavier events, with longer dry periods in between.[90]

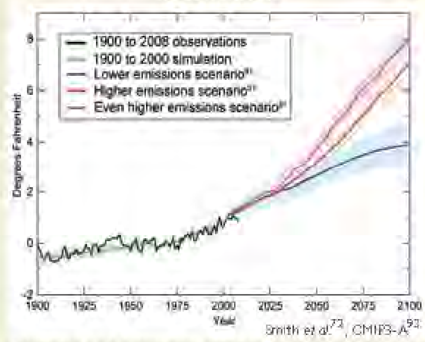
Models project a general tendency for more intense but fewer storms overall outside the tropics, with more extreme wind events and higher ocean waves in a number of regions in association with those



storms. Models also project a shift of storm tracks toward the poles in both hemispheres.[90]

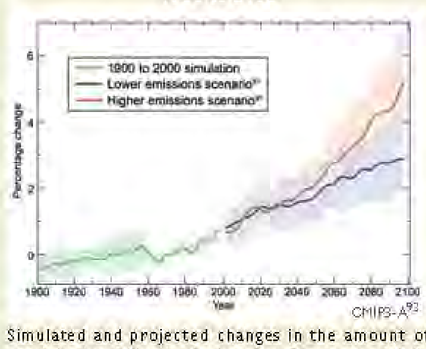
Changes in hurricanes are difficult to project because there are countervailing forces. Higher ocean temperatures lead to stronger storms with higher wind speeds and more rainfall.[98] But changes in wind speed and direction with height are also projected to increase in some regions, and this tends to work against storm formation and growth.[99-101] It currently appears that stronger, more rain-producing tropical storms and hurricanes are generally

Global Average Temperature
1900 to 2100



Observed and projected changes in the global average temperature under three IPCC no-policy emissions scenarios. The shaded areas show the likely ranges while the lines show the central projections from a set of climate models. A wider range of model types shows outcomes from 2 to 11.5°F.[90] Changes are relative to the 1960-1979 average.

Global Increase in Heavy Precipitation
1900 to 2100



Simulated and projected changes in the amount of precipitation falling in the heaviest 5 percent of daily events. The shaded areas show the likely ranges while the lines show the central projections from a set of climate models. Changes are relative to the 1960-1979 average.

more likely, though more research is required on these issues.[68] More discussion of Atlantic hurricanes, which most affect the United States, appears on page 34 in the *National Climate Change* section.

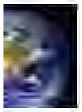
Sea level will continue to rise

Projecting future sea-level rise presents special challenges. Scientists have a well-developed understanding of the contributions of thermal expansion and melting glaciers to sea-level rise, so the models used to project sea-level rise include these processes. However, the contributions to past and future sea-level rise from ice sheets are less well understood. Recent observations of the polar ice sheets show that a number of complex processes control the movement of ice to the sea, and thus affect the contributions of ice sheets to sea-level rise.[29] Some of these processes are already producing substantial loss of ice mass. Because these processes are not well understood it is difficult to predict their future contributions to sea-level rise.[102]

Because of this uncertainty, the 2007 assessment by the IPCC could not quantify the contributions to sea-level rise due to changes in ice sheet dynamics, and thus projected a rise of the world's oceans from 8 inches to 2 feet by the end of this century.[90]

More recent research has attempted to quantify the potential contribution to sea-level rise from the accelerated flow of ice sheets to the sea[27,42] or to estimate future sea level based on its observed relationship to temperature.[103] The resulting estimates exceed those of the IPCC, and the average estimates under higher emissions scenarios are for sea-level rise between 3 and 4 feet by the end of this century. An important question that is often asked is, what is the upper bound of sea-level rise expected over this century? Few analyses have focused on this question. There is some evidence to suggest that it would be virtually impossible to have a rise of sea level higher than about 6.5 feet by the end of this century.[42]

The changes in sea level experienced at any particular location along the coast depend not only on the increase in the global average sea level, but also on changes in regional currents and winds, proximity to the mass of melting ice sheets, and on the vertical movements of the land due to geological



forces.[104] The consequences of sea-level rise at any particular location depend on the amount of sea-level rise relative to the adjoining land. Although some parts of the U.S. coast are undergoing uplift (rising), most shorelines are subsiding (sinking) to various degrees – from a few inches to over 2 feet per century.

Abrupt climate change

There is also the possibility of even larger changes in climate than current scenarios and models project. Not all changes in the climate are gradual. The long record of climate found in ice cores, tree rings, and other natural records show that Earth's climate patterns have undergone rapid shifts from one stable state to another within as short a period as a decade. The occurrence of abrupt changes in climate becomes increasingly likely as the human disturbance of the climate system grows.[90] Such changes can occur so rapidly that they would challenge the ability of human and natural systems to adapt.[105] Examples of such changes are abrupt shifts in drought frequency and duration. Ancient climate records suggest that in the United States, the Southwest may be at greatest risk for this kind of change, but that other regions including the Midwest and Great Plains have also had these kinds of abrupt shifts in the past and could experience them again in the future.

Rapid ice sheet collapse with related sea-level rise is another type of abrupt change that is not well understood or modeled and that poses a risk for the future. Recent observations show that melting on the surface of an ice sheet produces water that flows down through large cracks that create conduits through the ice to the base of the ice sheet where it lubricates ice previously frozen to the rock below.[20] Further, the interaction with warm ocean water, where ice meets the sea, can lead to sudden losses in ice mass and accompanying rapid global sea-level rise. Observations indicate that ice loss has increased dramatically over the last decade, though scientists are not yet confident that they can project how the ice sheets will respond in the future.

There are also concerns regarding the potential for abrupt release of methane from thawing of frozen soils, from the sea floor, and from wetlands in the tropics and the Arctic. While analyses suggest that an abrupt release of methane is very unlikely to occur within 100 years, it is very likely that warming will accelerate the pace of chronic methane emissions from these sources, potentially increasing the rate of global temperature rise.[106]

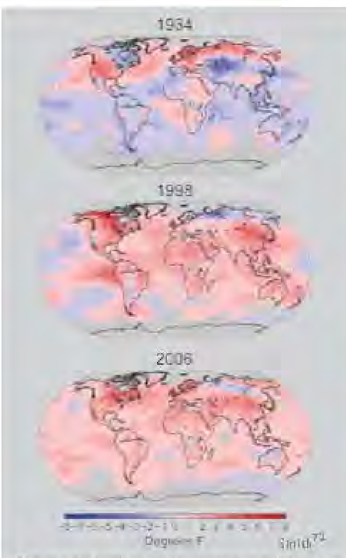
A third major area of concern regarding possible abrupt change involves the operation of the ocean currents that transport vast quantities of heat around the globe. One branch of the ocean circulation is in the North Atlantic. In this region, warm water flows northward from the tropics to the North Atlantic in the upper layer of the ocean, while cold water flows back from the North Atlantic to the tropics in the ocean's deep layers, creating a "conveyor belt" for heat. Changes in this circulation have profound impacts on the global climate system, from changes in African and Indian monsoon rainfall, to atmospheric circulation relevant to hurricanes, to changes in climate over North America and Western Europe.

Recent findings indicate that it is very likely that the strength of this North Atlantic circulation will decrease over the course of this century in response to increasing greenhouse gases. This is expected because warming increases the melting of glaciers and ice sheets and the resulting runoff of freshwater to the sea. This additional water is virtually salt-free, which makes it less dense than sea water. Increased precipitation also contributes fresh, less-dense water to the ocean. As a result, less surface water is dense enough to sink, thereby reducing the conveyor belt's transport of heat. The best estimate is that the strength of this circulation will decrease 25 to 30 percent in this century, leading to a reduction in heat transfer to the North Atlantic. It is considered very unlikely that this circulation would collapse entirely during the next 100 years or so, though it cannot be ruled out. While very unlikely, the potential consequences of such an abrupt event would be severe. Impacts would likely include sea-level rise around the North Atlantic of up to 2.5 feet (in addition to the rise expected from thermal expansion and melting glaciers and ice sheets), changes in atmospheric circulation conditions that influence hurricane activity, a southward shift of tropical rainfall belts with resulting agricultural impacts, and disruptions to marine ecosystems.[76]

National Climate Change

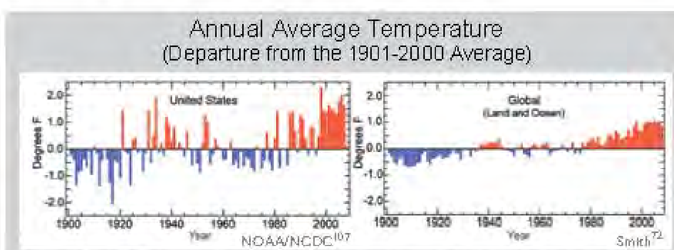
Key Messages:

- U.S. average temperature has risen more than 2°F over the past 50 years and is projected to rise more in the future; how much more depends primarily on the amount of heat-trapping gases emitted globally and how sensitive the climate is to those emissions.
- Precipitation has increased an average of about 5 percent over the past 50 years. Projections of future precipitation generally indicate that northern areas will become wetter, and southern areas, particularly in the West, will become drier.
- The amount of rain falling in the heaviest downpours has increased approximately 20 percent on average in the past century, and this trend is very likely to continue, with the largest increases in the wettest places.
- Many types of extreme weather events, such as heat waves and regional droughts, have become more frequent and intense during the past 40 to 50 years.
- The destructive energy of Atlantic hurricanes has increased in recent decades. The intensity of these storms is likely to increase in this century.
- In the eastern Pacific, the strongest hurricanes have become stronger since the 1980s, even while the total number of storms has decreased.
- Sea level has risen along most of the U.S. coast over the last 50 years, and will rise more in the future.
- Cold-season storm tracks are shifting northward and the strongest storms are likely to become stronger and more frequent.
- Arctic sea ice is declining rapidly and this is very likely to continue.

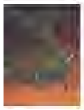


The maps show annual temperature difference from the 1961-1990 average for the 3 years that were the hottest on record in the United States: 1998, 1934 and 2006 (in rank order). Red areas were warmer than average, blue were cooler than average. The 1930s were very warm in much of the United States, but they were not unusually warm globally. On the other hand, the warmth of 1998 and 2006, as for most years in recent decades, has been global in extent.

Like the rest of the world, the United States has been warming significantly over the past 50 years in response to the build up of heat-trapping gases in the atmosphere. When looking at national climate, however, it is important to recognize that climate responds to local, regional, and global factors. Therefore, national climate varies more than the average global climate. While various parts of the world have had particularly hot or cold periods earlier in the historical record, these periods have not been global in scale, whereas the warming of recent decades has been global in scale – hence the term *global* warming. It is also important to recognize that at both the global and national scales, year-to-year fluctuations in natural weather and climate patterns can produce a period that does not follow the long-term trend. Thus, each year will not necessarily be warmer than every year before it, though the warming trend continues.



From 1901 to 2008, each year's temperature departure from the long-term average is one bar, with blue bars representing years cooler than the long-term average and red bars representing years warmer than that average. National temperatures vary much more than global temperatures, in part because of the moderating influence of the oceans on global temperatures.



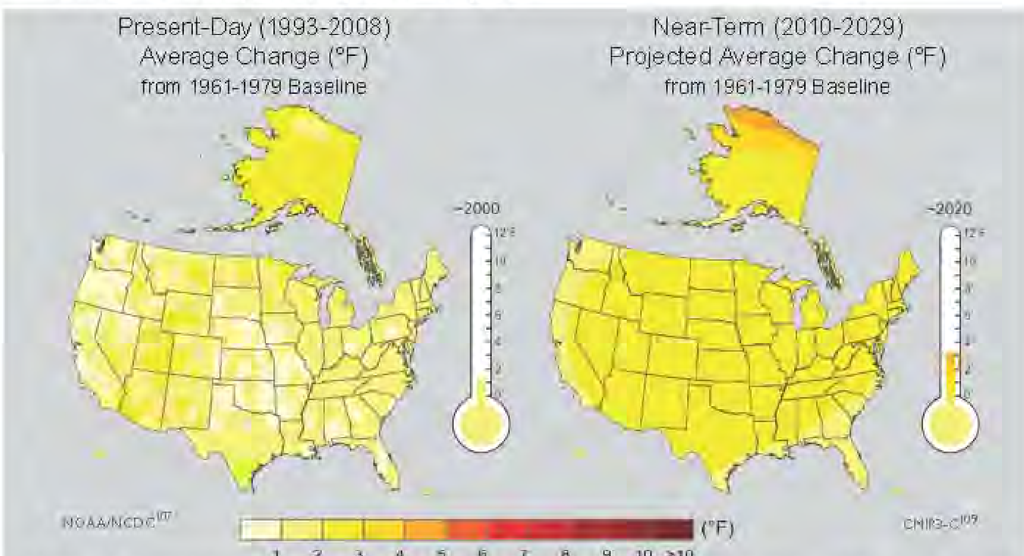
U.S. average temperature has risen more than 2°F over the past 50 years and is projected to rise more in the future; how much more depends primarily on the amount of heat-trapping gases emitted globally and how sensitive the climate is to those emissions.

The series of maps and thermometers on these two pages shows the magnitude of the observed and projected changes in annual average temperature. The map for the period around 2000 shows that most areas of the United States have warmed 1 to 2°F compared to the 1960s and 1970s. Although not reflected in these maps of annual average temperature, this warming has generally resulted in longer warm seasons and shorter, less intense cold seasons.

The remaining maps show projected warming over the course of this century under a lower emissions scenario and a higher emissions scenario[91] (see *Global Climate Change* section, page 23). Temperatures will continue to rise throughout the century under both emissions scenarios,[91] although higher emissions result in more warming by the middle of the century and significantly more by the end of the century.

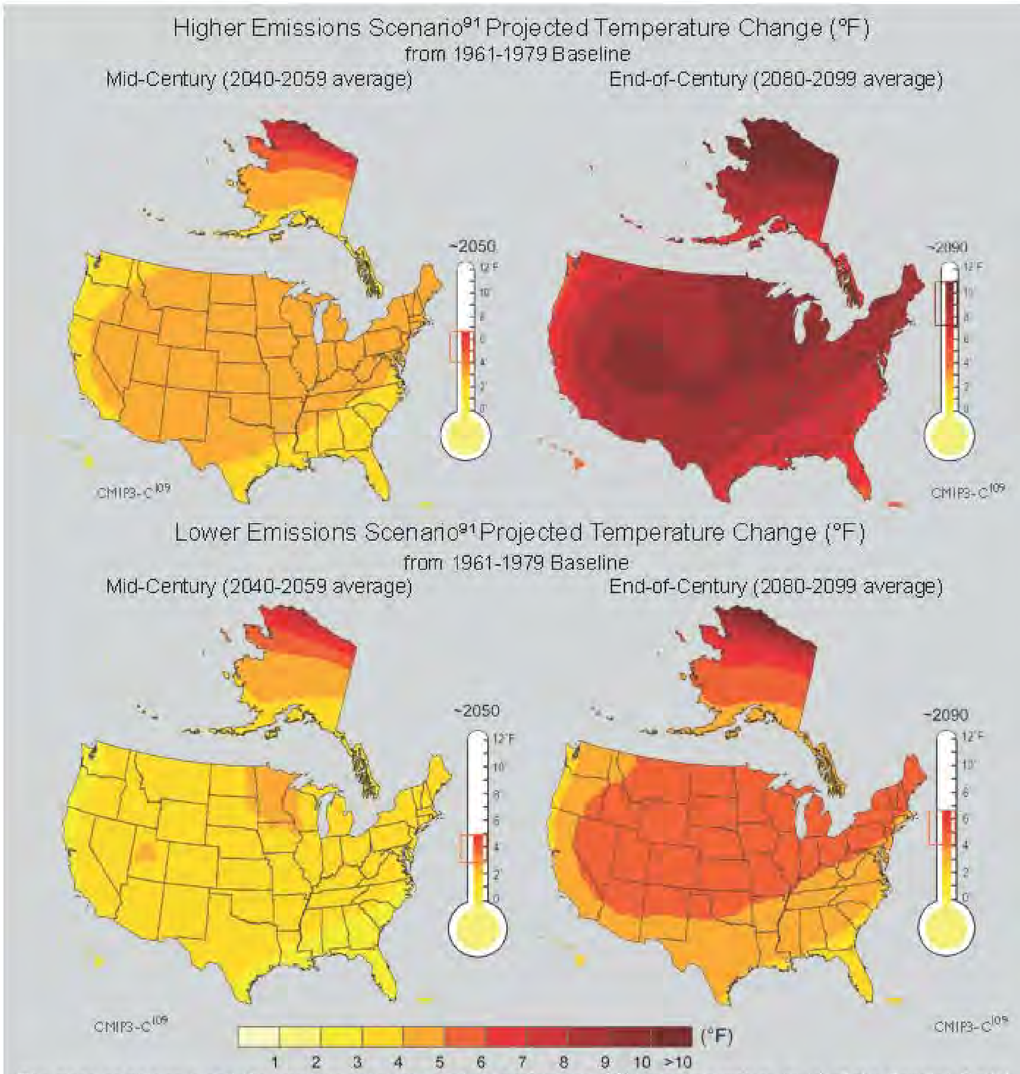
Temperature increases in the next couple of decades will be primarily determined by past emissions of heat-trapping gases. As a result, there is little difference in projected temperature between the higher and lower emissions scenarios[91] in the near-term (around 2020), so only a single map is shown for this timeframe. Increases after the next couple of decades will be primarily determined by future emissions.[90] This is clearly evident in greater projected warming in the higher emissions scenario[91] by the middle (around 2050) and end of this century (around 2090).

On a seasonal basis, most of the United States is projected to experience greater warming in summer than in winter, while Alaska experiences far more warming in winter than summer.[108]



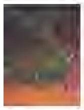
The maps and thermometers on this page and the next page show temperature differences (either measured or projected) from conditions as they existed during the period from 1961-1979. Comparisons to this period are made because the influence on climate from increasing greenhouse gas emissions has been greatest during the past five decades. The present-day map is based on the average observed temperatures from 1993-2008 minus the average from 1961-1979. Projected temperatures are based on results from 16 climate models for the periods 2010-2029, 2040-2059, and 2080-2099. The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible. The mid-century and end-of-century maps show projections for both the higher and lower emission scenarios.[91] The projection for the near-term is the average of the higher and lower emission scenarios[91] because there is little difference in that timeframe.

The average warming for the country as a whole is shown on the thermometers adjacent to each map. By the end of the century, the average U.S. temperature is projected to increase by approximately 7 to 11°F under the higher emissions scenario[91] and by approximately 4 to 6.5°F under the lower emissions scenario.[91] These ranges are due to differences among climate model results for the same emissions scenarios. Emissions scenarios even lower than the lower scenario shown here, such as the 450 ppm stabilization scenario described on pages 23-24, would yield lower temperature increases than those shown below.[25]



The maps on this page and the previous page are based on projections of future temperature by 16 of the Coupled Model Intercomparison Project Three (CMIP3) climate models using two emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC), *Special Report on Emission Scenarios* (SRES).[91] The "lower" scenario here is B1, while the "higher" is A2.[91] The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible. Additional information on these scenarios is on pages 22 and 23 in the previous section, *Global Climate Change*. These maps, and others in this report, show projections at national, regional, and sub-regional scales, using well-established techniques.[110]

29



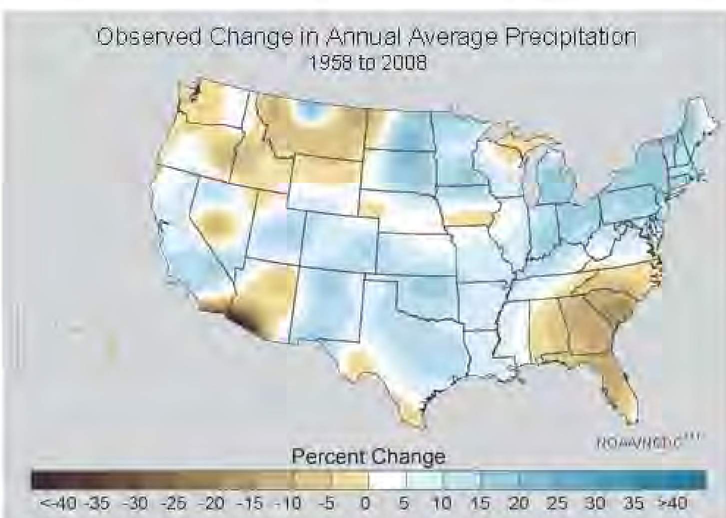
Precipitation has increased an average of about 5 percent over the past 50 years. Projections of future precipitation generally indicate that northern areas will become wetter, and southern areas, particularly in the West, will become drier.

While precipitation over the United States as a whole has increased, there have been important regional and seasonal differences. Increasing trends throughout much of the year have been predominant in the Northeast and large parts of the Plains and Midwest. Decreases occurred in much of the Southeast in all but the fall season and in the Northwest in all seasons except spring. Precipitation also generally decreased during the summer and fall in the Southwest, while winter and spring, which are the wettest seasons in states such as California and Nevada, have had increases in precipitation.[111]

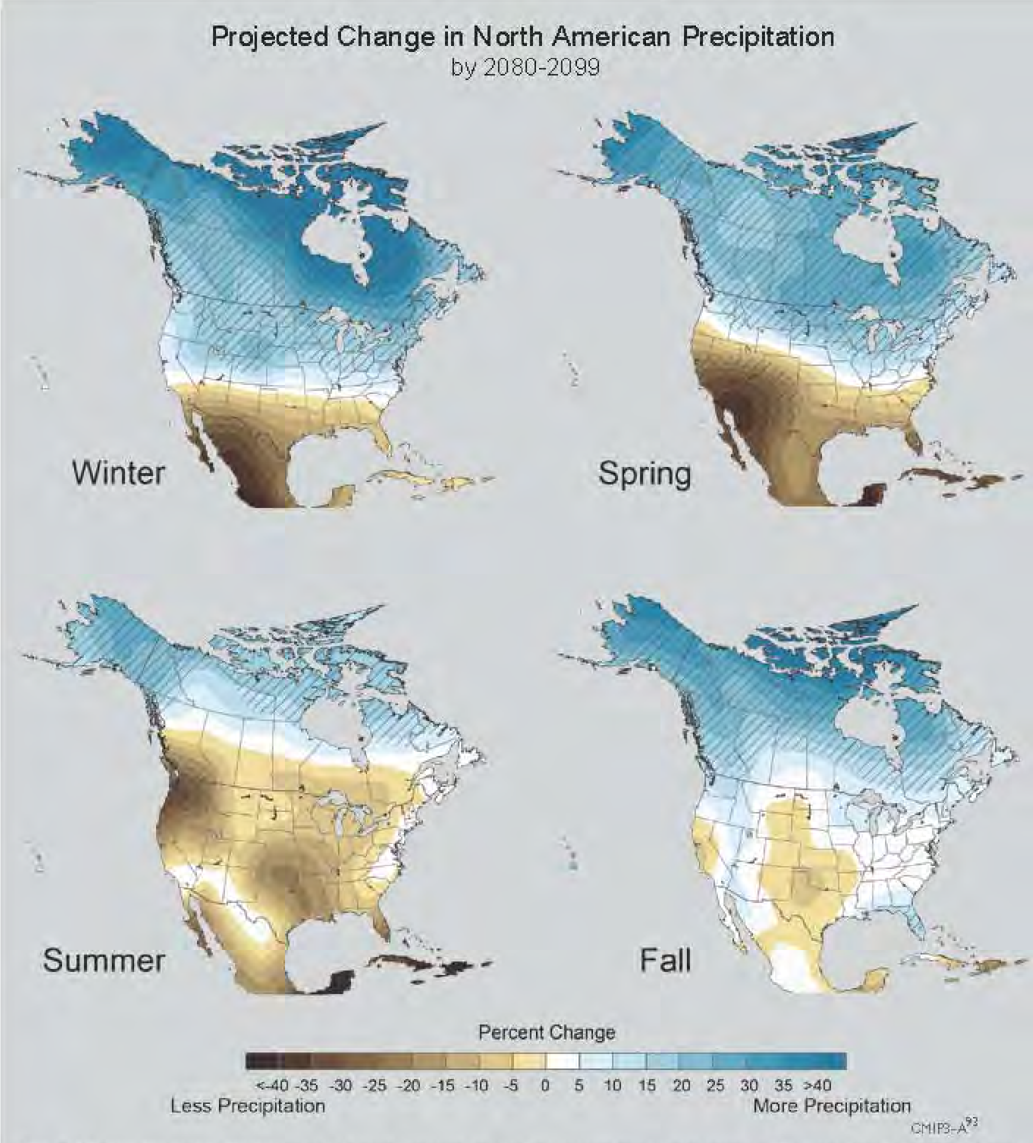
Future changes in total precipitation due to human-induced warming are more difficult to project than changes in temperature. In some seasons, some areas will experience an increase in precipitation, other areas will experience a decrease, and others will see little discernible change. The difficulty arises in predicting the extent of those areas and the amount of change. Model projections of future precipitation generally indicate that northern areas will become wetter, and southern areas, particularly in the West, will become drier.[97,108]

Confidence in projected changes is higher for winter and spring than for summer and fall. In winter and spring, northern areas are expected to receive significantly more precipitation than they do now, because the interaction of warm and moist air coming from the south with colder air from the north is projected to occur farther north than it did on average in the last century. The more northward incursions of warmer and moister air masses are expected to be particularly noticeable in northern regions that will change from very cold and dry atmospheric conditions to warmer but moister conditions.[68] Alaska, the Great Plains, the upper Midwest, and the Northeast are beginning to experience such changes for at least part of the year, with the likelihood of these changes increasing over time.

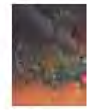
In some northern areas, warmer conditions will result in more precipitation falling as rain and less as snow. In addition, potential water resource benefits from increasing precipitation could be countered by the competing influences of increasing evaporation and runoff. In southern areas, significant reductions in precipitation are projected in winter and spring as the subtropical dry belt expands.[108] This is particularly pronounced in the Southwest, where it would have serious ramifications for water resources.



While U.S. annual average precipitation has increased about 5 percent over the past 50 years, there have been important regional differences as shown above.



The maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models. The simulations are for late this century, under a higher emissions scenario.[91] For example, in the spring, climate models agree that northern areas are likely to get wetter, and southern areas drier. There is less confidence in exactly where the transition between wetter and drier areas will occur. Confidence in the projected changes is highest in the hatched areas.



Increases in Amounts of Very Heavy Precipitation (1958 to 2007)

The map shows percent increases in the amount falling in very heavy precipitation events (defined as the heaviest 1 percent of all daily events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

The amount of rain falling in the heaviest downpours has increased approximately 20 percent on average in the past century, and this trend is very likely to continue, with the largest increases in the wettest places.

One of the clearest precipitation trends in the United States is the increasing frequency and intensity of heavy downpours. This increase was responsible for most of the observed increase in overall precipitation during the last 50 years. In fact, there has been little change or a decrease in the frequency of light and moderate precipitation during the past 30 years, while heavy precipitation has increased. In addition, while total average precipitation over the nation as a whole increased by about 7 percent over the past century, the amount of precipitation falling in the heaviest 1 percent of rain events increased nearly 20 percent.[112]

During the past 50 years, the greatest increases in heavy precipitation occurred in the Northeast and the Midwest. There have also been increases in heavy downpours in the other regions of the continental United States, as well as Alaska, Hawaii, and Puerto Rico.[112]

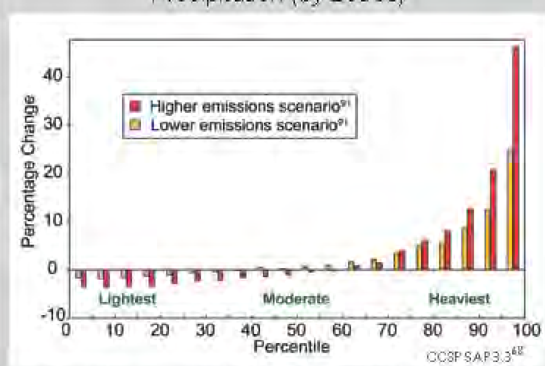
Climate models project continued increases in the heaviest downpours during this century, while the lightest precipitation is projected to decrease. Heavy downpours that are now 1-in-20-year occurrences are projected to occur about every 4 to 15 years by the end of this century, depending on location, and the intensity of heavy downpours is also expected to increase. The 1-in-20-year heavy downpour is expected to be between 10 and 25 percent heavier by the end of the century than it is now.[112]

Changes in these kinds of extreme weather and climate events are among the most serious challenges to our nation in coping with a changing climate.

Many types of extreme weather events, such as heat waves and regional droughts, have become more frequent and intense during the past 40 to 50 years.

Many extremes and their associated impacts are now changing. For example, in recent decades most of North America has been experiencing more unusually hot days and nights, fewer unusually cold days and nights, and fewer frost days. Droughts are becoming more severe in some regions. The power and frequency of Atlantic hurricanes have increased substantially in recent decades. The number of North American mainland landfalling hurricanes does

Projected Changes in Light, Moderate, and Heavy Precipitation (by 2090s)



The figure shows projected changes from the 1990s average to the 2090s average in the amount of precipitation falling in light, moderate, and heavy events in North America. Projected changes are displayed in 5 percent increments from the lightest drizzles to the heaviest downpours. As shown here, the lightest precipitation is projected to decrease, while the heaviest will increase, continuing the observed trend. The higher emission scenario[91] yields larger changes. Projections are based on the models used in the IPCC 2007 Fourth Assessment Report.

not appear to have increased over the past century. Outside the tropics, cold-season storm tracks are shifting northward and the strongest storms are becoming even stronger. These trends in storms outside the tropics are projected to continue throughout this century.[68,112,114]

Date of onset of spring runoff pulse. Reddish-brown circles indicate significant trends toward onsets more than 20 days earlier. Lighter circles indicate less advance of the onset. Blue circles indicate later onset. The changes depend on a number of factors in addition to temperature, including altitude and timing of snowfall.

Drought

Like precipitation, trends in drought have strong regional variations. In much of the Southeast and large parts of the West, the frequency of drought has increased coincident with rising temperatures over the past 50 years. In other regions, such as the Midwest and Great Plains, there has been a reduction in drought frequency.

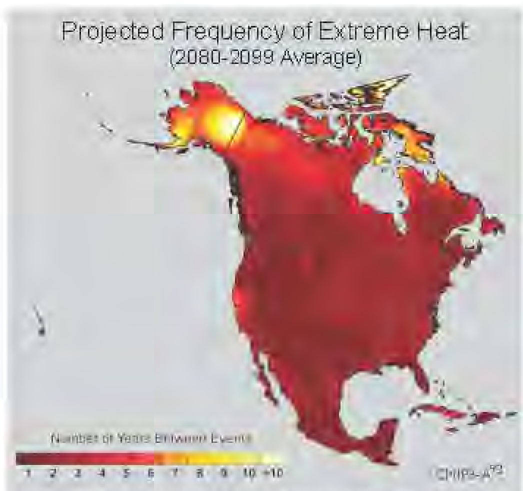
Although there has been an overall increase in precipitation and no clear trend in drought for the nation as a whole, increasing temperatures have made droughts more severe and widespread than they would have otherwise been. Without the observed increase in precipitation, higher temperatures would have led to an increase in the area of the contiguous United States in severe to extreme drought, with some estimates of a 30 percent increase.[112] In the future, droughts are likely to become more frequent and severe in some regions.[68] The Southwest, in particular, is expected to experience increasing drought as changes in atmospheric circulation patterns cause the dry zone just outside the tropics to expand farther northward into the United States.[97]

Rising temperatures have also led to earlier melting of the snowpack in the western United States.[40] Because snowpack runoff is critical to the water resources in the western United States, changes in the timing and amount of runoff can exacerbate problems with already limited water supplies in the region.

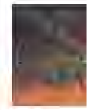
Heat waves

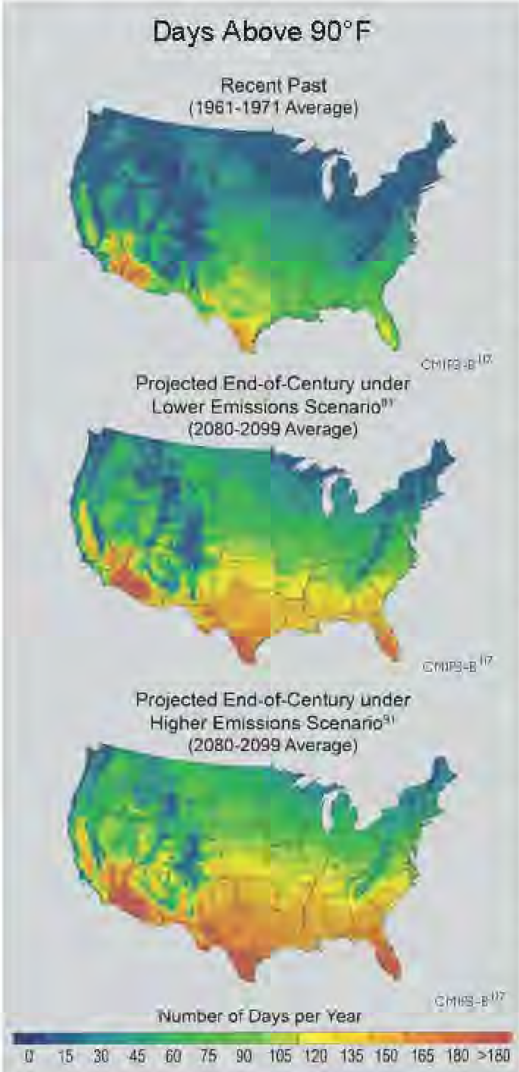
A heat wave is a period of several days to weeks of abnormally hot weather, often with high humidity. During the 1930s, there was a high frequency of heat waves due to high daytime temperatures resulting in large part from an extended multi-year period of intense drought. By contrast, in the past 3 to 4 decades, there has been an increasing trend in high-humidity heat waves, which are characterized by the persistence of extremely high nighttime temperatures.[112]

As average temperatures continue to rise throughout this century, the frequency of cold extremes will decrease and the frequency and intensity of high temperature extremes will increase.[115] The number of days with high temperatures above



Simulations for 2080-2099 indicate how currently rare extremes (a 1-in-20-year event) are projected to become more commonplace. A day so hot that it is currently experienced once every 20 years would occur every other year or more frequently by the end of the century under the higher emissions scenario.[91]





The average number of days per year when the maximum temperature exceeded 90°F from 1961-1979 (top) and the projected number of days per year above 90°F by the 2080s and 2090s for lower emissions (middle) and higher emissions (bottom).[91] Much of the southern United States is projected to have more than twice as many days per year above 90°F by the end of this century.

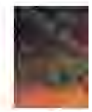
90°F is projected to increase throughout the country as illustrated in the maps on the left. Parts of the South that currently have about 60 days per year with temperatures over 90°F are projected to experience 150 or more days a year above 90°F by the end of this century, under a higher emissions scenario.[91] There is higher confidence in the regional patterns than in results for any specific location (see *An Agenda for Climate Impacts Science* section).

With rising high temperatures, extreme heat waves that are currently considered rare will occur more frequently in the future. Recent studies using an ensemble of models show that events that now occur once every 20 years are projected to occur about every other year in much of the country by the end of this century. In addition to occurring more frequently, at the end of this century these very hot days are projected to be about 10°F hotter than they are today.[68]

The destructive energy of Atlantic hurricanes has increased in recent decades. The intensity of these storms is likely to increase in this century.

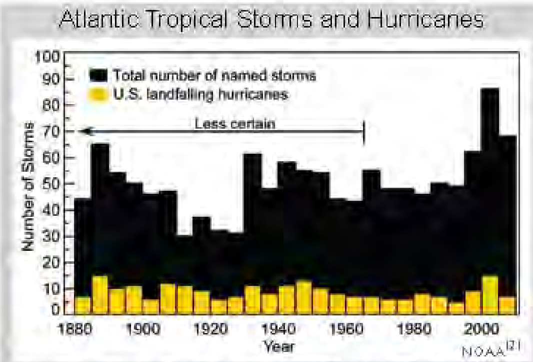
Of all the world's tropical storm and hurricane basins, the North Atlantic has been the most thoroughly monitored and studied. The advent of routine aircraft monitoring in the 1940s and the use of satellite observations since the 1960s have greatly aided monitoring of tropical storms and hurricanes. In addition, observations of tropical storm and hurricane strength made from island and mainland weather stations and from ships at sea began in the 1800s and continue today. Because of new and evolving observing techniques and technologies, scientists pay careful attention to ensuring consistency in tropical storm and hurricane records from the earliest manual observations to today's automated measurements. This is accomplished through collection, analysis, and cross-referencing of data from numerous sources and, where necessary, the application of adjustment techniques to account for differences in observing and reporting methodologies through time. Nevertheless, data uncertainty is larger in the early part of the record. Confidence in the tropical storm and hurricane record increases after 1900 and is greatest during the satellite era, from 1965 to the present.[112]

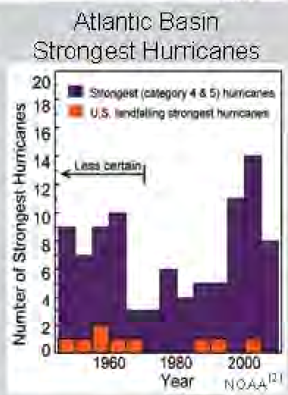
The total number of hurricanes and strongest hurricanes (Category 4 and 5) observed from 1881 through 2008 shows multi-decade periods of above average activity in the 1800s, the mid-1900s, and since 1995. The power and frequency of Atlantic hurricanes have increased substantially in recent decades.[112] There has been little change in the total number of landfalling hurricanes, in part because a variety of factors affect whether a hurricane will make landfall. These include large-scale steering winds, atmospheric stability, wind shear, and ocean heat content. This highlights the importance of understanding the broader changes occurring throughout the Atlantic Basin beyond the storms making landfall along the U.S. coast.[112]



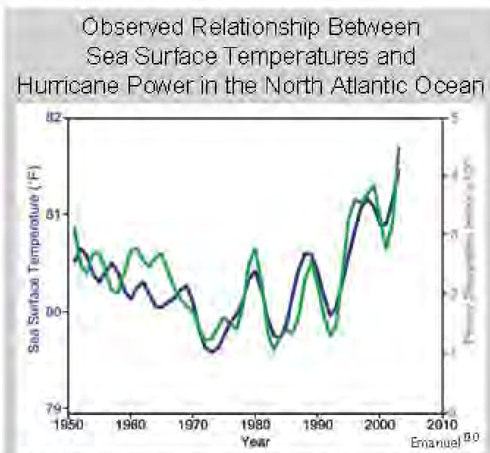
Tropical storms and hurricanes develop and gain strength over warm ocean waters. As oceans warm, they provide a source of energy for hurricane growth. During the past 30 years, annual sea surface temperatures in the main Atlantic hurricane development region increased nearly 2°F. This warming coincided with an increase in the destructive energy (as defined by the Power Dissipation Index, a combination of intensity, duration, and frequency) of Atlantic tropical storms and hurricanes. The strongest hurricanes (Category 4 and 5) have, in particular, increased in intensity.[112] The graph below shows the strong correlation between hurricane power and sea surface temperature in the Atlantic and the overall increase in both during the past 30 years. Climate models project that hurricane intensity will continue to increase, though at a lesser rate than that observed in recent decades.[100]

New evidence has emerged recently for other temperature related linkages that can help





Top: Total numbers of North Atlantic named storms (tropical storms and hurricanes) (black) and total U.S. landfalling hurricanes (yellow) in 5-year periods based on annual data from 1881 to 2008. The bar for the last 5-year period is based on the assumption that the level of activity from 2006 to 2008 persists through 2010. In the era before satellites, indicated by the arrow above, the total number of named storms is less certain and has been adjusted upward to account for missing storms. Adjustments are based on relationships established during the satellite era between the number of observed storms and the number that would have been missed if satellite data had not been available.
Bottom: Total number of strongest (Category 4 and 5) North Atlantic basin hurricanes (purple) and strongest U.S. landfalling hurricanes (orange) in 5-year periods based on annual data from 1946 to 2008. The bar for the last 5-year period is based on the assumption that the level of activity from 2006 to 2008 persists through 2010. From 1946 to the mid-1960s, as indicated by the arrow above, hurricane intensity was measured primarily by aircraft reconnaissance. Data prior to aircraft reconnaissance are not shown due to the greater uncertainty in estimates of a hurricane's maximum intensity. Satellites have increased the reliability of hurricane intensity estimates since the mid-1960s.



Observed sea surface temperature (blue) and the Power Dissipation Index (green), which combines frequency, intensity and duration for North Atlantic hurricanes.[130] Hurricane rainfall and wind speeds are likely to increase in response to human-caused warming. Analyses of model simulations suggest that for each 1.8°F increase in tropical sea surface temperatures, rainfall rates will increase by 6 to 18 percent.[82]

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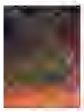
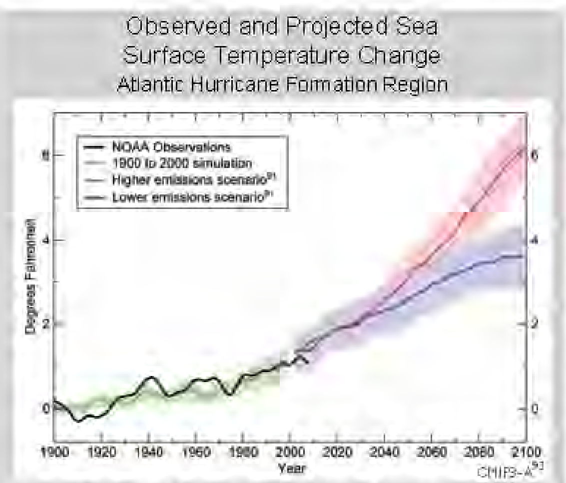


explain the increase in Atlantic hurricane activity. This includes the contrast in sea surface temperature between the main hurricane development region and the broader tropical ocean.[99,118,119] Other causes beyond the rise in ocean temperature, such as atmospheric stability and circulation, can also influence hurricane power. For these and other reasons, a confident assessment requires further study.[68]

Evidence of increasing hurricane strength in the Atlantic and other oceans with linkages to rising sea surface temperatures is also supported by satellite records dating back to 1981. An increase in the maximum wind speeds of the strongest hurricanes has been documented and linked to increasing sea surface temperatures.[122]

Projections are that sea surface temperatures in the main Atlantic hurricane development region will increase at even faster rates during the second half of this century under higher emissions scenarios. This highlights the need to better understand the relationship between increasing temperatures and hurricane intensity. As ocean temperatures continue to increase in the future, it is likely that hurricane rainfall and wind speeds will increase in response to human-caused warming.[68] Analyses



Observed (black) and projected temperatures (blue = lower scenario; red = higher scenario) in the Atlantic hurricane formation region. Increased intensity of hurricanes is linked to rising sea surface temperatures in the region of the ocean where hurricanes form. The shaded areas show the likely ranges while the lines show the central projections from a set of climate models.

of model simulations suggest that for each 1.8°F increase in tropical sea surface temperatures, core rainfall rates will increase by 6 to 18 percent and the surface wind speeds of the strongest hurricanes will increase by about 1 to 8 percent.[114] Even without further coastal development, storm surge levels and hurricane damages are likely to increase because of increasing hurricane intensity coupled with sea-level rise, the latter being a virtually certain outcome of the warming global climate.[68]

In the eastern Pacific, the strongest hurricanes have become stronger since the 1980s, even while the total number of storms has decreased.

Although on average more hurricanes form in the eastern Pacific than the Atlantic each year, cool ocean waters along the U.S. West Coast and atmospheric steering patterns help protect the contiguous U.S. from landfalls. Threats to the Hawaiian Islands are greater, but landfalling storms are rare in comparison to those of the U.S. East and Gulf Coasts. Nevertheless, changes in hurricane intensity and frequency could influence the impact of landfalling Pacific hurricanes in the future.

The total number of tropical storms and hurricanes in the eastern Pacific on seasonal to multi-decade time periods is generally opposite to that observed in the Atlantic. For example, during El Niño events it is common for hurricanes in the Atlantic to be suppressed while the eastern Pacific is more active. This reflects the large-scale atmospheric circulation patterns that extend across both the Atlantic and the Pacific oceans.[123,124]

Within the past three decades the total number of tropical storms and hurricanes and their destructive energy have decreased in the eastern Pacific.[68,124] However, satellite observations have shown that like the Atlantic, the strongest hurricanes (the top 5 percent), have gotten stronger since the early 1980s.[122,125] As ocean temperatures rise, the strongest hurricanes are likely to increase in both the eastern Pacific and the Atlantic.[68]

Sea level has risen along most of the U.S. coast over the past 50 years, and will rise more in the future.

Recent global sea-level rise has been caused by the warming-induced expansion of the oceans, accelerated melting of most of the world's glaciers, and loss of ice on the Greenland and Antarctic ice sheets.[37] There is strong evidence that global sea level is currently rising at an increased rate.[37,126] A warming global climate will cause further sea-level rise over this century and beyond.[90,105]

During the past 50 years, sea level has risen up to 8 inches or more along some coastal areas of the United States, and has fallen in other locations. The amount of relative sea-level rise experienced along different parts of the U.S. coast depends on the changes in elevation of the land that occur as a result of subsidence (sinking) or uplift (rising), as well as increases in global sea level due to warming. In addition, atmospheric and oceanic circulation, which will be affected by climate change, will influence regional sea level. Regional differences in sea-level rise are also expected to be related to where the meltwater originates.[104]

Human-induced sea-level rise is occurring globally. Large parts of the Atlantic Coast and Gulf of Mexico Coast have experienced significantly higher rates of relative sea-level rise than the global average during the last 50 years, with the local differences mainly due to land subsidence.[127] Portions of the Northwest and Alaska coast have, on the other hand, experienced slightly falling sea level as a result of long-term uplift as a consequence of glacier melting and other geological processes.

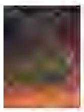
Regional variations in relative sea-level rise are expected in the future. For example, assuming historical geological forces continue, a 2-foot rise in global sea level (which is within the range of recent estimates) by the end of this century would result in a relative sea-level rise of 2.3 feet at New York City, 2.9 feet at Hampton Roads, Virginia, 3.5 feet at Galveston, Texas, and 1 foot at Neah Bay in Washington state.[128]

Relative Sea-Level Changes on U.S. Coastlines, 1958 to 2008

Observed changes in relative sea level from 1958 to 2008 for locations on the U.S. coast. Some areas along the Atlantic and Gulf coasts saw increases greater than 8 inches over the past 50 years.

37

Cold-season storm tracks are shifting northward and the strongest storms are likely to become stronger and more frequent.



Large-scale storm systems are the dominant weather phenomenon during the cold season in the United States. Although the analysis of these storms is complicated by a relatively short length of most observational records and by the highly variable nature of strong storms, some clear patterns have emerged.[112]

Storm tracks have shifted northward over the last 50 years as evidenced by a decrease in the frequency of storms in mid-latitude areas of the Northern Hemisphere, while high-latitude activity has increased. There is also evidence of an increase in the intensity of storms in both the mid- and high-latitude areas of the Northern Hemisphere, with greater confidence in the increases occurring in high latitudes.[112] The northward shift is projected to continue, and strong cold season storms are likely to become stronger and more frequent, with greater wind speeds and more extreme wave heights.[68]

Snowstorms

The northward shift in storm tracks is reflected in regional changes in the frequency of snowstorms. The South and lower Midwest saw reduced snowstorm frequency during the last century. In contrast, the Northeast and upper Midwest saw increases in snowstorms, although considerable decade-to-decade variations were present in all regions, influenced, for example, by the frequency of El Niño events.[112]

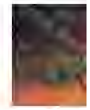
There is also evidence of an increase in lake-effect snowfall along and near the southern and eastern shores of the Great Lakes since 1950.[97] Lake-effect snow is produced by the strong flow of cold air across large areas of relatively warmer ice-free water. As the climate has warmed, ice coverage on the Great Lakes has fallen. The maximum seasonal coverage of Great Lakes ice decreased at a rate of 8.4 percent per decade from 1973 through 2008, amounting to a roughly 30 percent decrease in ice coverage (see *Midwest* region). This has created conditions conducive to greater evaporation of moisture and thus heavier snowstorms. Among recent extreme lake-effect snow events was a February 2007 10-day storm total of over 10 feet of snow in western New York state. Climate models suggest that lake-effect snowfalls are likely to increase over the next few decades.[130] In the longer term, lake-effect snows are likely to decrease as temperatures continue to rise, with the precipitation then falling as rain.[129]

Areas in New York state east of Lake Ontario received over 10 feet of lake-effect snow during a 10-day period in early February 2007.

Tornadoes and severe thunderstorms

Reports of severe weather including tornadoes and severe thunderstorms have increased during the past 50 years. However, the increase in the number of reports is widely believed to be due to improvements in monitoring technologies such as Doppler radars combined with changes in population and increasing public awareness. When adjusted to account for these factors, there is no clear trend in the frequency or strength of tornadoes since the 1950s for the United States as a whole.[112]

The distribution by intensity for the strongest 10 percent of hail and wind reports is little changed, providing no evidence of an observed increase in the severity of events.[112] Climate models project future increases in the frequency of environmental conditions favorable to severe thunderstorms.[131] But the inability to adequately model the small-scale conditions involved in thunderstorm development remains a limiting factor in projecting the future character of severe thunderstorms and other small-scale weather phenomena.[68]



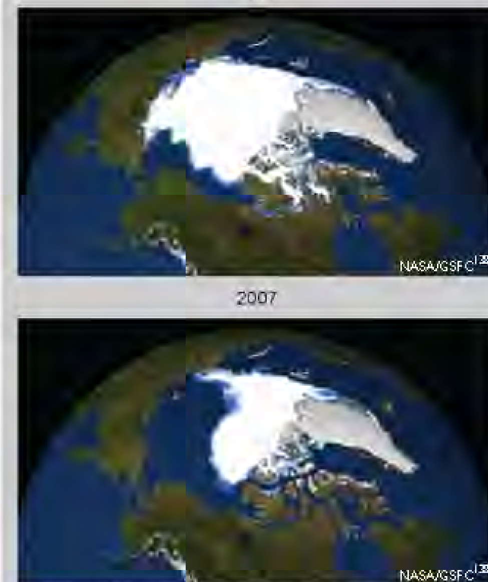
Arctic sea ice is declining rapidly and this is very likely to continue.

Sea ice is a very important part of the climate system. In addition to direct impacts on coastal areas of Alaska, it more broadly affects surface reflectivity, ocean currents, cloudiness, humidity, and the exchange of heat and moisture at the ocean's surface. Open ocean water is darker in color than sea ice, which causes it to absorb more of the Sun's heat, which increases the warming of the water even more.[40,132]

The most complete record of sea ice is provided by satellite observations of sea ice extent since the 1970s. Prior to that, aircraft, ship, and coastal observations in the Arctic make it possible to extend the record of Northern Hemisphere sea ice extent back to at least 1900, although there is a lower level of confidence in the data prior to 1953.[40]

Arctic Sea Ice Annual Minimum

1979

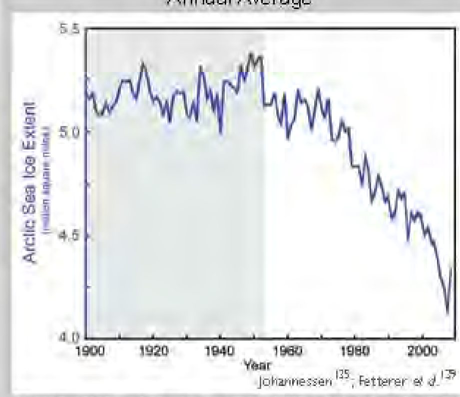


Arctic sea ice reaches its annual minimum in September. The satellite images above show September Arctic sea ice in 1979, the first year these data were available, and 2007.

Arctic sea ice extent has fallen at a rate of 3 to 4 percent per decade over the last three decades. End-of-summer Arctic sea ice has fallen at an even faster rate of more than 11 percent per decade in that time. The observed decline in Arctic sea ice has been more rapid than projected by climate models.[133] Year-to-year changes in sea ice extent and record low amounts are influenced by natural variations in atmospheric pressure and wind patterns.[134] However, clear linkages between rising greenhouse gas concentrations and declines in Arctic sea ice have been identified in the climate record as far back as the early 1990s.[61] The extreme loss in Arctic sea ice that occurred in 2007 would not have been possible without the long-term reductions that have coincided with a sustained increase in the atmospheric concentration of carbon dioxide and the rapid rise in global temperatures that have occurred since the mid-1970s.[135] Although the 2007 record low was not eclipsed in 2008, the 2008 sea ice extent is well below the long-term average, reflecting a continuation of the long-term decline in Arctic sea ice. In addition, the total volume of Arctic sea ice in 2008 was likely a record low because the ice was unusually thin.[136]

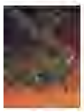
Arctic Sea Ice Extent

Annual Average



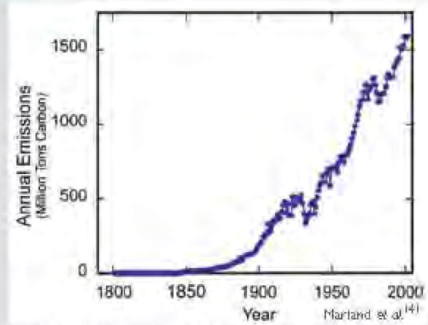
Observations of annual average Arctic sea ice extent for the period 1900 to 2008. The gray shading indicates less confidence in the data before 1953.

It is expected that declines in Arctic sea ice will continue in the coming decades with year-to-year fluctuations influenced by natural atmospheric variability. The overall rate of decline will be influenced mainly by the rate at which carbon dioxide and other greenhouse gas concentrations increase.[137]



U.S. Emission and Absorption of Heat-Trapping Gases

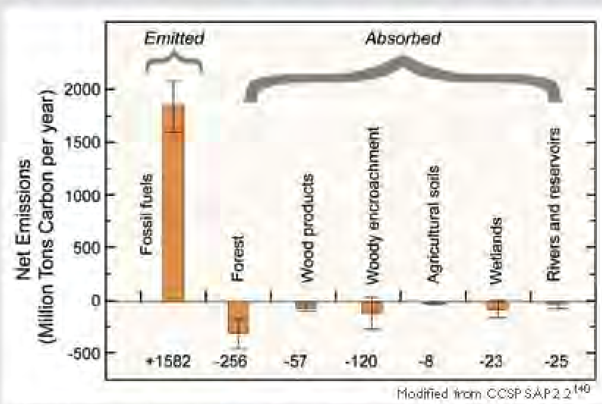
Since the industrial revolution, the United States has been the world's largest emitter of heat-trapping gases. With 4.5 percent of world's population, the United States is responsible for about 28 percent of the human-induced heat-trapping gases in the atmosphere today.[136] Although China has recently surpassed the United States in current total annual emissions, per capita emissions remain much higher in the United States. Carbon dioxide, the most important of the heat-trapping gases produced directly by human activities, is a cumulative problem because it has a long atmospheric lifetime. Roughly one-half of the carbon dioxide released from fossil fuel burning remains in the atmosphere after 100 years, and roughly one-fifth of it remains after 1,000 years.[90]



U.S. annual emissions of CO_2 from fossil-fuel use.[141]

U.S. carbon dioxide emissions grew dramatically over the past century. These emissions come almost entirely from burning fossil fuels. These sources of carbon dioxide are one side of the equation and on the other side are "sinks" that take up carbon dioxide. The growth of trees and other plants is an important natural carbon sink. In recent years, it is estimated that about 20 percent of U.S. carbon dioxide emissions have been offset by U.S. forest growth and other sinks (see figure below).[140] It is not known whether U.S. forests and other sinks will continue to take up roughly this amount of carbon dioxide in the future as climate change alters carbon release and uptake. For example, a warming-induced lengthening of the growing season would tend to increase carbon uptake. On the other hand, the increases in forest fires and in the decomposition rate of dead plant matter would decrease uptake, and might convert the carbon sink into a source.[140]

The amount of carbon released and taken up by natural sources varies considerably from year to year depending on climatic and other conditions. For example, fires release carbon dioxide, so years with many large fires result in more carbon release and less uptake as natural sinks (the vegetation) are lost. Similarly, the trees destroyed by intense storms or droughts release carbon dioxide as they decompose, and the loss results in reduced strength of natural sinks until regrowth is well underway. For example, Hurricane Katrina killed or severely damaged over 320 million large trees. As these trees decompose over the next few years, they will release an amount of carbon dioxide equivalent to that taken up by all U.S. forests in a year.[112] The net change in carbon storage in the long run will depend on how much is taken up by the regrowth as well as how much was released by the original disturbance.



U.S. carbon dioxide emissions and uptake in millions of tons of carbon per year in 2003. The bar marked "Emitted" indicates the amount of carbon as carbon dioxide added to the atmosphere from U.S. emissions. The bars marked "Absorbed" indicate amounts of carbon as carbon dioxide removed from the atmosphere. The thin lines on each bar indicate estimates of uncertainty.

Water Resources

Key Messages:

- Climate change has already altered, and will continue to alter, the water cycle, affecting where, when, and how much water is available for all uses.
- Floods and droughts are likely to become more common and more intense as regional and seasonal precipitation patterns change, and rainfall becomes more concentrated into heavy events (with longer, hotter dry periods in between).
- Precipitation and runoff are likely to increase in the Northeast and Midwest in winter and spring, and decrease in the West, especially the Southwest, in spring and summer.
- In areas where snowpack dominates, the timing of runoff will continue to shift to earlier in the spring and flows will be lower in late summer.
- Surface water quality and groundwater quantity will be affected by a changing climate.
- Climate change will place additional burdens on already stressed water systems.
- The past century is no longer a reasonable guide to the future for water management.

Changes in the water cycle, which are consistent with the warming observed over the past several decades, include:

- changes in precipitation patterns and intensity
- changes in the incidence of drought
- widespread melting of snow and ice
- increasing atmospheric water vapor
- increasing evaporation
- increasing water temperatures
- reductions in lake and river ice
- changes in soil moisture and runoff

For the future, marked regional differences are projected, with increases in annual precipitation, runoff, and soil moisture in much of the Midwest and Northeast, and declines in much of the West, especially the Southwest.

Skagit River and surrounding mountains in the Northwest

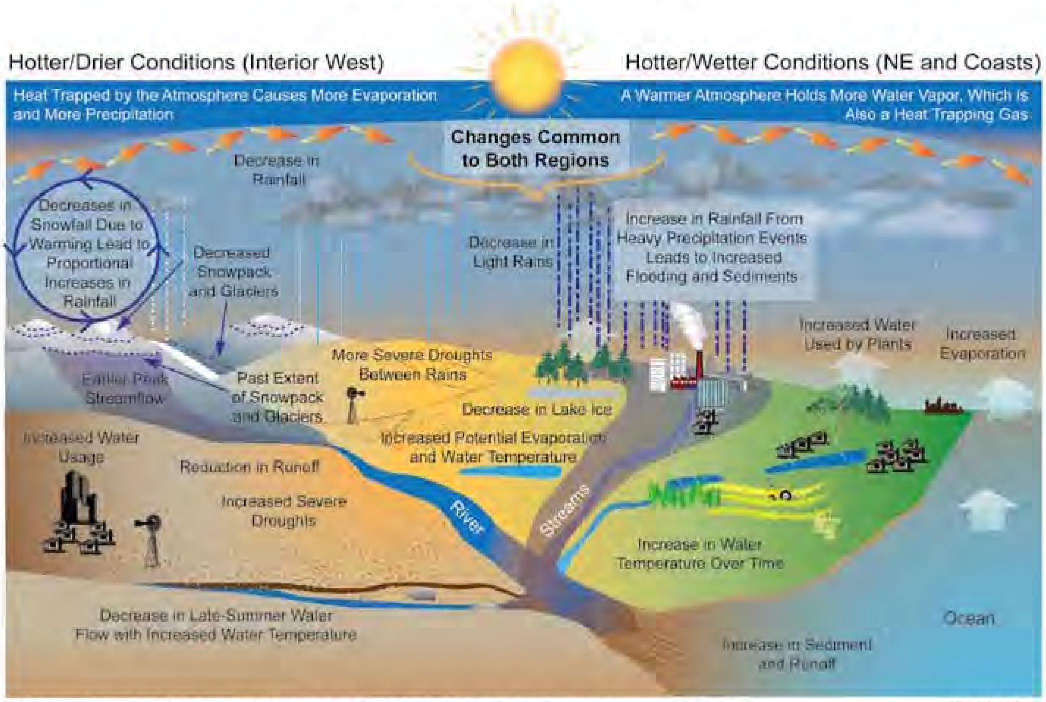
The impacts of climate change include too little water in some places, too much water in other places, and degraded water quality. Some locations are expected to be subject to all of these conditions during different times of the year. Water cycle changes are expected to continue and to adversely affect energy production and use, human health, transportation, agriculture, and ecosystems (see table on page 50).[142]

Climate change has already altered, and will continue to alter, the water cycle, affecting where, when, and how much water is available for all uses.

Substantial changes to the water cycle are expected as the planet warms because the movement of water in the atmosphere and oceans is one of the primary mechanisms for the redistribution of heat around the world. Evidence is mounting that human-induced climate change is already altering many of the existing patterns of precipitation in the United States, including when, where, how much, and what kind of precipitation falls.[68,142] A warmer climate increases evaporation of water from land and sea, and allows more moisture to be held in the atmosphere. For every 1°F rise in temperature, the water holding capacity of the atmosphere increases by about 4 percent.[49]

41

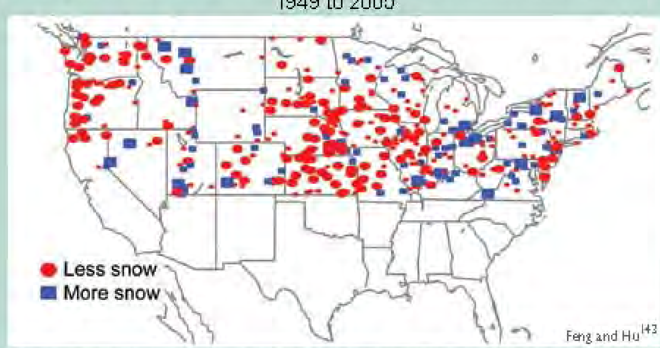
Projected Changes in the Water Cycle



The water cycle exhibits many changes as the Earth warms. Wet and dry areas respond differently. NOAA/NCDC

In addition, changes in atmospheric circulation will tend to move storm tracks northward with the result that dry areas will become drier and wet areas wetter. Hence, the arid Southwest is projected to experience longer and more severe droughts from the combination of increased evaporation and reductions in precipitation.[108]

Changes in Snowfall Contributions to Wintertime Precipitation
1949 to 2005



Trends in winter snow-to-total precipitation ratio from 1949 to 2005. Red circles indicate less snow, while blue squares indicate more snow. Large circles and squares indicate the most significant trends.[143] Areas south of 37°N latitude were excluded from the analysis because most of that area receives little snowfall. White areas above that line have inadequate data for this analysis.

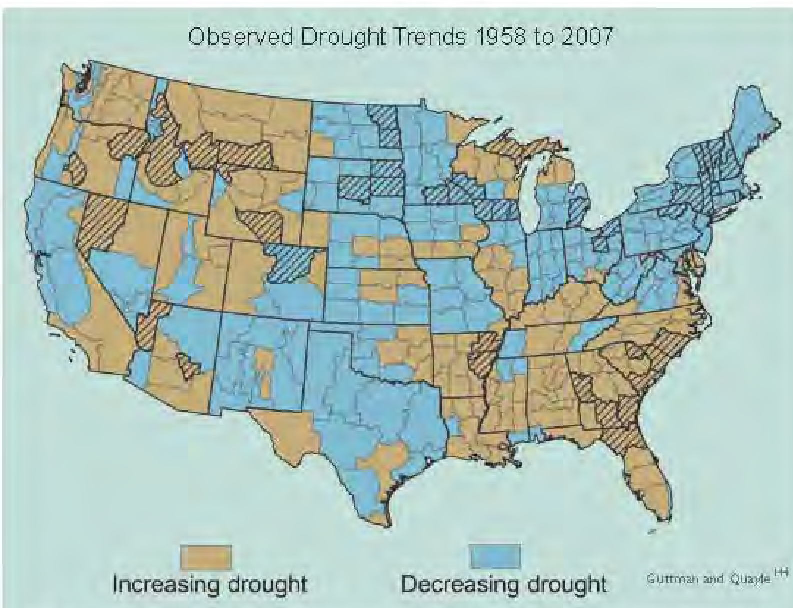
The additional atmospheric moisture contributes to more overall precipitation in some areas, especially in much of the Northeast, Midwest, and Alaska. Over the past 50 years, precipitation and streamflow have increased in much of the Northeast and Midwest, with a reduction in drought duration and severity. Much of the Southeast and West has had reductions in precipitation and increases in drought severity and duration, especially in the Southwest.

In most areas of the country, the fraction of precipitation falling as rain versus snow has increased during the last 50 years. Despite this general shift from snow to rain, snowfalls

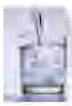
42

Observed Water-Related Changes During the Last Century[142]

Observed Change	Direction of Change	Region Affected
One to four week earlier peak streamflow due to earlier warming-driven snowmelt	Earlier	West and Northeast
Proportion of precipitation falling as snow	Decreasing	West and Northeast
Duration and extent of snow cover	Decreasing	Most of the United States
Mountain snow water equivalent	Decreasing	West
Annual precipitation	Increasing	Most of the United States
Annual precipitation	Decreasing	Southwest
Frequency of heavy precipitation events	Increasing	Most of the United States
Runoff and streamflow	Decreasing	Colorado and Columbia River Basins
Streamflow	Increasing	Most of East
Amount of ice in mountain glaciers	Decreasing	U.S. western mountains, Alaska
Water temperature of lakes and streams	Increasing	Most of the United States
Ice cover on lakes and rivers	Decreasing	Great Lakes and Northeast
Periods of drought	Increasing	Parts of West and East
Salinization of surface waters	Increasing	Florida, Louisiana
Widespread thawing of permafrost	Increasing	Alaska



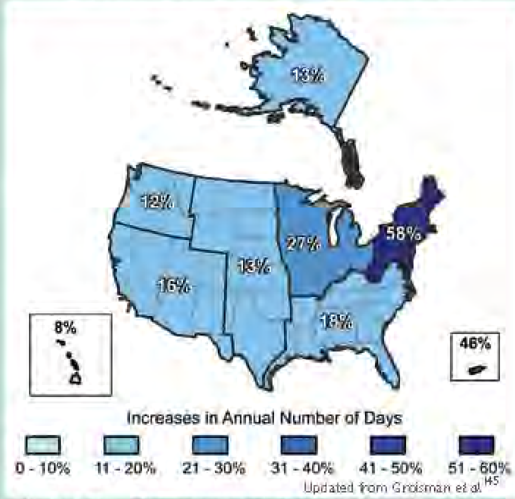
Trends in end-of-summer drought as measured by the Palmer Drought Severity Index from 1958 to 2007 in each of 344 U.S. climate divisions.[144] Hatching indicates significant trends.



along the downwind coasts of the Great Lakes have increased. Factors contributing to this increase include reduced ice cover due to warming, which lengthens the period of open water. In addition, cold air moving over relatively warm, open lake water induces strong evaporation, often causing heavy lake-effect snow. Heavy snowfall and snowstorm frequency have increased in many northern parts of the United States. In the South however, where temperatures are already marginal for heavy snowfall, climate warming has led to a reduction in heavy snowfall and snowstorm frequency. These trends suggest a northward shift in snowstorm occurrence.[68]

Floods and droughts are likely to become more common and more intense as regional and seasonal precipitation patterns change, and rainfall becomes more concentrated into heavy events (with longer, hotter dry periods in between).

Increases in the Number of Days with Very Heavy Precipitation (1958 to 2007)



The map shows the percentage increases in the average number of days with very heavy precipitation (defined as the heaviest 1 percent of all events) from 1958 to 2007 for each region. There are clear trends toward more days with very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

While it sounds counterintuitive, a warmer world produces both wetter and drier conditions. Even though total global precipitation increases, the regional and seasonal distribution of precipitation changes, and more precipitation comes in heavier rains (which can cause flooding) rather than light events. In the past century, averaged over the United States, total precipitation has increased by about 7 percent, while the heaviest 1 percent of rain events increased by nearly 20 percent.[68] This has been especially noteworthy in the Northeast, where the annual number of days with very heavy precipitation has increased most in the past 50 years, as shown in the adjacent figure. Flooding often occurs when heavy precipitation persists for weeks to months in large river basins. Such extended periods of heavy precipitation have also been increasing over the past century, most notably in the past two to three decades in the United States.[112]

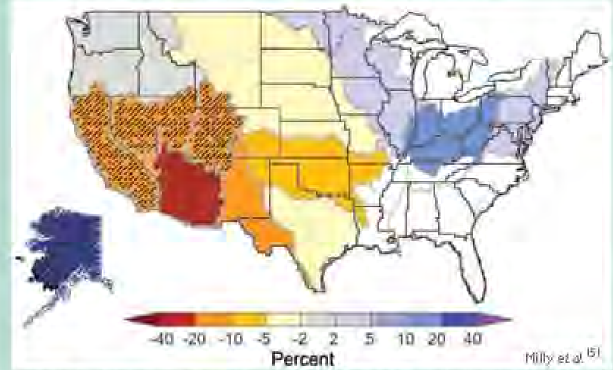
Observations also show that over the past several decades, extended dry periods have become more frequent in parts of the United States, especially the Southwest and the eastern United States.[146,147] Longer periods between rainfalls, combined with higher air temperatures, dry out soils and vegetation, causing drought.

For the future, precipitation intensity is projected to increase everywhere, with the largest increases occurring in areas in which average precipitation increases the most. For example, the Midwest and Northeast, where total precipitation is expected to increase the most, would also experience the largest increases in heavy precipitation events. The number of dry days between precipitation events is also projected to increase, especially in the more arid areas. Mid-continental areas and the Southwest are particularly threatened by future drought. The magnitude of the projected changes in extremes is expected to be greater than changes in averages, and hence detectable sooner.[49,68,90,142,148]

Precipitation and runoff are likely to increase in the Northeast and Midwest in winter and spring, and decrease in the West, especially the Southwest, in spring and summer.

Runoff, which accumulates as streamflow, is the amount of precipitation that is not evaporated, stored as snowpack or soil moisture, or filtered down to groundwater. The proportion of precipitation that runs off is determined by a variety of factors including temperature, wind speed, humidity, solar intensity at the ground, vegetation, and soil moisture. While runoff generally tracks precipitation, increases and decreases in precipitation do not necessarily lead to equal increases and decreases in runoff. For example, droughts cause soil moisture reductions that can reduce expected runoff until soil moisture is replenished. Conversely, water-saturated soils can generate floods with only moderate additional precipitation. During the last century, consistent increases in precipitation have been found in the Midwest and Northeast along with increased runoff.[149,150] Climate models consistently project that the East will experience increased runoff, while there will be substantial declines in the interior West, especially the Southwest. Projections for runoff in California and other parts of the West also show reductions, although less than in the interior West. In short, wet areas are projected to get wetter and dry areas drier. Climate models also consistently project heat-related summer soil moisture reductions in the middle of the continent.[115,142,146,149]

Projected Changes in Annual Runoff

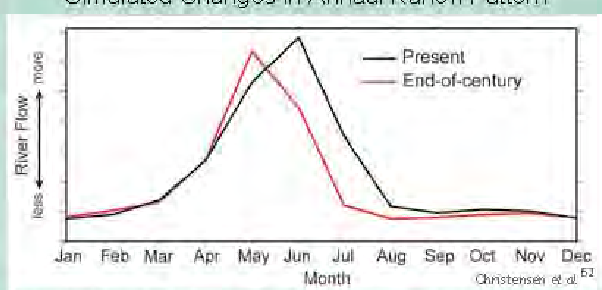


Projected changes in median runoff for 2041-2060, relative to a 1901-1970 baseline, are mapped by water-resource region. Colors indicate percentage changes in runoff. Hatched areas indicate greater confidence due to strong agreement among model projections. White areas indicate divergence among model projections. Results are based on emissions in between the lower and higher emissions scenarios.[91]

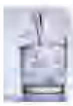
In areas where snowpack dominates, the timing of runoff will continue to shift to earlier in the spring and flows will be lower in late summer.

Large portions of the West and some areas in the Northeast rely on snowpack as a natural reservoir to hold winter precipitation until it later runs off as streamflow in spring, summer, and fall. Over the last 50 years, there have been widespread temperature-related reductions in snowpack in the West, with the largest reductions occurring in lower elevation mountains in the Northwest and California where snowfall occurs at temperatures close to the freezing point.[142,153] The Northeast has also experienced snowpack reductions during a similar period. Observations indicate a transition to more rain and less snow in both the West and Northeast in the last 50 years.[143,154-156] Runoff in snowmelt-dominated areas is occurring up to 20 days earlier in the West, and up to 14 days earlier in the Northeast.[157,158] Future projections for most snowmelt-dominated basins in the West consistently indicate earlier spring

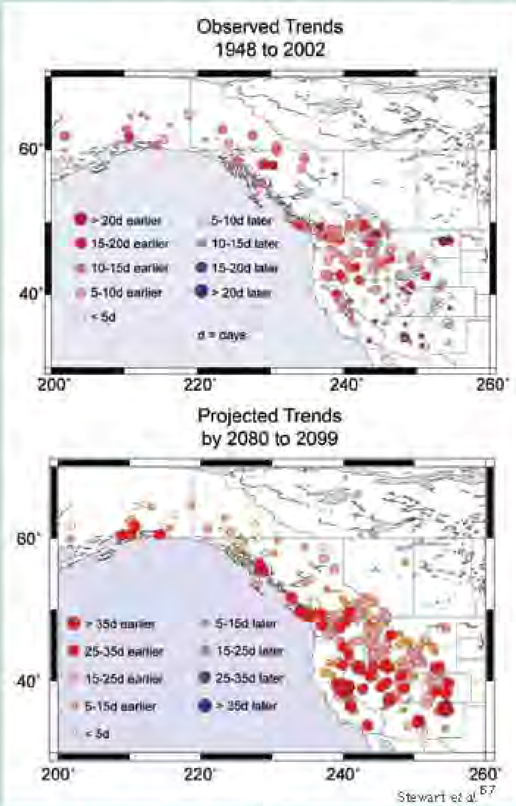
Simulated Changes in Annual Runoff Pattern



General schematic of changes in the annual pattern of runoff for snowmelt-dominated streams. Compared to the historical pattern, runoff peak is projected to shift to earlier in the spring and late summer flows are expected to be lower. The above example is for the Green River, which is part of the Colorado River watershed.



Trends in Peak Streamflow Timing



Top map shows changes in runoff timing in snowmelt-driven streams from 1948 to 2002 with red circles indicating earlier runoff, and blue circles indicating later runoff. Bottom map shows projected changes in snowmelt-driven streams by 2080-2099, compared to 1951-1980, under a higher emissions scenario.[91]

runoff, in some cases up to 60 days earlier.[157,159] For the Northeast, projections indicate spring runoff will advance by up to 14 days.[150] Earlier runoff produces lower late-summer streamflows, which stress human and environmental systems through less water availability and higher water temperatures.[145] Scientific analyses to determine the causes of recent changes in snowpack, runoff timing, and increased winter temperatures have attributed these changes to human-caused climate change.[34,160,161]

Surface water quality and groundwater quantity will be affected by a changing climate.

Changes in water quality

Increased air temperatures lead to higher water temperatures, which have already been detected in many streams, especially during low-flow periods. In lakes and reservoirs, higher water temperatures lead to longer periods of summer stratification (when surface and bottom waters do not mix). Dissolved oxygen is reduced in lakes, reservoirs, and rivers at higher temperatures. Oxygen is an essential resource for many living things, and its availability is reduced at higher temperatures both because the amount that can be dissolved in water is lower and because respiration rates of living things are higher. Low oxygen stresses aquatic animals such as coldwater fish and the insects and crustaceans on which they feed.[142] Lower oxygen levels also decrease the self-purification capabilities of rivers.

The negative effects of water pollution, including sediments, nitrogen from agriculture, disease pathogens, pesticides, herbicides, salt, and thermal pollution, will be amplified by observed and projected increases in precipitation intensity and longer periods when streamflows are low.[146] The U.S. Environmental Protection Agency expects the number of waterways considered “impaired” by water pollution to increase.[162] Heavy downpours lead to increased sediment in runoff and outbreaks of waterborne diseases.[163,164] Increases in pollution carried to lakes, estuaries, and the coastal ocean, especially when coupled with increased temperature, can result in blooms of harmful algae and bacteria. However, pollution has the potential of being diluted in regions that experience increased streamflow.

Water-quality changes during the last century were probably due to causes other than climate change, primarily changes in pollutants.[149]

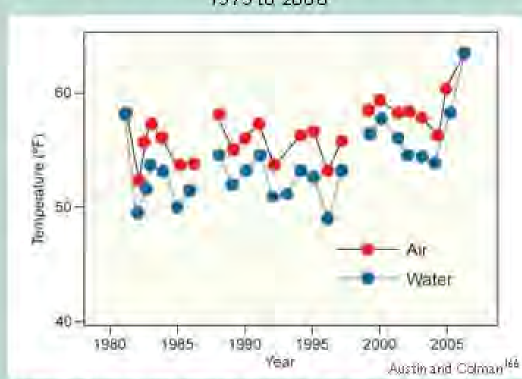
Changes in groundwater

Many parts of the United States are heavily dependent on groundwater for drinking, residential, and agricultural water supplies.[164] How climate change will affect groundwater is not well known,

Heavy rain can cause sediments to become suspended in water, reducing its quality, as seen in the brown swath above in New York City's Ashokan reservoir following Hurricane Floyd in September 1999.

but increased water demands by society in regions that already rely on groundwater will clearly stress this resource, which is often drawn down faster than it can be recharged.[164] In many locations, groundwater is closely connected to surface water and thus trends in surface water supplies over time affect groundwater. Changes in the water cycle that reduce precipitation or increase evaporation and runoff would reduce the amount of water available for recharge. Changes in vegetation and soils that occur as temperature changes or due to fire or pest outbreaks are also likely to affect recharge by altering evaporation and infiltration rates. More frequent and larger floods are likely to increase groundwater recharge in semi-arid and arid areas, where most recharge occurs through dry streambeds after heavy rainfalls and floods.[142]

Lake Superior Summer Air and Water Temperatures
1979 to 2006



The recent large jump in summer water temperature is related to the recent large reduction in ice cover (see *Midwest* region).

Sea-level rise is expected to increase saltwater intrusion into coastal freshwater aquifers, making some unusable without desalination.[146] Increased evaporation or reduced recharge into coastal aquifers exacerbates saltwater intrusion. Shallow groundwater aquifers that exchange water with streams are likely to be the most sensitive part of the groundwater system to climate change. Small reductions in groundwater levels can lead to large reductions in streamflow and increases in groundwater levels can increase streamflow.[165] Further, the interface between streams and groundwater is an important site for pollution removal by microorganisms. Their activity will change in response to increased temperature and increased or decreased streamflow as climate changes, and this will affect water quality. Like water quality, research on the impacts of climate change on groundwater has been minimal.[149]

Climate change will place additional burdens on already stressed water systems.

In many places, the nation's water systems are already taxed due to aging infrastructure, population increases, and competition among water needs for farming, municipalities, hydropower, recreation, and ecosystems.[167-169] Climate change will add another factor to existing water management challenges, thus increasing vulnerability.[170] The U.S. Bureau of Reclamation has identified many areas in the West that are already at risk for serious conflict over water, even in the absence of climate change[171] (see figure next page).

Adapting to gradual changes, such as changes in average amounts of precipitation, is less difficult than adapting to changes in extremes. Where extreme events, such as droughts or floods, become more intense or more frequent with climate change, the economic and social costs of these events will increase.[172] Water systems have life spans of many years and are designed with spare capacity. These systems are thus able to cope with small changes in average conditions.[172] Water resource planning today considers a broad range of stresses and hence adaptation to climate change will be one factor among many in deciding what actions will be taken to minimize vulnerability.[172-174]

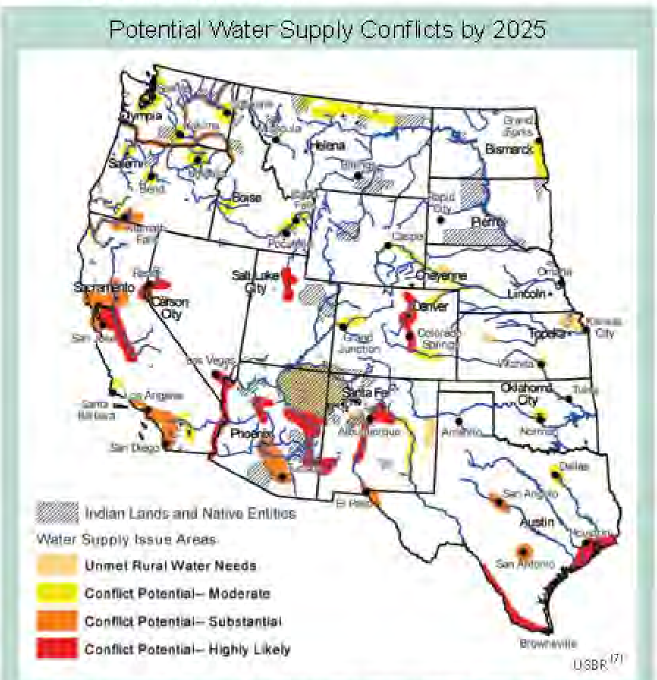
Rapid regional population growth

The U.S. population is estimated to have grown to more than 300 million people, nearly a 7 percent increase since the 2000 Census. Current Census Bureau projections are for this growth rate to continue, with the national population projected to reach 350 million by 2025 and 420 million by 2050. The highest rates of population growth to 2025 are projected to occur in areas such as the Southwest that are at risk for reductions in water supplies due to climate change.[167]

Damage to the city water system in Asheville, North Carolina, due to heavy rain in 2004.

Aging water infrastructure

The nation's drinking water and wastewater infrastructure is aging. In older cities, some buried water mains are over 100 years old and breaks of these lines are a significant problem. Sewer overflows resulting in the discharge of untreated wastewater also occur frequently. Heavier downpours will exacerbate existing problems in many cities, especially where stormwater catchments and sewers are combined. Drinking water and sewer infrastructure is very expensive to install and maintain. Climate change will present a new set of challenges for designing upgrades to the nation's water delivery and sewage removal infrastructure.[168]



The map shows regions in the West where water supply conflicts are likely to occur by 2025 based on a combination of factors including population trends and potential endangered species' needs for water. The red zones are where the conflicts are most likely to occur. This analysis does not factor in the effects of climate change, which is expected to exacerbate many of these already-identified issues.[171]

Existing water disputes across the country

Many locations in the United States are already undergoing water stress. The Great Lakes states are establishing an interstate compact to protect against reductions in lake levels and potential water exports. Georgia, Alabama, and Florida are in a dispute over water for drinking, recreation, farming, environmental purposes, and hydropower in the Apalachicola–Chattahoochee–Flint River system.[175,176]

The State Water Project in California is facing a variety of problems in the Sacramento Delta, including endangered species, saltwater intrusion, and potential loss of islands due to flood- or earthquake-caused levee failures.[177-182] A dispute over endangered fish in the Rio Grande has been ongoing for many years.[183] The Klamath River in Oregon and California has been the location of a multi-year disagreement over native fish, hydropower, and farming.[184,185] The Colorado River has been the site of numerous interstate quarrels over the last century.[186,187] Large, unquantified Native

American water rights challenge existing uses in the West (see *Southwest* region).[188] By changing the existing patterns of precipitation and runoff, climate change will add another stress to existing problems.

Changing water demands

Water demands are expected to change with increased temperatures. Evaporation is projected to increase over most of the United States as temperatures rise. Higher temperatures and longer dry periods are expected to lead to increased water demand for irrigation. This may be partially offset by more efficient use of water by plants due to rising atmospheric carbon dioxide. Higher temperatures are projected to increase cooling water withdrawals by electrical generating stations. In addition, greater cooling requirements in summer will increase electricity use, which in turn will require more cooling water for power plants. Industrial and municipal demands are expected to increase slightly.[146]

The past century is no longer a reasonable guide to the future for water management.

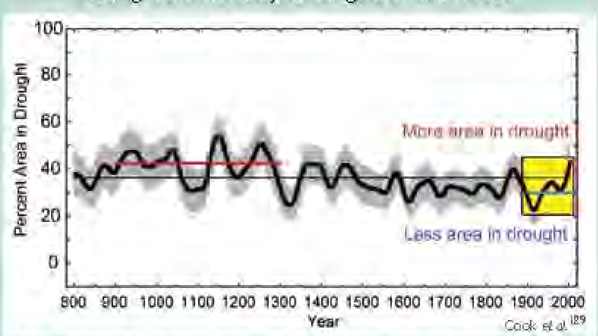
Water planning and management have been based on historical fluctuations in records of stream flows, lake levels, precipitation, temperature, and water demands. All aspects of water management including reservoir sizing, reservoir flood operations, maximum urban stormwater runoff amounts, and projected water demands have been based on these records. Water managers have proven adept at balancing supplies and demand through the significant climate variability of the past century.[142] Because climate change will significantly modify many aspects of the water cycle, the assumption of an unchanging climate is no longer appropriate for many aspects of water planning. Past assumptions derived from the historical record about supply and demand will need to be revisited for existing and proposed water projects.[142,151,174]

Drought studies that consider the past 1,200 years indicate that in the West, the last century was significantly wetter than most other centuries. Multi-decade "megadroughts" in the years 900 to 1300 were substantially worse than the worst droughts of the last century, including the Dust Bowl era. The causes of these events are only partially known; if they were to reoccur, they would clearly stress water management, even in the absence of climate change (see figure below).[97,149,189]

The intersection of substantial changes in the water cycle with multiple stresses such as population growth and competition for water supplies means that water planning will be doubly challenging. The ability to modify operational rules and water allocations is likely to be critical for the protection of infrastructure, for public safety, to ensure reliability of water delivery, and to protect the environment. There are, however, many institutional and legal barriers to such changes in both the short and long term.[190] Four examples:

- The allocation of the water in many interstate rivers is governed by compacts, international treaties, federal laws, court decrees, and other agreements that are difficult to modify.
- Reservoir operations are governed by "rule curves" that require a certain amount of space to be saved in a reservoir at certain times of

Long-Term Aridity Changes in the West



The black line shows the percentage of the area affected by drought (Palmer Drought Severity Index less than –1) in the West over the past 1,200 years. The red line indicates the average drought area in the years 900 to 1300. The blue horizontal line in the yellow box indicates the average during the period from 1900 to 2000, illustrating that the most recent period, during which population and water infrastructure grew rapidly in the West, was wetter than the long-term average (thin horizontal black line).[129] Droughts shown in the period 1100-1300 significantly exceed those that have occurred over the past 100 years.

49

year to capture a potential flood. Developed by the U.S. Army Corps of Engineers based on historical flood data, many of these rule curves have never been modified, and modifications might require Environmental Impact Statements.[151]

Highlights of Water-Related Impacts by Sector

Sector	Examples of Impacts
Human Health	Heavy downpours increase incidence of waterborne disease and floods, resulting in potential hazards to human life and health.[163]
Energy Supply and Use	Hydropower production is reduced due to low flows in some regions. Power generation is reduced in fossil fuel and nuclear plants due to increased water temperatures and reduced cooling water availability.[191]
Transportation	Floods and droughts disrupt transportation. Heavy downpours affect harbor infrastructure and inland waterways. Declining Great Lakes levels reduce freight capacity.[192]
Agriculture and Forests	Intense precipitation can delay spring planting and damage crops. Earlier spring snowmelt leads to increased number of forest fires.[193]
Ecosystems	Coldwater fish threatened by rising water temperatures. Some warmwater fish will expand ranges.[70]

- In most parts of the West, water is allocated based on a "first in time means first in right" system, and because agriculture was developed before cities were established, large volumes of water typically are allocated to agriculture. Transferring agricultural rights to municipalities, even for short periods during drought, can involve substantial expense and time and can be socially divisive.
- Conserving water does not necessarily lead to a right to that saved water, thus creating a disincentive for conservation.

Total U.S. water diversions peaked in the 1980s, which implies that expanding supplies in many areas to meet new needs are unlikely to be a viable option, especially in arid areas likely to experience less precipitation. However, over the last 30 years, per capita water use has decreased significantly (due, for example, to more efficient technologies such as drip irrigation) and it is anticipated that per capita use will continue to decrease, thus easing stress.[149]

Adaptation: New York City Begins Planning for Climate Change

The New York City Department of Environmental Protection (DEP), the agency in charge of providing the city's drinking water and wastewater treatment, is beginning to alter its planning to take into account the effects of climate change – sea-level rise, higher temperatures, increases in extreme events, and changing precipitation patterns – on the city's water systems. In partnership with Columbia University, DEP is evaluating climate change projections, impacts, indicators, and adaptation and mitigation strategies.

City planners have begun to address these issues by defining risks using probabilistic climate scenarios and considering potential adaptations that relate to operations/management, infrastructure, and policy. For example, DEP is examining the feasibility of relocating critical control systems to higher floors in low-lying buildings or to higher ground, building flood walls, and modifying design criteria to reflect changing hydrologic processes.

Important near-term goals of the overall effort include updating the existing 100-year flood elevations using climate model projections and identifying additional monitoring stations needed to track changes. DEP will also establish a system for reporting the impacts of extreme weather events on the City's watershed and infrastructure. In the immediate future, DEP will evaluate flood protection measures for three existing water pollution control plants that are scheduled for renovation.[194]

Spotlight on the Colorado River

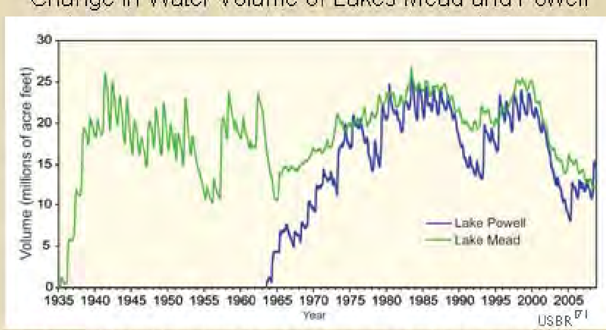
The Colorado River system supplies water to over 30 million people in the Southwest including Los Angeles, Phoenix, Las Vegas, and Denver. Reservoirs in the system, including the giant lakes Mead and Powell, were nearly full in 1999, with almost four times the annual flow of the river stored. By 2007, the system had lost approximately half of that storage after enduring the worst drought in 100 years of record keeping.[29] Runoff was reduced due to low winter precipitation, and warm, dry, and windy spring seasons that substantially reduced snowpack.

Matching photographs taken 18 months apart during the most serious period of recent drought show a significant decrease in Lake Powell.

Numerous studies over the last 30 years have indicated that the river is likely to experience reductions in runoff due to climate change. In addition, diversions from the river to meet the needs of cities and agriculture are approaching its average flow. Under current conditions, even without climate change, large year-to-year fluctuations in reservoir storage are possible.[152] If reductions in flow projected to accompany global climate change occur, water managers will be challenged to satisfy all existing demands, let alone the increasing demands of a rapidly growing population.[167,195]

Efforts are underway to address these challenges. In 2005, the Department of Interior's Bureau of Reclamation began a process to formalize operating rules for lakes Mead and Powell during times of low flows and to apportion limited water among the states.[196]

Change in Water Volume of Lakes Mead and Powell



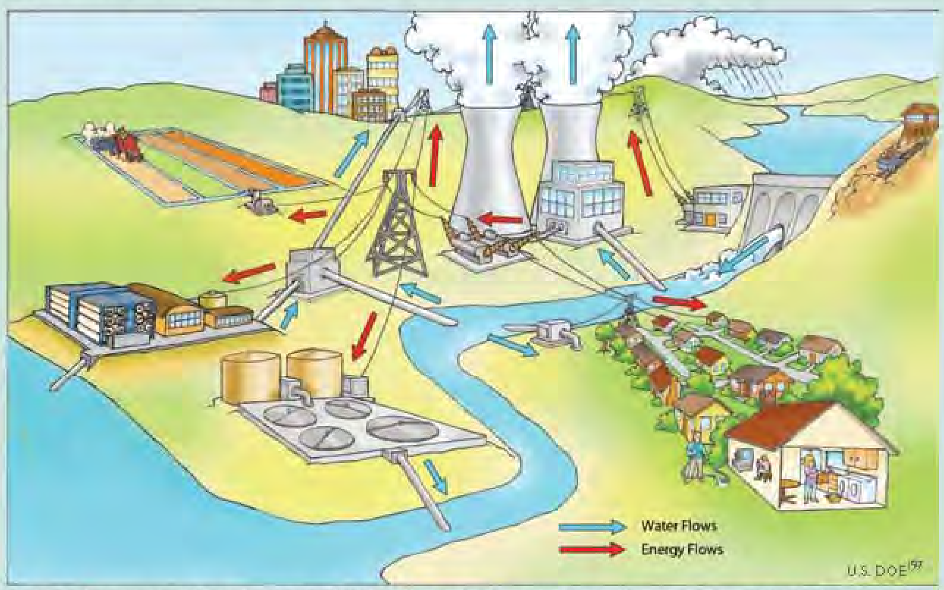
The filling of Lake Mead (green) was initiated in 1935, and that of Lake Powell (blue) in 1963. In 1999, the lakes were nearly full, but by 2007, the lakes had lost nearly half of their storage water after the worst drought in 100 years.

51

Water and Energy Connections

Water and energy are tightly interconnected; water systems use large amounts of energy, and energy systems use large amounts of water. Both are expected to be under increasing pressure in the future and both will be affected by a changing climate. In the energy sector, water is used directly for hydropower, and cooling water is critical for nearly all other forms of electrical power generation. Withdrawals of freshwater used to cool power plants that use heat to generate electricity are very large, nearly equaling the water withdrawn for irrigation. Water consumption by power plants is about 20 percent of all non-agricultural uses, or half that of all domestic use.[197]

In the water sector, two very unusual attributes of water, significant weight due to its relatively high density, and high heat capacity, make water use energy intensive. Large amounts of energy are needed for pumping, heating, and treating drinking water and wastewater. Water supply and treatment consumes roughly 4 percent of the nation's power supply, and electricity accounts for about 75 percent of the cost of municipal water processing and transport. In California, 30 percent of all non-power plant natural gas is used for water-related activities.[198,199] The energy required to provide water depends on its source (groundwater, surface water, desalinated water, treated wastewater, or recycled water), the distance the water is conveyed, the amount of water moved, and the local topography. Surface water often requires more treatment than groundwater. Desalination requires large amounts of energy to produce freshwater. Treated wastewater and recycled water (used primarily for agriculture and industry) require energy for treatment, but little energy for supply and conveyance. Conserving water has the dual benefit of conserving energy and potentially reducing greenhouse gas emissions if fossil fuels are the predominant source of that energy.



Water and energy are intimately connected. Water is used by the power generation sector for cooling, and energy is used by the water sector for pumping, drinking water treatment, and wastewater treatment. Without energy, there would be limited water distribution, and without water, there would be limited energy production.

Energy Supply and Use

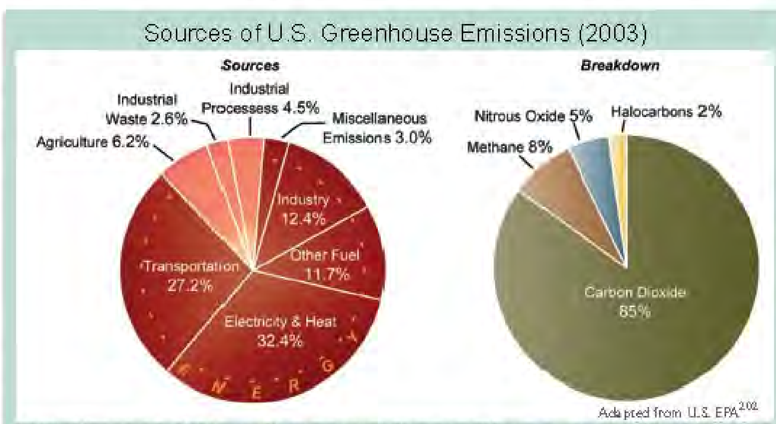
Key Messages:

- Warming will be accompanied by decreases in demand for heating energy and increases in demand for cooling energy. The latter will result in significant increases in electricity use and higher peak demand in most regions.
- Energy production is likely to be constrained by rising temperatures and limited water supplies in many regions.
- Energy production and delivery systems are exposed to sea-level rise and extreme weather events in vulnerable regions.
- Climate change is likely to affect some renewable energy sources across the nation, such as hydropower production in regions subject to changing patterns of precipitation or snowmelt.

Energy is at the heart of the global warming challenge.[3] It is humanity's production and use of energy that is the primary cause of global warming, and in turn, climate change will eventually affect our production and use of energy. The vast majority of U.S. greenhouse gas emissions, about 87 percent, come from energy production and use.[200]

At the same time, other U.S. trends are increasing energy use: population shifts to the South, especially the Southwest, where air conditioning use is high, an increase in the square footage built per person, increased electrification of the residential and commercial sectors, and increased market penetration of air conditioning.[201]

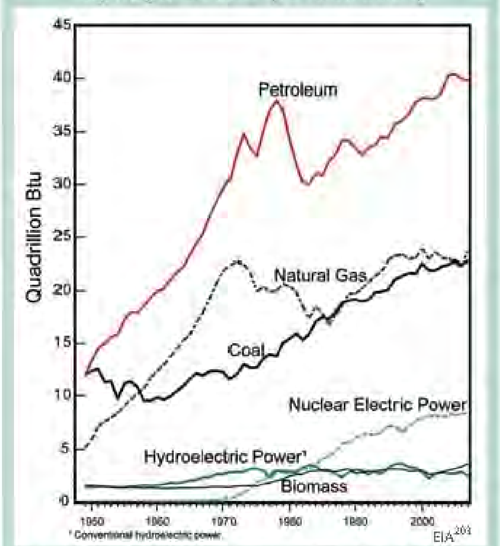
Many of the effects of climate change on energy production and use in the United States are not well studied. Some of the effects of climate change, however, have clear implications for energy production and use. For instance, rising temperatures are expected to increase energy requirements for cooling and reduce energy requirements for heating.[164,201] Changes in precipitation have the potential to affect prospects for hydropower, positively or negatively.[201] Increases in hurricane intensity are likely to cause further disruptions to oil and gas operations in the Gulf, like those experienced in 2005 with Hurricane Katrina and in 2008 with Hurricane Ike.[201] Concerns about climate



About 87 percent of U.S. greenhouse gas emissions come from energy production and use, as shown in the left pie chart. The right pie chart breaks down these emissions by greenhouse gas.

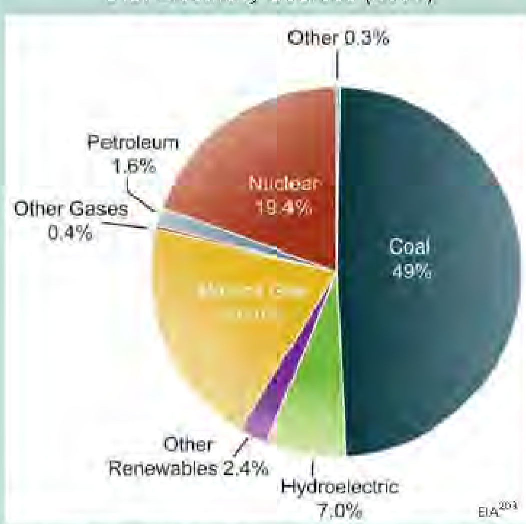
53

Primary Energy Consumption by Major Source (1949 to 2007)



U.S. energy supply is dominated by fossil fuels. Petroleum, the top source of energy shown above, is primarily used for transportation (70 percent of oil use). Natural gas is used in roughly equal parts to generate electricity, power industrial processes, and heat water and buildings. Coal is primarily used to generate electricity (91 percent of coal use). Nuclear power is used entirely for electricity generation.

U.S. Electricity Sources (2007)



Coal, natural gas, and nuclear power plants together account for about 90 percent of current U.S. electricity production.

change impacts will almost certainly alter perceptions and valuations of energy technology alternatives. These effects are very likely to be relevant for energy policies, decisions, and institutions in the United States, affecting courses of action and appropriate strategies for risk management.[201]

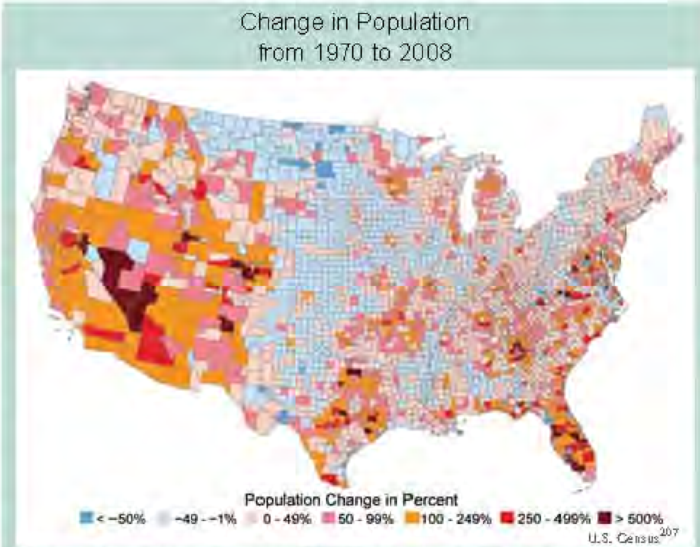
The overall scale of the national energy economy is very large, and the energy industry has both the financial and the managerial resources to be adaptive. Impacts due to climate change are likely to be most apparent at sub-national scales, such as regional effects of extreme weather events and reduced water availability, and effects of increased cooling demands on especially vulnerable places and populations.[204]

Warming will be accompanied by decreases in demand for heating energy and increases in demand for cooling energy. The latter will result in significant increases in electricity use and higher peak demand in most regions.

Research on the effects of climate change on energy production and use has largely been limited to impacts on energy use in buildings. These studies have considered effects of global warming on energy requirements for heating and cooling in buildings in the United States.[205] They find that the demand for cooling energy increases from 5 to 20 percent per 1.8°F of warming, and the demand for heating energy drops by 3 to 15 percent per 1.8°F of warming.[205] These ranges reflect different assumptions about factors such as the rate of market penetration of improved building equipment technologies.[205]

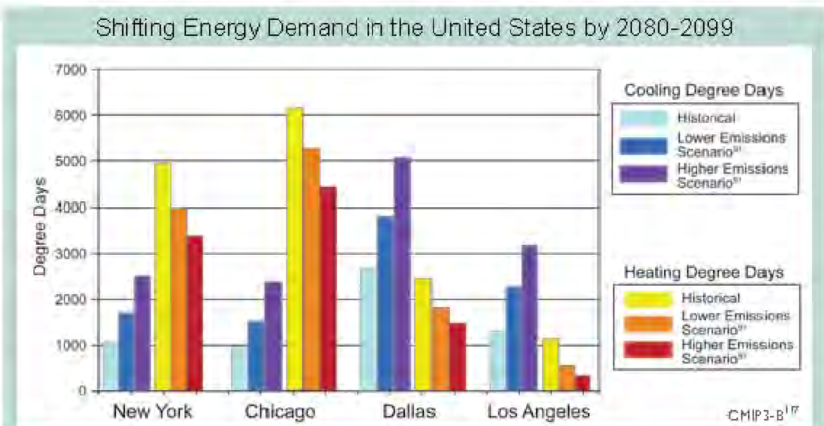
Studies project that temperature increases due to global warming are very likely to increase peak demand for electricity in most regions of the country.[205] An increase in peak demand can lead to a disproportionate increase in energy infrastructure investment.[205]

Since nearly all of the cooling of buildings is provided by electricity use, whereas the vast majority of the heating of buildings is provided by natural gas and fuel oil,[201,206] the projected changes imply increased demands for electricity. This is especially the case where climate change would result in significant increases in the heat index in summer, and where relatively little space cooling has been needed in the past, but demands are likely to increase in the future.[205] The increase in electricity demand is likely to be accelerated by population movements to the South and Southwest, which are regions of especially high per capita electricity use, due to demands for cooling in commercial buildings and households.[205] Because nearly half of the nation's electricity is currently generated from coal, these factors have the potential to increase total national carbon dioxide emissions in the absence of improved energy efficiency, development of non-carbon energy sources, and/or carbon capture and storage.[205]



The map above, showing percentage changes in county population between 1970 and 2008, graphically illustrates the large increases in places that require air conditioning. Areas with very large increases are shown in orange, red, and maroon. Some places had enormous growth, in the hundreds of thousands of people. For example, counties in the vicinity of South Florida, Atlanta, Los Angeles, Phoenix, Las Vegas, Denver, Dallas, and Houston all had very large increases.

Other effects of climate change on energy consumption are less clear, because little research has been done.[205] For instance, in addition to cooling, air conditioners also remove moisture from the air; thus the increase in humidity projected to accompany global warming is likely to increase electricity consumption by air conditioners even further.[205] As other examples, warming would increase the use of air conditioners in highway vehicles, and water scarcity in some regions has the potential to increase energy demands for water pumping. It is important to improve the information available about these other kinds of effects.



"Degree days" are a way of measuring the energy needed for heating and cooling by adding up how many degrees hotter or colder each day's average temperature is from 65°F over the course of a year. Colder locations have high numbers of heating degree days and low numbers of cooling degree days, while hotter locations have high numbers of cooling degree days and low numbers of heating degree days. Nationally, the demand for energy will increase in summer and decrease in winter. Cooling uses electricity while heating uses a combination of energy sources, so the overall effect nationally and in most regions will be an increased need for electricity. The projections shown in the chart are for late this century. The higher emissions scenario[91] used here is referred to as "even higher" on page 23.

55

Energy production is likely to be constrained by rising temperatures and limited water supplies in many regions.

In some regions, reductions in water supply due to decreases in precipitation and/or water from melting snowpack are likely to be significant, increasing the competition for water among various sectors including energy production (see *Water Resources* sector).[191,208]

The production of energy from fossil fuels (coal, oil, and natural gas) is inextricably linked to the availability of adequate and sustainable supplies of water.[191,208] While providing the United States with the majority of its annual energy needs, fossil fuels also place a high demand on the nation's water resources in terms of both quantity and quality impacts.[191,208] Generation of electricity in thermal power plants (coal, nuclear, gas, or oil) is water intensive. Power plants rank only slightly behind irrigation in terms of freshwater withdrawals in the United States.[191]

There is a high likelihood that water shortages will limit power plant electricity production in many regions. Future water constraints on electricity production in thermal power plants are projected for Arizona, Utah, Texas, Louisiana, Georgia, Alabama, Florida, California, Oregon, and Washington state by 2025.[191] Additional parts of the United States could face similar constraints as a result of drought, growing populations, and increasing demand for water for various uses, at least seasonally.[209] Situations where the development of new power plants is being slowed down or halted due to inadequate cooling water are becoming more frequent throughout the nation.[191]

The issue of competition among various water uses is dealt with in more detail in the *Water Resources* sector. In connection with these issues and other regional water scarcity impacts, energy is likely to be needed to move and manage water. This is one of many examples of interactions among the impacts of climate change on various sectors that, in this case, affects energy requirements.

Nuclear, coal, and natural gas power plants require large amounts of water for cooling.[191]

In addition to the problem of water availability, there are issues related to an increase in water temperature. Use of warmer water reduces the efficiency of thermal power plant cooling technologies. And, warmer water discharged from power plants can alter species composition in aquatic ecosystems.[210] Large coal and nuclear plants have been limited in their operations by reduced river levels caused by higher temperatures and thermal limits on water discharge.[191]

The efficiency of thermal power plants, fossil or nuclear, is sensitive to ambient air and water temperatures; higher temperatures reduce power outputs by affecting the efficiency of cooling.[191] Although this effect is not large in percentage terms, even a relatively small change could have significant implications for total national electric power supply.[191] For example, an average reduction of 1 percent in electricity generated by thermal power plants nationwide would mean a loss of 25 billion kilowatt-hours per year,[211] about the amount of electricity consumed by 2 million Americans, a loss that would need to be supplied in some other way or offset through measures that improve energy efficiency.

Energy production and delivery systems are exposed to sea-level rise and extreme weather events in vulnerable regions.

Sea-level rise

A significant fraction of America's energy infrastructure is located near the coasts, from power plants, to oil refineries, to facilities that receive oil and gas deliveries.[191] Rising sea levels are likely to lead to direct losses, such as equipment damage from flooding or erosion, and indirect effects, such as the costs of raising vulnerable assets to higher levels or building new facilities farther inland, increasing transportation costs.[191] The U.S. East Coast and Gulf Coast have been identified as particularly vulnerable to sea-level rise because the land is relatively flat and also sinking in many places.[191]

Extreme events

Observed and projected increases in a variety of extreme events will have significant impacts on the energy sector. As witnessed in 2005, hurricanes can have a debilitating impact on energy infrastructure. Direct losses to the energy industry in 2005 are estimated at $15 billion,[191] with millions more in restoration and recovery costs. As one example, the Yscloskey Gas Processing Plant (located on the Louisiana coast) was forced to close for six months following Hurricane Katrina, resulting in lost revenues to the plant's owners and employees, and higher prices to consumers, as gas had to be procured from other sources.[191]

The impacts of an increase in severe weather are not limited to hurricane-prone areas. For example, rail transportation lines, which carry approximately two-thirds of the coal to the nation's power plants,[212] often follow riverbeds, especially in the Appalachian region.[191] More intense rainstorms, which have been observed and projected,[68,112] can lead to rivers flooding, which can "wash out" or degrade nearby railbeds and roadbeds.[191] This is also a problem in the Midwest, which experienced major flooding of the Mississippi River in 1993 and 2008.[213]

Development of new energy facilities could be restricted by siting concerns related to sea-level rise, exposure to extreme events, and increased capital costs resulting from a need to provide greater protection from extreme events.[191]

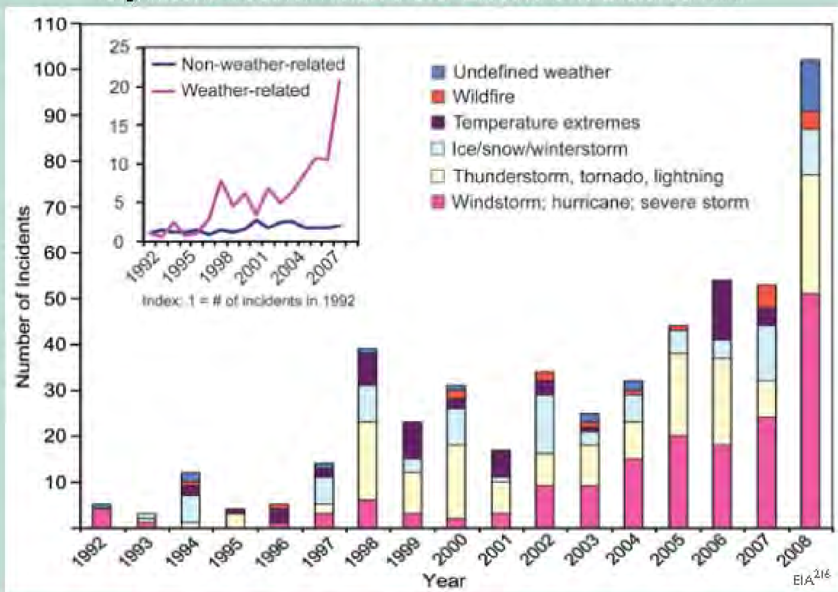
The electricity grid is also vulnerable to climate change effects, from temperature changes to severe weather events.[191] The most familiar example is

Regional Spotlight: Gulf Coast Oil and Gas

The Gulf Coast is home to the U.S. oil and gas industries, representing nearly 30 percent of the nation's crude oil production and approximately 20 percent of its natural gas production. One-third of the national refining and processing capacity lies on coastal plains adjacent to the Gulf of Mexico. Several thousand offshore drilling platforms, dozens of refineries, and thousands of miles of pipelines are vulnerable to damage and disruption due to sea-level rise and the high winds and storm surge associated with hurricanes and other tropical storms. For example, hurricanes Katrina and Rita halted all oil and gas production from the Gulf, disrupted nearly 20 percent of the nation's refinery capacity, and closed many oil and gas pipelines.[214] Relative sea-level rise in parts of the Gulf Coast region (Louisiana and East Texas) is projected to be as high as 2 to 4 feet by 2050 to 2100, due to the combination of global sea-level rise caused by warming oceans and melting ice and local land sinking.[215] Combined with onshore and offshore storm activity, this would represent an increased threat to this regional energy infrastructure. Some adaptations to these risks are beginning to emerge (see Adaptation box, page 58).

Offshore oil production is particularly susceptible to extreme weather events. Hurricane Ivan in 2004 destroyed seven platforms in the Gulf of Mexico, significantly damaged 24 platforms, and damaged 102 pipelines. Hurricanes Katrina and Rita in 2005 destroyed more than 100 platforms and damaged 558 pipelines. For example, Chevron's $250 million "Typhoon" platform was damaged beyond repair. Plans are being made to sink its remains to the seafloor.

Significant Weather-Related U.S. Electric Grid Disturbances



The number of incidents caused by extreme weather has increased tenfold since 1992. The portion of all events that are caused by weather-related phenomena has more than tripled from about 20 percent in the early 1990s to about 65 percent in recent years. The weather-related events are more severe, with an average of about 180,000 customers affected per event compared to about 100,000 for non-weather-related events (and 50,000 excluding the massive blackout of August 2003).[201] The data shown include disturbances that occurred on the nation's large-scale "bulk" electric transmission systems. Most outages occur in local distribution networks and are not included in the graph. Although the figure does not demonstrate a cause-effect relationship between climate change and grid disruption, it does suggest that weather and climate extremes often have important effects on grid disruptions. We do know that more frequent weather and climate extremes are likely in the future,[48] which poses unknown new risks for the electric grid.

Adaptation: Addressing Oil Infrastructure Vulnerabilities in the Gulf Coast

Port Fourchon, Louisiana, supports 75 percent of deepwater oil and gas production in the Gulf of Mexico, and its role in supporting oil production in the region is increasing. The Louisiana Offshore Oil Port, located about 20 miles offshore, links daily imports of 1 million barrels of oil and production of 300,000 barrels in the Gulf of Mexico to 50 percent of national refining capacity. One road, Louisiana Highway 1, connects Port Fourchon with the nation. It transports machinery, supplies, and workers and is the evacuation route for onshore and offshore workers. Responding to threats of storm surge and flooding, related in part to concerns about climate change, Louisiana is currently upgrading Highway 1, including elevating it above the 500-year flood level and building a higher bridge over Bayou LaFourche and the Boudreaux Canal.[217]

Regional Spotlight: Florida's Energy Infrastructure

Florida's energy infrastructure is particularly vulnerable to sea-level rise and storm impacts. Most of the petroleum products consumed in Florida are delivered by barge to three ports, two on the east coast and one on the west coast. The interdependencies of natural gas distribution, transportation fuel distribution and delivery, and electrical generation and distribution were found to be major issues in Florida's recovery from recent major hurricanes.[171]

effects of severe weather events on power lines, such as from ice storms, thunderstorms, and hurricanes. In the summer heat wave of 2006, for example, electric power transformers failed in several areas (including St. Louis, Missouri, and Queens, New York) due to high temperatures, causing interruptions of electric power supply. It is not yet possible to project effects of climate change on the grid, because so many of the effects would be more localized than current climate change models can depict; but, weather-related grid disturbances are recognized as a challenge for strategic planning and risk management.

Climate change is likely to affect some renewable energy sources across the nation, such as hydropower production in regions subject to changing patterns of precipitation or snowmelt.

Renewable sources currently account for about 9 percent of electricity production in the United States.[203] Hydroelectric power is by far the largest renewable contributor to electricity generation,[191] accounting for about 7 percent of total U.S. electricity.[218] Like many things discussed in this report, renewable energy resources have strong interrelationships with climate change; using renewable energy can reduce the magnitude of climate change, while climate change can affect the prospects for using some renewable energy sources.

Hydropower is a major source of electricity in some regions of the United States, notably in the Northwest.[191] It is likely to be significantly affected by climate change in regions subject to reduced precipitation and/or water from melting snowpack. Significant changes are already being detected in the timing and amount of streamflows in many western rivers,[164] consistent with the predicted effects of global warming. More precipitation coming as rain rather than snow, reduced snowpack, earlier peak runoff, and related effects are beginning to affect hydropower availability.[164]

Hydroelectric generation is very sensitive to changes in precipitation and river discharge. For example, every 1 percent decrease in precipitation results in a 2 to 3 percent drop in streamflow;[219] every 1 percent decrease in streamflow in the Colorado River Basin results in a 3 percent drop in power generation.[191] Such magnifying sensitivities occur because water flows through multiple power plants in a river basin.[191]

Climate impacts on hydropower occur when either the total amount or the timing of runoff is altered, such as when natural water storage in snowpack and glaciers is reduced under hotter conditions. Glaciers, snowpack, and their associated runoff are already declining in the West, and larger declines are projected.[164]

Hydropower operations are also affected by changes to air temperatures, humidity, or wind patterns due to climate change.[191] These variables cause changes in water quantity and quality, including water temperature. Warmer air and water generally increase the evaporation of water from the surface

Hydroelectric dam in the Northwest

of reservoirs, reducing the amount of water available for power production and other uses. Huge reservoirs with large surface areas, located in arid, sunny parts of the country, such as Lake Mead (located on Arizona-Nevada border on the Colorado River), are particularly susceptible to increased evaporation due to warming, meaning less water will be available for all uses, including hydropower.[191] And, where hydropower dams flow into waterways that support trout, salmon or other coldwater fisheries, warming of reservoir releases might have detrimental consequences that require changes in operations that reduce power production.[191] Such impacts will increasingly translate into competition for water resources.

Climate change is also likely to affect other renewable energy sources. For example, changing cloud cover affects solar energy resources, changes in winds affect wind power, and temperature and water availability affect biomass production (particularly related to water requirements for biofuels).[191] The limited research to date on these important issues does not support firm conclusions about where such impacts would occur and how significant they would be.[205] This is an area that calls for much more study (see *An Agenda for Climate Impacts Science* section, Recommendation 2).

Regional Spotlight: Energy Impacts of Alaska's Rapid Warming

Significant impacts of warming on the energy sector can already be observed in Alaska, where temperatures have risen about twice as much as the rest of the nation. In Alaska, frozen ground and ice roads are an important means of winter travel, and warming has resulted in a much shorter cold season. Impacts on the oil and natural gas industries on Alaska's North Slope have been one of the results. For example, the season during which oil and gas exploration and extraction equipment can be operated on the tundra has been shortened due to warming. In addition, the thawing of permafrost, on which buildings, pipelines, airfields, and coastal installations supporting oil and gas development are located, adversely affects these structures and increases the cost of maintaining them.[191]

Different energy impacts are expected in the marine environment as sea ice continues to retreat and thin. These trends are expected to improve shipping accessibility, including oil and gas transport by sea, around the margins of the Arctic Basin, at least in the summer. The improved accessibility, however, will not be uniform throughout the different regions. Offshore oil exploration and extraction might benefit from less extensive and thinner sea ice, although equipment will have to be designed to withstand increased wave forces and ice movement.[191,220]

Transportation

Key Messages:

- Sea-level rise and storm surge will increase the risk of major coastal impacts, including both temporary and permanent flooding of airports, roads, rail lines, and tunnels.
- Flooding from increasingly intense downpours will increase the risk of disruptions and delays in air, rail, and road transportation, and damage from mudslides in some areas.
- The increase in extreme heat will limit some transportation operations and cause pavement and track damage. Decreased extreme cold will provide some benefits such as reduced snow and ice removal costs.
- Increased intensity of strong hurricanes would lead to more evacuations, infrastructure damage and failure, and transportation interruptions.
- Arctic warming will continue to reduce sea ice, lengthening the ocean transport season, but also resulting in greater coastal erosion due to waves. Permafrost thaw in Alaska will damage infrastructure. The ice road season will become shorter.

The U.S. transport sector is a significant source of greenhouse gases, accounting for 27 percent of U.S. emissions.[221] While it is widely recognized that emissions from transportation have a major impact on climate, climate change will also have a major impact on transportation.

Buildings and debris float up against a railroad bridge on the Cedar River during record flooding in June 2008, in Cedar Rapids, Iowa.

Climate change impacts pose significant challenges to our nation's multi-modal transportation system and cause disruptions in other sectors across the economy. For example, major flooding in the Midwest in 1993 and 2008 restricted regional travel of all types, and disrupted freight and rail shipments across the country, such as those bringing coal to power plants and chlorine to water treatment systems. The U.S. transportation network is vital to the nation's economy, safety, and quality of life.

Extreme events present major challenges for transportation, and such events are becoming more frequent and intense. Historical weather patterns are no longer a reliable predictor of the future.[222] Transportation planners have not typically accounted for climate change in their long-term planning and project development. The longevity of transportation infrastructure, the long-term nature of climate change, and the potential impacts identified by recent studies warrant serious attention to climate change in planning new or rehabilitated transportation systems.[223]

The strategic examination of national, regional, state, and local networks is an important step toward understanding the risks posed by climate change. A range of adaptation responses can be employed to reduce risks through redesign or relocation of infrastructure, increased redundancy of critical services, and operational improvements. Adapting to climate change is an evolutionary process. Through adoption of longer planning horizons, risk management, and adaptive responses, vulnerable transportation infrastructure can be made more resilient.[215]

Sea-level rise and storm surge will increase the risk of major coastal impacts, including both temporary and permanent flooding of airports, roads, rail lines, and tunnels.

Sea-level rise

Transportation infrastructure in U.S. coastal areas is increasingly vulnerable to sea-level rise. Given the high population density near the coasts, the potential exposure of transportation infrastructure to flooding is immense. Population swells in these areas during the summer months because beaches are very important tourist destinations.[222]

In the Gulf Coast area alone, an estimated 2,400 miles of major roadway and 246 miles of freight rail lines are at risk of permanent flooding within 50 to 100 years as global warming and land subsidence (sinking) combine to produce an anticipated relative sea-level rise in the range of 4 feet.[217] Since the Gulf Coast region's transportation network is interdependent and relies on minor roads and other low-lying infrastructure, the risks of service disruptions due to sea-level rise are likely to be even greater.[217]

Coastal areas are also major centers of economic activity. Six of the nation's top 10 freight gateways (measured by the value of shipments) will be threatened by sea-level rise.[222] Seven of the 10 largest ports (by tons of traffic) are located on the Gulf Coast.[223] The region is also home to the U.S. oil and gas industry, with its offshore drilling platforms, refineries, and pipelines. Roughly two-thirds of all U.S. oil imports are transported through this region[224] (see *Energy* sector). Sea-level rise would potentially affect commercial transportation activity valued in the hundreds of billions of dollars annually through inundation of area roads, railroads, airports, seaports, and pipelines.[217]

Storm surge

More intense storms, especially when coupled with sea-level rise, will result in far-reaching and damaging storm surges. An estimated 60,000 miles of coastal highway are already exposed to periodic flooding from coastal storms and high waves.[222] Some of these highways currently serve as evacuation routes during hurricanes and other coastal storms, and these routes could become seriously compromised in the future.

Gulf Coast Area Roads at Risk from Sea-Level Rise

Within 50 to 100 years, 2,400 miles of major roadway are projected to be inundated by sea-level rise in the Gulf Coast region. The map shows roadways at risk in the event of a sea-level rise of about 4 feet, within the range of projections for this region in this century under medium- and high-emissions scenarios.[91] In total, 24 percent of interstate highway miles and 28 percent of secondary road miles in the Gulf Coast region are at elevations below 4 feet.[217]

62

Regional Spotlight: Gulf Coast

Sea-level rise, combined with high rates of subsidence in some areas, will make much of the existing infrastructure more prone to frequent or permanent inundation; 27 percent of the major roads, 9 percent of the rail lines, and 72 percent of the ports in the area shown on the map on the previous page are built on land at or below 4 feet in elevation, a level within the range of projections for relative sea-level rise in this region in this century. Increased storm intensity may lead to increased service disruption and infrastructure damage. More than half of the area's major highways (64 percent of interstates, 57 percent of arterials), almost half of the rail miles, 29 airports, and virtually all of the ports, are below 23 feet in elevation and subject to flooding and damage due to hurricane storm surge. These factors merit consideration in today's transportation decisions and planning processes.[217]

Coastal areas are projected to experience continued development pressures as both retirement and tourist destinations. Many of the most populous counties of the Gulf Coast, which already experience the effects of tropical storms, are expected to grow rapidly in the coming decades.[222] This growth will generate demand for more transportation infrastructure and services, challenging transportation planners to meet the demand, address current and future flooding, and plan for future conditions.[223]

Land

More frequent inundation and interruptions in travel on coastal and low-lying roadways and rail lines due to storm surge are projected, potentially requiring changes to minimize disruptions. More frequent evacuations due to severe storm surges are also likely. Across the United States, many coastal cities have subways, tunnels, parking lots, and other transportation infrastructure below ground. Underground tunnels and other low-lying infrastructure will experience more frequent and severe flooding. Higher sea levels and storm surges will also erode road base and undermine bridge supports. The loss of coastal wetlands and barrier islands will lead to further coastal erosion due to the loss of natural protection from wave action.

Water

Impacts on harbor infrastructure from wave damage and storm surges are projected to increase. Changes will be required in harbor and port facilities to accommodate higher tides and storm surges. There will be reduced clearance under some waterway bridges for boat traffic. Changes in the navigability of channels are expected; some will become more accessible (and extend farther inland) because of deeper waters, while others will be restricted because of changes in sedimentation rates and sandbar locations. In some areas, waterway systems will become part of open water as barrier islands disappear. Some channels are likely to have to be dredged more frequently as has been done across large open-water bodies in Texas.[222]

Regional Spotlight: New York Metropolitan Area

With the potential for significant sea-level rise estimated under continued high levels of emissions, the combined effects of sea-level rise and storm surge are projected to increase the frequency of flooding. What is currently called a 100-year storm is projected to occur as often as every 10 years by late this century. Portions of lower Manhattan and coastal areas of Brooklyn, Queens, Staten Island, and Nassau County, would experience a marked increase in flooding frequency. Much of the critical transportation infrastructure, including tunnels, subways, and airports, lies well within the range of projected storm surge and would be flooded during such events.[222,225,369]

Air

Airports in coastal cities are often located adjacent to rivers, estuaries, or open ocean. Airport runways in coastal areas face inundation unless effective protective measures are taken. There is the potential for closure or restrictions for several of the nation's busiest airports that lie in coastal zones, affecting service to the highest density populations in the United States.

Flooding from increasingly intense downpours will increase the risk of disruptions and delays in air, rail, and road transportation, and damage from mudslides in some areas.

Heavy downpours have already increased substantially in the United States; the heaviest 1 percent of precipitation events increased by 20 percent, while total precipitation increased by only 7 percent over the past century.[112] Such intense precipitation is likely to increase the frequency and severity of events such as the Great Flood of 1993, which caused catastrophic flooding along 500 miles of the Mississippi and Missouri river system, paralyzing surface transportation systems, including rail, truck, and marine traffic. Major east-west traffic was halted for roughly six weeks in an area stretching from St. Louis, Missouri, west to Kansas City, Missouri and north to Chicago, Illinois, affecting one-quarter of all U.S. freight, which either originated or terminated in the flood-affected region.[222]

The June 2008 Midwest flood was the second record-breaking flood in the past 15 years. Dozens of levees were breached or overtopped in Iowa, Illinois, and Missouri, flooding huge areas, including nine square miles in and around Cedar Rapids, Iowa. Numerous highway and rail bridges were impassable due to flooding of approaches and transport was shut down along many stretches of highway, rail lines, and normally navigable waterways.

Planners have generally relied on weather extremes of the past as a guide to the future, planning, for example, for a "100-year flood," which is now likely to come more frequently as a result of climate change. Historical analysis of weather data has thus become less reliable as a forecasting tool. The accelerating changes in climate make it more difficult to predict the frequency and intensity of weather events that can affect transportation.[222]

Land

The increase in heavy precipitation will inevitably cause increases in weather-related accidents, delays, and traffic disruptions in a network already challenged by increasing congestion.[215] There will be increased flooding of evacuation routes, and construction activities will be disrupted. Changes in rain, snowfall, and seasonal flooding will impact safety and maintenance operations on the nation's roads and railways. For example, if more precipitation falls as rain rather than snow in winter and spring, there will be an increased risk of landslides, slope failures, and floods from the runoff, causing road closures as well as the need for road repair and reconstruction[223] (see *Water Resources* sector).

Increased flooding of roadways, rail lines, and underground tunnels is expected. Drainage systems will be overloaded more frequently and severely, causing backups and street flooding. Areas where flooding is already common will face more frequent and severe problems. For example, Louisiana Highway 1, a critical link in the transport of oil from the Gulf of Mexico, has recently experienced increased flooding, prompting authorities to elevate the road (see Adaptation Box page 58).[217] Increases in road washouts, damage to railbed support structures, and landslides and mudslides that damage roads and other infrastructure are expected. If soil moisture levels become too high, the structural integrity of roads, bridges, and tunnels, which in some cases are already under age-related stress and in need of repair, could be compromised. Standing water will have adverse impacts on road base. For example, damage due to long term submersion of roadways in Louisiana was estimated to be $50 million for just 200 miles of state-owned highway. The Louisiana Department of Transportation and Development noted that a total of 1,800 miles of roads were under water for long periods, requiring costly repairs.[217] Pipelines are likely to be damaged because intense precipitation can cause the ground to sink underneath the pipeline; in shallow river-

Adaptation: Climate Proofing a Road

Completion of a road around the 42-square mile island of Kosrae in the U.S.-affiliated Federated States of Micronesia provides a good example of adaptation to climate change. A road around the island's perimeter existed, except for a 10-mile gap. Filling this gap would provide all-weather land access to a remote village and allow easier access to the island's interior.

In planning this new section of road, authorities decided to "climate-proof" it against projected increases in heavy downpours and sea-level rise. This led to the section of road being placed higher above sea level and with an improved drainage system to handle the projected heavier rainfall. While there were additional capital costs for incorporating this drainage system, the accumulated costs, including repairs and maintenance, would be lower after about 15 years, equating to a good rate of return on investment. Adding this improved drainage system to roads that are already built is more expensive than on new construction, but still has been found to be cost effective.[226]

beds, pipelines are more exposed to the elements and can be subject to scouring and shifting due to heavy precipitation.[217]

Water

Facilities on land at ports and harbors will be vulnerable to short term flooding from heavy downpours, interrupting shipping service. Changes in silt and debris buildup resulting from extreme precipitation events will affect channel depth, increasing dredging costs. The need to expand stormwater treatment facilities, which can be a significant expense for container and other terminals with large impermeable surfaces, will increase.

Air

Increased delays due to heavy downpours are likely to affect operations, causing increasing flight delays and cancellations.[222] Stormwater runoff that exceeds the capacity of collection and drainage systems will cause flooding, delays, and airport closings. Heavy downpours will affect the structural integrity of airport facilities, such as through flood damage to runways and other infrastructure. All of these impacts have implications for emergency evacuation planning, facility maintenance, and safety.[222]

The increase in extreme heat will limit some transportation operations and cause pavement and track damage. Decreased extreme cold will provide some benefits such as reduced snow and ice removal costs.

Land

Longer periods of extreme heat in summer can damage roads in several ways, including softening of asphalt that leads to rutting from heavy traffic.[164] Sustained air temperature over 90°F is a significant threshold for such problems (see maps page 34). Extreme heat can cause deformities in rail tracks, at minimum resulting in speed restrictions and, at worst, causing derailments. Air temperatures above 100°F can lead to equipment failure (see maps page 90). Extreme heat also causes thermal expansion of bridge joints, adversely affecting bridge operations and increasing maintenance costs. Vehicle overheating and tire deterioration are additional concerns.[222] Higher temperatures will also increase refrigeration needs for goods during transport, particularly in the South, raising transportation costs.[217]

Increases in very hot days and heat waves are expected to limit construction activities due to health and safety concerns for highway workers. Guid-

An example of intense precipitation affecting transportation infrastructure was the record-breaking 24-hour rainstorm in July 1996, which resulted in flash flooding in Chicago and its suburbs, with major impacts. Extensive travel delays occurred on metropolitan highways and railroads, and streets and bridges were damaged. Commuters were unable to reach Chicago for up to three days, and more than 300 freight trains were delayed or rerouted.[222]

The June 2008 Midwest floods caused I-80 in eastern Iowa to be closed for more than five days, disrupting major east-west shipping routes for trucks and the east-west rail lines through Iowa. These floods exemplify the kind of extreme precipitation events and their direct impacts on transportation that are likely to become more frequent in a warming world. These extremes create new and more difficult problems that must be addressed in the design, construction, rehabilitation, and operation of the nation's transportation infrastructure.

ance from the U.S. Occupational Safety and Health Administration states that concern for heat stress for moderate to heavy work begins at about 80°F as measured by an index that combines temperature, wind, humidity, and direct sunlight. For dry climates, such as Phoenix and Denver, National Weather Service heat indices above 90°F might allow work to proceed, while higher humidity areas such as New Orleans or Miami should consider 80 to 85°F as an initial level for work restrictions.[227] These trends and associated impacts will be exacerbated in many places by urban heat island effects (see *Human Health* and *Society* sectors).

Wildfires are projected to increase, especially in the Southwest (see *Southwest* region), threatening communities and infrastructure directly and bringing about road and rail closures in affected areas.

In many northern states, warmer winters will bring about reductions in snow and ice removal costs, lessen adverse environmental impacts from the use of salt and chemicals on roads and bridges, extend the construction season, and improve the mobility and safety of passenger and freight travel through reduced winter hazards. On the other hand, more freeze-thaw conditions are projected to occur in northern states, creating frost heaves and potholes on road and bridge surfaces and resulting in load restrictions on certain roads to minimize the damage. With the expected earlier onset of seasonal warming, the period of springtime load restrictions might be reduced in some areas, but it is likely to expand in others with shorter winters but longer thaw seasons. Longer construction seasons will be a benefit in colder locations.[222]

Water

Warming is projected to mean a longer shipping season but lower water levels for the Great Lakes and St. Lawrence Seaway. Higher temperatures, reduced lake ice, and increased evaporation are expected to combine to produce lower water levels as climate warming proceeds (see *Midwest* region). With lower lake levels, ships will be unable to carry as much cargo and hence shipping costs will increase. A recent study, for example, found that the projected reduction in Great Lakes water levels would result in an estimated 13 to 29 percent increase in shipping costs for Canadian commercial navigation by 2050, all else remaining equal.[222]

If low water levels become more common because of drier conditions due to climate change, this could create problems for river traffic, reminiscent of the stranding of more than 4,000 barges on the Mississippi River during the drought in 1988. Freight movements in the region could be seriously impaired, and extensive dredging could be required to keep shipping channels open. On the other hand, a longer shipping season afforded by a warmer climate could offset some of the resulting adverse economic effects.

Navigable Inland Waterways

Inland waterways are an important part of the transportation network in various parts of the United States. For example, these waterways provide 20 states with access to the Gulf of Mexico.[217] As conditions become drier, these main transportation pathways are likely to be adversely affected by the resulting lower water levels, creating problems for river traffic. Names of navigable rivers are shown above.

In cold areas, the projected decrease in very cold days will mean less ice accumulation on vessels, decks, riggings, and docks; less ice fog; and fewer ice jams in ports.[223]

Air

Rising temperatures will affect airport ground facilities, runways in particular, in much the same way they affect roads. Airports in some areas are likely to benefit from reduction in the cost of snow and ice removal and the impacts of salt and chemical use, though some locations have seen increases in snowfall. Airlines could benefit from reduced need to de-ice planes.

More heat extremes will create added operational difficulties, for example, causing greater energy consumption by planes on the ground. Extreme heat also affects aircraft lift; because hotter air is less dense, it reduces the lift produced by the wing and the thrust produced by the engine – problems exacerbated at high altitudes and high temperatures. As a result, planes need to take off faster, and if runways are not sufficiently long for aircraft to build up enough speed to generate lift, aircraft weight must be reduced. Thus, increases in extreme heat will result in payload restrictions, could cause flight cancellations and service disruptions at affected airports, and could require some airports to lengthen runways. Recent hot summers have seen flights cancelled due to heat, especially in high altitude locations. Economic losses are expected at affected airports. A recent illustrative analysis projects a 17 percent reduction in freight carrying capacity for a single Boeing 747 at the Denver airport by 2030 and a 9 percent reduction at the Phoenix airport due to increased temperature and water vapor.[222]

Drought

Rising air temperatures increase evaporation, contributing to dry conditions, especially when accompanied by decreasing precipitation. Even where total annual precipitation does not decrease, precipitation is projected to become less frequent in many parts of the country.[68] Drought is expected to be an increasing problem in some regions; this, in turn, has impacts on transportation. For example, increased susceptibility to wildfires during droughts could threaten roads and other transportation infrastructure directly, or cause road closures due to fire threat or reduced visibility such as has occurred in Florida and California in recent years. There is also increased susceptibility to mudslides in areas deforested by wildfires. Airports could suffer from decreased visibility due to wildfires. River transport is seriously affected by drought, with reductions in the routes available, shipping season, and cargo carrying capacity.

Increased intensity of strong hurricanes would lead to more evacuations, infrastructure damage and failure, and transportation interruptions.

More intense hurricanes in some regions are a projected effect of climate change. Three aspects of tropical storms are relevant to transportation: precipitation, winds, and wind-induced storm surge. Stronger hurricanes have longer periods of intense precipitation, higher wind speeds (damage increases exponentially with wind speed[228]), and higher storm surge and waves. Transportation planners, designers, and operators may need to adopt probabilistic approaches to developing transportation projects rather than relying on standards and the deterministic approaches of the past. The uncertainty associated with projecting impacts over a 50- to 100-year time period makes risk management a reasonable approach for realistically incorporating climate change into decision making and investment.[215]

Land

There will be a greater probability of infrastructure failures such as highway and rail bridge decks being displaced and railroad tracks being washed away. Storms leave debris on roads and rail lines, which can damage the infrastructure and interrupt travel and shipments of goods. In Louisiana, the Department of Transportation and Development spent $74 million for debris removal alone in the wake of hurricanes Katrina and Rita. The Mississippi Department of Transportation expected to spend in excess of $1 billion to replace the Biloxi and Bay St. Louis bridges, repair other portions of roadway, and remove debris. As of June 2007, more than $672 million had been spent.

There will be more frequent and potentially more extensive emergency evacuations. Damage to signs, lighting fixtures, and supports will increase. The lifetime of highways that have been exposed to flooding is expected to decrease. Road and rail infrastructure for passenger and freight services are likely to face increased flooding by strong hurricanes. In the Gulf Coast, more than one-third of the rail miles are likely to flood when subjected to a storm surge of 18 feet.[217]

Spotlight on Hurricane Katrina

Hurricane Katrina was one of the most destructive and expensive natural disasters in U.S. history, claiming more than 1,800 lives and causing an estimated $134 billion in damage.[217,229] It also seriously disrupted transportation systems as key highway and railroad bridges were heavily damaged or destroyed, necessitating rerouting of traffic and placing increased strain on other routes, particularly other rail lines. Replacement of major infrastructure took from months to years. The CSX Gulf Coast line was re-opened after five months and $250 million in reconstruction costs, while the Biloxi-Ocean Springs Bridge took more than two years to reopen. Barge shipping was halted, as was grain export out of the Port of New Orleans, the nation's largest site of grain exports. The extensive oil and gas pipeline network was shut down by the loss of electrical power, producing shortages of natural gas and petroleum products. Total recovery costs for the roads, bridges, and utilities as well as debris removal have been estimated at $15 billion to $18 billion.[217]

Hurricane Katrina damage to bridge

Redundancies in the transportation system, as well as the storm timing and track, helped keep the storm from having major or long-lasting impacts on national-level freight flows. For example, truck traffic was diverted from the collapsed bridge that carries highway I-10 over Lake Pontchartrain to highway I-12, which parallels I-10 well north of the Gulf Coast. The primary north-south highways that connect the Gulf Coast with major inland transportation hubs were not damaged and were open for nearly full commercial freight movement within days. The railroads were able to route some traffic not bound directly for New Orleans through Memphis and other Midwest rail hubs. While a disaster of historic proportions, the effects of Hurricane Katrina could have been even worse if not for the redundancy and resilience of the transportation network in the area.

Water

All aspects of shipping are disrupted by major storms. For example, freight shipments need to be diverted from the storm region. Activities at offshore drilling sites and coastal pumping facilities are generally suspended and extensive damage to these facilities can occur, as was amply demonstrated during the 2005 hurricane season. Refineries and pipelines are also vulnerable to damage and disruption due to the high winds and storm surge associated with hurricanes and other tropical storms (see *Energy* sector). Barges that are unable to get to safe harbors can be destroyed or severely damaged. Waves and storm surge will damage harbor infrastructure such as cranes, docks, and other terminal facilities. There are implications for emergency evacuation planning, facility maintenance, and safety management.

Air

More frequent interruptions in air service and airport closures can be expected. Airport facilities including terminals, navigational equipment, perimeter fencing, and signs are likely to sustain increased wind damage. Airports are frequently located in low-lying areas and can be expected to flood with more intense storms. As a response to this vulnerability, some airports, such as LaGuardia in New York City, are already protected by levees. Eight airports in the Gulf Coast region of Louisiana and Texas are located in historical 100-year flood plains; the 100-year flood events will be more frequent in the future, creating the likelihood of serious costs and disruption.[217]

Arctic warming will continue to reduce sea ice, lengthening the ocean transport season, but also resulting in greater coastal erosion due to waves. Permafrost thaw in Alaska will damage infrastructure. The ice road season will become shorter.

Special issues in Alaska

Warming has been most rapid in high northern regions. As a result, Alaska is warming at twice the rate of the rest of the nation, bringing both major opportunities and major challenges. Alaska's transportation infrastructure differs sharply from that of the lower 48 states. Although Alaska is twice the size of Texas, its population and road mileage are more like Vermont's. Only 30 percent of Alaska's roads are paved. Air travel is much more common than in other states. Alaska has 84 commercial airports and more than 3,000 airstrips, many of which are the only means of transport for rural communities. Unlike other states, over much of Alaska, the land is generally more accessible in winter, when the ground is frozen and ice roads and bridges formed by frozen rivers are available.

Sea ice decline

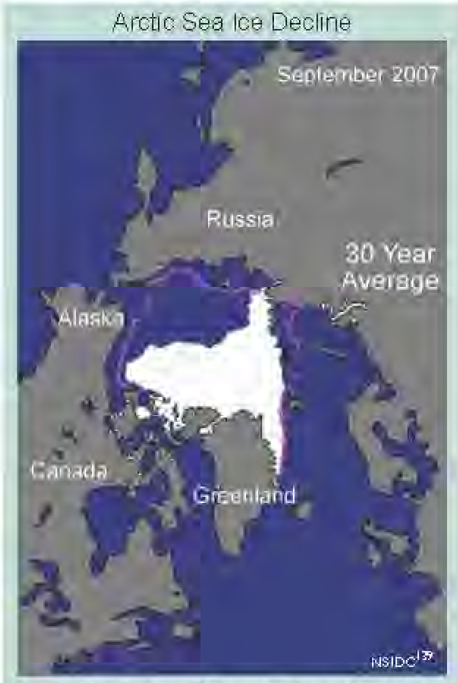
The striking thinning and downward trend in the extent of Arctic sea ice is regarded as a considerable opportunity for shippers. Continued reduction in sea ice should result in opening of additional ice-free ports, improved access to ports and natural resources in remote areas, and longer shipping seasons, but it is likely to increase erosion rates on land as well, raising costs for maintaining ports and other transportation infrastructure.[132,220]

Later this century and beyond, shippers are looking forward to new Arctic shipping routes, including the fabled Northwest Passage, which could provide significant costs savings in shipping times and distances. However, the next few decades are likely to be very unpredictable for shipping through these new routes. The past three decades have seen very high year-to-year variability of sea ice extent in the Canadian Arctic, despite the overall decrease in September sea ice extent. The loss of sea ice from the shipping channels of the Canadian Archipelago might actually allow more frequent intrusions of icebergs, which would continue to impede shipping through the Northwest Passage.

Lack of sea ice, especially on the northern shores of Alaska, creates conditions whereby storms produce waves that cause serious coastal erosion.[137,219] Already a number of small towns, roads, and airports are threatened by retreating coastlines, necessitating the planned relocation of these communities (see *Alaska* region).[132,220]

Thawing ground

The challenges warming presents for transportation on land are considerable.[164] For highways, thawing of permafrost causes settling of the roadbed and



The pink line shows the average September sea ice extent from 1979 through the present. The white area shows September 2007 sea ice extent. In 2008, the extent was slightly larger than 2007, but the ice was thinner, resulting in a lower total volume of sea ice. In addition, recent years have had less ice that persisted over numerous years and more first-year ice, which melts more quickly.[139]

frost heaves that adversely affect the integrity of the road structure and its load-carrying capacity. The majority of Alaska's highways are located in areas where permafrost is discontinuous, and dealing with thaw settlement problems already claims a significant portion of highway maintenance dollars.

Bridges and large culverts are particularly sensitive to movement caused by thawing permafrost and are often much more difficult than roads to repair and modify for changing site conditions. Thus, designing these facilities to take climate change into account is even more critical than is the case for roads.

Another impact of climate change on bridges is increased scouring. Hotter, drier summers in Alaska have led to increased glacial melting and longer periods of high streamflows, causing both increased sediment in rivers and scouring of bridge supporting piers and abutments. Temporary ice roads and bridges are commonly used in many parts of Alaska to access northern communities and provide support for the mining and oil and gas industries. Rising temperatures have already shortened the season during which these critical facilities can be used. Like the highway system, the Alaska Railroad crosses permafrost terrain, and frost heave and settlement from thawing affect some portions of the track, increasing maintenance costs.[28,132,220]

A significant number of Alaska's airstrips in the southwest, northwest, and interior of the state are built on permafrost. These airstrips will require major repairs or relocation if their foundations are compromised by thawing.

The cost of maintaining Alaska's public infrastructure is projected to increase 10 to 20 percent by 2030 due to warming, costing the state an additional $4 billion to $6 billion, with roads and airports accounting for about half of this cost.[230] Private infrastructure impacts have not been evaluated.[217]

The Trans-Alaska Pipeline System, which stretches from Prudhoe Bay in the north to the ice-free port of Valdez in the south, crosses a wide range of permafrost types and varying temperature conditions. More than half of the 800-mile pipeline is elevated on vertical supports over potentially unstable permafrost. Because the system was designed in the early 1970s on the basis of permafrost and climate conditions of the 1950 to 1970 period, it requires continuous monitoring and some supports have had to be replaced.

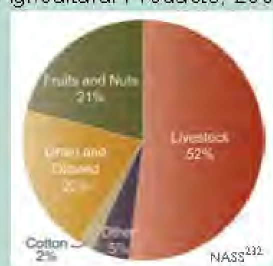
Travel over the tundra for oil and gas exploration and extraction is limited to the period when the ground is sufficiently frozen to avoid damage to the fragile tundra. In recent decades, the number of days that exploration and extraction equipment could be used has dropped from 200 days to 100 days per year due to warming.[220] With continued warming, the number of exploration days is expected to decline even more.

Agriculture

Key Messages:

- Many crops show positive responses to elevated carbon dioxide and low levels of warming, but higher levels of warming often negatively affect growth and yields.
- Extreme events such as heavy downpours and droughts are likely to reduce crop yields because excesses or deficits of water have negative impacts on plant growth.
- Weeds, diseases, and insect pests benefit from warming, and weeds also benefit from a higher carbon dioxide concentration, increasing stress on crop plants and requiring more attention to pest and weed control.
- Forage quality in pastures and rangelands generally declines with increasing carbon dioxide concentration because of the effects on plant nitrogen and protein content, reducing the land's ability to supply adequate livestock feed.
- Increased heat, disease, and weather extremes are likely to reduce livestock productivity.

Relative Contributions to Agricultural Products, 2002



Agriculture in the United States is extremely diverse in the range of crops grown and animals raised, and produces over $200 billion a year in food commodities, with livestock accounting for more than half. Climate change will increase productivity in certain crops and regions and reduce productivity in others (see for example *Midwest* and *Great Plains* regions).[193]

While climate change clearly affects agriculture, climate is also affected by agriculture, which contributes 13.5 percent of all human-induced greenhouse gas emissions globally. In the United States, agriculture represents 8.6 percent of the nation's total greenhouse gas emissions, including 80 percent of its nitrous oxide emissions and 31 percent of its methane emissions.[231]

Market Value of Agricultural Products Sold, 2002

Increased agricultural productivity will be required in the future to supply the needs of an increasing population. Agricultural productivity is dependent upon the climate and land resources. Climate change can have both beneficial and detrimental impacts on plants. Throughout history, agricultural enterprises have coped with changes in climate through changes in management and in crop or animal selection. However, under higher heat-trapping gas emissions scenarios, the projected climate changes are likely to increasingly challenge U.S. capacity to as efficiently produce food, feed, fuel, and livestock products.

Many crops show positive responses to elevated carbon dioxide and low levels of warming, but higher levels of warming often negatively affect growth and yields.

Crop responses in a changing climate reflect the interplay among three factors: rising temperatures, changing water resources, and increasing carbon dioxide concentrations. Warming generally causes plants that are below their optimum temperature to grow faster, with obvious benefits. For some plants, such as cereal crops, however, faster growth means there is less time for the grain itself to grow and mature, reducing yields.[193] For some annual crops, this can be compensated for by adjusting the planting date to avoid late season heat stress.[164]

The grain-filling period (the time when the seed grows and matures) of wheat and other small grains shortens dramatically with rising temperatures. Analysis of crop responses suggests that even moderate increases in temperature will decrease yields of corn, wheat, sorghum, bean, rice, cotton, and peanut crops.[193]

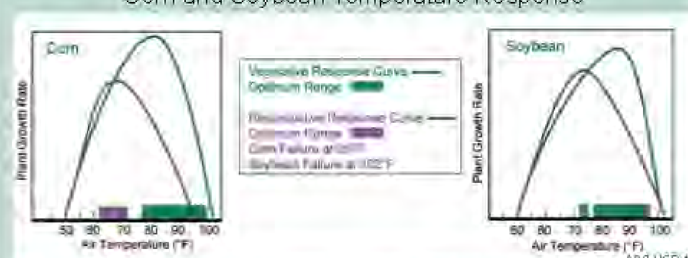
Some crops are particularly sensitive to high nighttime temperatures, which have been rising even faster than daytime temperatures.[68] Nighttime temperatures are expected to continue to rise in the future. These changes in temperature are especially critical to the reproductive phase of growth because warm nights increase the respiration rate and reduce the amount of carbon that is captured during the day by photosynthesis to be retained in the fruit or grain. Further, as temperatures continue to rise and drought periods increase, crops will be more frequently exposed to temperature thresholds at which pollination and grain-set processes begin to fail and quality of vegetable crops decreases. Grain, soybean, and canola crops have relatively low optimal temperatures, and thus will have reduced yields and will increasingly begin to experience failure as warming proceeds.[193] Common snap beans show substantial yield reduction when nighttime temperatures exceed 80°F.

Higher temperatures will mean a longer growing season for crops that do well in the heat, such as melon, okra, and sweet potato, but a shorter growing season for crops more suited to cooler conditions, such as potato, lettuce, broccoli, and spinach.[193] Higher temperatures also cause plants to use more water to keep cool. This is one example of how the interplay between rising temperatures and water availability is critical to how plants respond to climate change. But fruits, vegetables, and grains can suffer even under well-watered conditions if temperatures exceed the maximum level for pollen viability in a particular plant; if temperatures exceed the threshold for that plant, it won't produce seed and so it won't reproduce.[193]

Temperature increases will cause the optimum latitude for crops to move northward; decreases in temperature would cause shifts toward the equator. Where plants can be efficiently grown depends upon climate conditions, of which temperature is one of the major factors.

Plants need adequate water to maintain their temperature within an optimal range. Without water for cooling, plants will suffer heat stress. In many regions, irrigation water is used to maintain adequate temperature conditions for the growth of cool season plants (such as many vegetables), even in warm environments. With increasing demand and competition for freshwater supplies, the water needed for these crops might be increasingly limited. If water supply variability increases, it will affect plant growth and cause

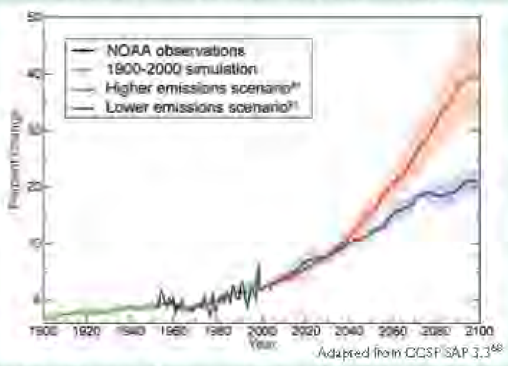
Corn and Soybean Temperature Response



ARS USDA

For each plant variety, there is an optimal temperature for vegetative growth, with growth dropping off as temperatures increase or decrease. Similarly, there is a range of temperatures at which a plant will produce seed. Outside of this range, the plant will not reproduce. As the graphs show, corn will fail to reproduce at temperatures above 95°F and soybean above 102°F.

Increase in Percent of Very Warm Nights



The graph shows the observed and projected change in percent of very warm nights from the 1950-1990 average in the United States. Under the lower emissions scenario,[91] the percentage of very warm nights is projected to increase about 20 percent by 2100. Under the higher emissions scenario,[91] it is projected to increase by about 40 percent.[68] The shaded areas show the likely ranges while the lines show the central projections from a set of climate models. The projections appear smooth because they show the calculated average of many models.

reduced yields. The amount and timing of precipitation during the growing season are also critical, and will be affected by climate change. Changes in season length are also important and affect crops differently.[193]

Higher carbon dioxide levels generally cause plants to grow larger. For some crops, this is not necessarily a benefit because they are often less nutritious, with reduced nitrogen and protein content. Carbon dioxide also makes some plants more water-use efficient, meaning they produce more plant material, such as grain, on less water.[193] This is a benefit in water-limited areas and in seasons with less than normal rainfall amounts.

In some cases, adapting to climate change could be as simple as changing planting dates, which can be an effective no- or low-cost option for taking advantage of a longer growing season or avoiding crop exposure to adverse climatic conditions such as high temperature stress or low rainfall periods. Effectiveness will depend on the region, crop, and the rate and amount of warming. It is unlikely to be effective if a farmer goes to market when the supply-demand balance drives prices down. Predicting the optimum planting date for maximum profits will be more challenging in a future with increased uncertainty regarding climate effects on not only local productivity, but also on supply from competing regions.[193]

Another adaptation strategy involves changing to crop varieties with improved tolerance to heat or drought, or those that are adapted to take advantage of a longer growing season. This is less likely to be cost-effective for perennial crops, for which changing varieties is extremely expensive and new plantings take several years to reach maximum productivity. Even for annual crops, changing varieties is not always a low-cost option. Seed for new stress-tolerant varieties can be expensive, and new varieties often require investments in new planting equipment or require adjustments in a wide range of farming practices. In some cases, it is difficult to breed for genetic tolerance to elevated temperature or to identify an alternative variety that is adapted to the new climate and to local soils, practices, and market demands.

Fruits that require long winter chilling periods will experience declines. Many varieties of fruits (such as popular varieties of apples and berries) require between 400 and 1,800 cumulative hours below 45°F each winter to produce abundant yields the following summer and fall. By late this century, under higher emissions scenarios,[91] winter temperatures in many important fruit-producing regions such as the Northeast will be too consistently warm to meet these requirements. Cranberries have a particularly high chilling requirement, and there are no known low-chill varieties. Massachusetts and New Jersey supply nearly half the nation's cranberry crop. By the middle of this century, under higher emissions scenarios,[91] it is unlikely that these areas will support cranberry production due to a lack of the winter chilling they need.[233,234] Such impacts will vary by region. For example, though there will still be risks of early-season frosts and damaging winter thaws, warming is expected to improve the climate for fruit production in the Great Lakes region.[164]

A seemingly paradoxical impact of warming is that it appears to be increasing the risk of plant frost

Effects of Increased Air Pollution on Crop Yields

Ground-level ozone (a component of smog) is an air pollutant that is formed when nitrogen oxides emitted from fossil fuel burning interact with other compounds, such as unburned gasoline vapors, in the atmosphere,[237] in the presence of sunlight. Higher air temperatures result in greater concentrations of ozone. Ozone levels at the land surface have risen in rural areas of the United States over the past 50 years, and they are forecast to continue increasing with warming, especially under higher emissions scenarios.[91] Plants are sensitive to ozone, and crop yields are reduced as ozone levels increase. Some crops that are particularly sensitive to ozone pollution include soybeans, wheat, oats, green beans, peppers, and some types of cotton.[193]

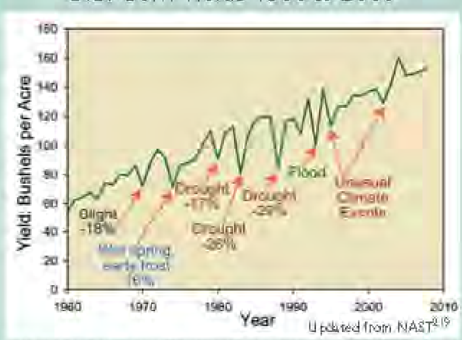
damage. Mild winters and warm, early springs, which are beginning to occur more frequently as climate warms, induce premature plant development and blooming, resulting in exposure of vulnerable young plants and plant tissues to subsequent late-season frosts. For example, the 2007 spring freeze in the eastern United States caused widespread devastation of crops and natural vegetation because the frost occurred during the flowering period of many trees and during early grain development on wheat plants.[235] Another example is occurring in the Rocky Mountains where in addition to the process described above, reduced snow cover leaves young plants unprotected from spring frosts, with some plant species already beginning to suffer as a result[236] (see *Ecosystems* sector).

Extreme events such as heavy downpours and droughts are likely to reduce crop yields because excesses or deficits of water have negative impacts on plant growth.

One of the most pronounced effects of climate change is the increase in heavy downpours. Precipitation has become less frequent but more intense, and this pattern is projected to continue across the United States.[112] One consequence of excessive rainfall is delayed spring planting, which jeopardizes profits for farmers paid a premium for early season production of high-value crops such as melon, sweet corn, and tomatoes. Field flooding during the growing season causes crop losses due to low oxygen levels in the soil, increased susceptibility to root diseases, and increased soil compaction due to the use of heavy farm equipment on wet soils. In spring 2008, heavy rains caused the Mississippi River to rise to about 7 feet above flood stage, inundating hundreds of thousands of acres of cropland. The flood hit just as farmers were preparing to harvest wheat and plant corn, soybeans, and cotton. Preliminary estimates of agricultural losses are around $8 billion.[213] Some farmers were put out of business and others will be recovering for years to come. The flooding caused severe erosion in some areas and also caused an increase in runoff and leaching of agricultural chemicals into surface water and groundwater.[233]

Another impact of heavy downpours is that wet conditions at harvest time result in reduced quality of many crops. Storms with heavy rainfall often are accompanied by wind gusts, and both strong winds and rain can flatten crops, causing significant damage. Vegetable and fruit crops are sensitive to even short-term, minor stresses, and as such are par-

U.S. Corn Yields 1960 to 2008



Updated from NAST[219]

While technological improvements have resulted in a general increase in corn yields, extreme weather events have caused dramatic reductions in yields in particular years. Increased variation in yield is likely to occur as temperatures increase and rainfall becomes more variable during the growing season. Without dramatic technological breakthroughs, yields are unlikely to continue their historical upward trend as temperatures rise above the optimum level for vegetative and reproductive growth.

ticularly vulnerable to weather extremes.[193] More rainfall concentrated into heavy downpours also increases the likelihood of water deficiencies at other times because of reductions in rainfall frequency.

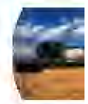
Drought frequency and severity are projected to increase in the future over much of the United States, particularly under higher emissions scenarios.[90,91] Increased drought will be occurring at a time when crop water requirements also are increasing due to rising temperatures. Water deficits are detrimental for all crops.[233]

Temperature extremes will also pose problems. Even crop species that are well-adapted to warmth, such as tomatoes, can have reduced yield and/or quality when daytime maximum temperatures exceed 90°F for even short periods during critical reproductive stages (see maps page 34).[112] For many high-value crops, just hours or days of moderate heat stress at critical growth stages can reduce grower profits by negatively affecting visual or flavor quality, even when total yield is not reduced.[238]

Weeds, diseases, and insect pests benefit from warming, and weeds also benefit from a higher carbon dioxide concentration, increasing stress on crop plants and requiring more attention to pest and weed control.

Weeds benefit more than cash crops from higher temperatures and carbon dioxide levels.[193] One concern with continued warming is the northward expansion of invasive weeds. Southern farmers currently lose more of their crops to weeds than do northern farmers. For example, southern farmers lose 64 percent of the soybean crop to weeds, while northern farmers lose 22 percent.[239] Some extremely aggressive weeds plaguing the South (such as kudzu) have historically been confined to areas where winter temperatures do not drop below specific thresholds. As temperatures continue to rise, these weeds will expand their ranges northward into important agricultural areas.[240] Kudzu currently has invaded 2.5 million acres of the Southeast and is a carrier of the fungal disease soybean rust, which represents a major and expanding threat to U.S. soybean production.[234]

Controlling weeds currently costs the United States more than $11 billion a year, with the majority spent on herbicides;[241] so both herbicide use and costs are likely to increase as temperatures and carbon dioxide levels rise. At the same time, the most widely used herbicide in the United States, glyphosate (RoundUp®), loses its efficacy on weeds grown at carbon dioxide levels that are projected to occur in the coming decades (see photos below). Higher concentrations of the chemical and more frequent spraying thus will be needed, increasing economic and environmental costs associated with chemical use.[233]



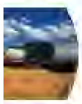
Many insect pests and crop diseases thrive due to warming, increasing losses and necessitating greater pesticide use. Warming aids insects and diseases in several ways. Rising temperatures allow both insects and pathogens to expand their ranges northward. In addition, rapidly rising winter temperatures allow more insects to survive over the winter, whereas cold winters once controlled their populations. Some of these insects, in addition to directly

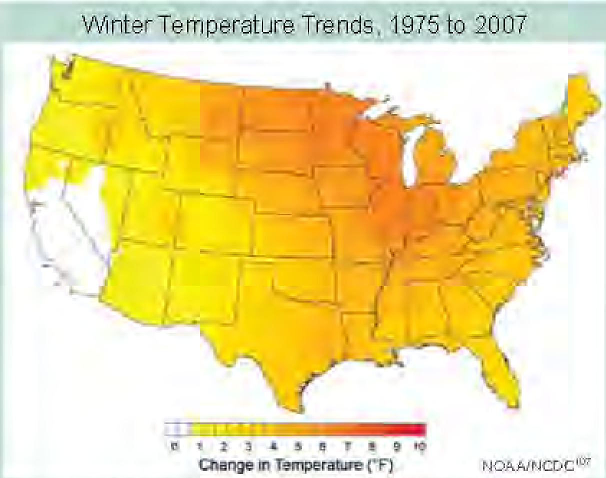
Herbicide Loses Effectiveness at Higher CO_2

Current CO_2 (380 ppm) Potential Future CO_2 (680 ppm)

The left photo shows weeds in a plot grown at a carbon dioxide (CO_2) concentration of about 380 parts per million (ppm), which approximates the current level. The right photo shows a plot in which the CO_2 level has been raised to about 680 ppm. Both plots were equally treated with herbicide.[233]

damaging crops, also carry diseases that harm crops. Crop diseases in general are likely to increase as earlier springs and warmer winters allow proliferation and higher survival rates of disease pathogens and parasites.[193,234] The longer growing season will allow some insects to produce more generations in a single season, greatly increasing their populations. Finally, plants grown in higher carbon dioxide conditions tend to be less nutritious, so insects must eat more to meet their protein requirements, causing greater destruction to crops.[193]





Temperatures are rising faster in winter than in any other season, especially in many key agricultural regions. This allows many insect pests and crop diseases to expand and thrive, creating increasing challenges for agriculture. As indicated by the map, the Midwest and northern Great Plains have experienced increases of more than 7°F in average winter temperatures over the past 30 years.

Due to the increased presence of pests, spraying is already much more common in warmer areas than in cooler areas. For example, Florida sweet corn growers spray their fields 15 to 32 times a year to fight pests such as corn borer and corn earworm, while New York farmers average zero to five times.[193] In addition, higher temperatures are known to reduce the effectiveness of certain classes of pesticides (pyrethroids and spinosad).

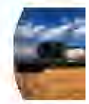
A particularly unpleasant example of how carbon dioxide tends to favor undesirable plants is found in the response of poison ivy to rising carbon dioxide concentrations. Poison ivy thrives in air with extra carbon dioxide in it, growing bigger and producing a more toxic form of the oil, urushiol, which causes painful skin reactions in 80 percent of people. Contact with poison ivy is one of the most widely reported ailments at poison centers in the United States, causing more than 350,000 cases of contact dermatitis each year. The growth stimulation of poison ivy due to increasing carbon dioxide concentration exceeds that of most other woody species. Given continued increases in carbon dioxide emissions, poison ivy is expected to become more abundant and more toxic in the future, with implications for forests and human health.[234]

Higher temperatures, longer growing seasons, and increased drought will lead to increased agricultural water use in some areas. Obtaining the maximum "carbon dioxide fertilization" benefit often requires more efficient use of water and fertilizers that better synchronize plant demand with supply. Farmers are likely to respond to more aggressive and invasive weeds, insects, and pathogens with increased use of herbicides, insecticides, and fungicides. Where increases in water and chemical inputs become necessary, this will increase costs for the farmer, as well as having society-wide impacts by depleting water supply, increasing reactive nitrogen and pesticide loads to the environment, and increasing risks to food safety and human exposure to pesticides.

Forage quality in pastures and rangelands generally declines with increasing carbon dioxide concentration because of the effects on plant nitrogen and protein content, reducing the land's ability to supply adequate livestock feed.

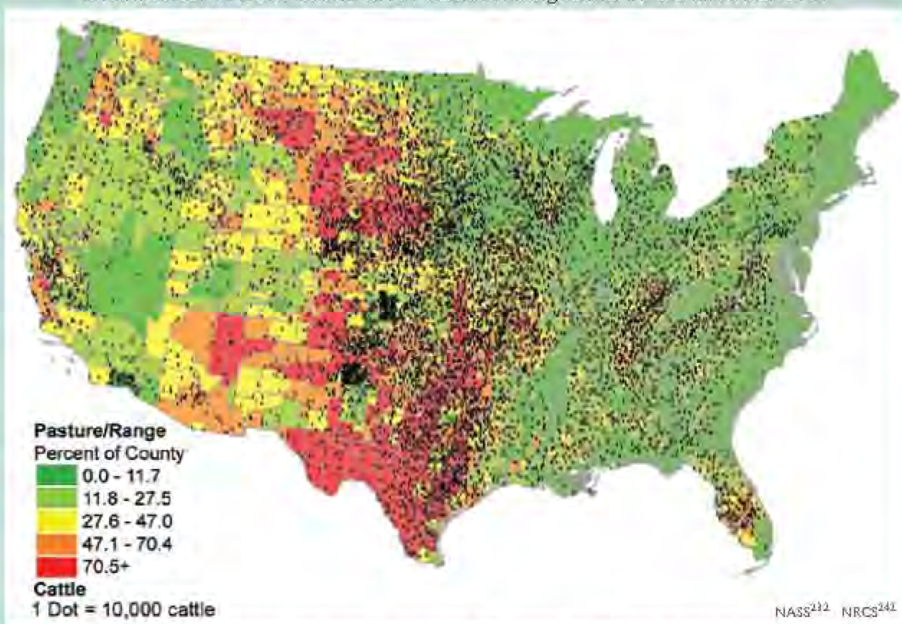
Beef cattle production takes place in every state in the United States, with the greatest number raised in regions that have an abundance of native or planted pastures for grazing. Generally, eastern pasturelands are planted and managed, whereas western rangelands are native pastures, which are not seeded and receive much less rainfall. There are transformations now underway in many semi-arid rangelands as a result of increasing atmospheric carbon dioxide concentration and the associated climate change. These transformations include which species of grasses dominate, as well as the forage quality of the dominant grasses. Increases in carbon dioxide are generally reducing the quality of the forage, so that more acreage is needed to provide animals with the same nutritional value, resulting in an overall decline in livestock productivity. In addition, woody shrubs and invasive cheatgrass are encroaching into grasslands, further reducing their forage value.[193] The combination of these factors leads to an overall decline in livestock productivity.

While rising atmospheric carbon dioxide concentration increases forage quantity, it has negative impacts on forage quality because plant nitrogen and protein concentrations often decline with higher concentrations of carbon dioxide.[193] This reduction in protein reduces forage quality and counters the positive effects of carbon dioxide enrichment on carbohydrates. Rising carbon dioxide concentration also has the potential to reduce the digestibility of forages that are already of poor quality. Reductions in forage quality could have pronounced detrimental effects on animal growth, reproduction, and survival, and could render livestock production unsustainable unless animal diets are supplemented with protein, adding more costs to production. On shortgrass prairie, for example, a carbon dioxide enrichment experiment reduced the protein concentration of autumn forage below critical maintenance levels for livestock in 3 out of 4 years and reduced the digestibility of forage by 14 percent in mid-summer and by 10 percent in autumn. Significantly, the grass type that thrived the most under excess carbon dioxide conditions also had the lowest protein concentration.[193]



At the scale of a region, the composition of forage plant species is determined mostly by climate and soils. The primary factor controlling the distribution and abundance of plants is water: both the

Distribution of Beef Cattle and Pasture/Rangeland in Continental U.S.



The colors show the percent of the county that is cattle pasture or rangeland, with red indicating the highest percentage. Each dot represents 10,000 cattle. Livestock production occurs in every state. Increasing concentration of carbon dioxide reduces the quality of forage, necessitating more acreage and resulting in a decline in livestock productivity.

amount of water plants use and water availability over time and space. The ability to anticipate vegetation changes at local scales and over shorter periods is limited because at these scales the response of vegetation to global-scale changes depends on a variety of local processes including the rate of disturbances such as fire and grazing, and the rate at which plant species can move across sometimes-fragmented landscapes. Nevertheless, some general patterns of vegetation change are beginning to emerge. For example, experiments indicate that a higher carbon dioxide concentration favors weeds and invasive plants over native species because invasives have traits (such as rapid growth rate and prolific seed production) that allow a larger growth response to carbon dioxide. In addition, the effect of a higher carbon dioxide concentration on plant species composition appears to be greatest where the land has been disturbed (such as by fire or grazing) and nutrient and light availability are high.[193]

Increases in temperature lengthen the growing season, and thus are likely to extend forage production into the late fall and early spring. However, overall productivity remains dependent on precipitation during the growing season.[193]

Increased heat, disease, and weather extremes are likely to reduce livestock productivity.

Like human beings, cows, pigs, and poultry are warm-blooded animals that are sensitive to heat. In terms of production efficiency, studies show that the negative effects of hotter summers will outweigh the positive effects of warmer winters. The more the U.S. climate warms, the more production will fall. For example, an analysis projected that a warming in the range of 9 to 11°F (as in the higher emissions scenarios[91]) would cause a 10 percent decline in livestock yields in cow/calf and dairy operations in Appalachia, the Southeast (including the Mississippi Delta), and southern Plains regions, while a warming of 2.7°F would cause less than a 1 percent decline.

Temperature and humidity interact to cause stress in animals, just as in humans; the higher the heat and humidity, the greater the stress and discomfort, and the larger the reduction in the animals' ability to produce milk, gain weight, and reproduce. Milk production declines in dairy operations, the number of days it takes for cows to reach their target weight grows longer in meat operations, conception rate in cattle falls, and swine growth rates decline due to heat. As a result, swine, beef, and milk production are all projected to decline in a warmer world.[193]

The projected increases in air temperatures will negatively affect confined animal operations (dairy, beef, and swine) located in the central United States, increasing production costs as a result of reductions in performance associated with lower feed intake and increased requirements for energy to maintain healthy livestock. These costs do not account for the increased death of livestock associated with extreme weather events such as heat waves. Nighttime recovery is an essential element of survival when livestock are stressed by extreme heat. A feature of recent heat waves is the lack of nighttime relief. Large numbers of deaths have occurred in recent heat waves, with individual states reporting losses of 5,000 head of cattle in a single heat wave in one summer.[193]

Warming also affects parasites and disease pathogens. The earlier arrival of spring and warmer winters allow greater proliferation and survival of parasites and disease pathogens.[193] In addition, changes in rainfall distributions are likely to lead to changes in diseases sensitive to moisture. Heat stress reduces animals' ability to cope with other stresses, such as diseases and parasites. Furthermore, changes in rainfall distributions could lead to changes in diseases sensitive to relative humidity.

Maintaining livestock production would require modifying facilities to reduce heat stress on animals, using the best understanding of the chronic and acute stresses that livestock will encounter to determine the optimal modification strategy.[193]

Changing livestock species as an adaptation strategy is a much more extreme, high-risk, and, in most cases, high-cost option than changing crop varieties. Accurate predictions of climate trends and development of the infrastructure and market for the new livestock products are essential to making this an effective response.

Ecosystems

Key Messages:

- Ecosystem processes, such as those that control growth and decomposition, have been affected by climate change.
- Large-scale shifts have occurred in the ranges of species and the timing of the seasons and animal migration, and are very likely to continue.
- Fires, insect pests, disease pathogens, and invasive weed species have increased, and these trends are likely to continue.
- Deserts and drylands are likely to become hotter and drier, feeding a self-reinforcing cycle of invasive plants, fire, and erosion.
- Coastal and near-shore ecosystems are already under multiple stresses. Climate change and ocean acidification will exacerbate these stresses.
- Arctic sea ice ecosystems are already being adversely affected by the loss of summer sea ice and further changes are expected.
- The habitats of some mountain species and coldwater fish, such as salmon and trout, are very likely to contract in response to warming.
- Some of the benefits ecosystems provide to society will be threatened by climate change, while others will be enhanced.

The natural functioning of the environment provides both goods – such as food and other products that are bought and sold – and services, which our society depends upon. For example, ecosystems store large amounts of carbon in plants and soils; they regulate water flow and water quality; and they stabilize local climates. These services are not assigned a financial value, but society nonetheless depends on them. Ecosystem processes are the underpinning of these services: photosynthesis, the process by which plants capture carbon dioxide from the atmosphere and create new growth; the plant and soil processes that recycle nutrients from decomposing matter and maintain soil fertility; and the processes by which plants draw water from soils and return water to the atmosphere. These ecosystem processes are affected by climate and by the concentration of carbon dioxide in the atmosphere.[70]

The diversity of living things (biodiversity) in ecosystems is itself an important resource that maintains the ability of these systems to provide the services upon which society depends. Many factors affect biodiversity including: climatic conditions; the influences of competitors, predators, parasites, and diseases; disturbances such as fire; and other physical factors. Human-induced climate change, in conjunction with other stresses, is exerting major influences on natural environments and biodiversity, and these influences are generally expected to grow with increased warming.[70]

Ecosystem processes, such as those that control growth and decomposition, have been affected by climate change.

Climate has a strong influence on the processes that control growth and development in ecosystems. Temperature increases generally speed up plant growth, rates of decomposition, and how rapidly the cycling of nutrients occurs, though other factors, such as whether sufficient water is available, also influence these rates. The growing season is lengthening as higher temperatures occur earlier in the spring. Forest growth has risen over the past several decades as a consequence of a number of factors – young forests reaching maturity, an increased concentration of carbon dioxide in the atmosphere, a longer growing season, and increased deposition of nitrogen from the atmosphere. Based on the current understanding of these processes, the individual effects are difficult to disentangle.[243]

79

A higher atmospheric carbon dioxide concentration causes trees and other plants to capture more carbon from the atmosphere, but experiments show that trees put much of this extra carbon into producing fine roots and twigs, rather than new wood. The effect of carbon dioxide in increasing growth thus seems to be relatively modest, and generally is seen most strongly in young forests on fertile soils where there is also sufficient water to sustain this growth. In the future, as atmospheric carbon dioxide continues to rise, and as climate continues to change, forest growth in some regions is projected to increase, especially in relatively young forests on fertile soils.[243]

Forest productivity is thus projected to increase in much of the East, while it is projected to decrease in much of the West where water is scarce and projected to become more so. Wherever droughts increase, forest productivity will decrease and tree death will increase. In addition to occurring in much of the West, these conditions are projected to occur in parts of Alaska and in the eastern part of the Southeast.[243]

Butterfly Range Shifts Northward

As climate warms, many species in the United States are shifting their ranges northward and to higher elevations. The map shows the response of Edith's checkerspot butterfly populations to a warming climate over the past 136 years in the American West. Over 70 percent of the southernmost populations (shown in yellow) have gone extinct. The northernmost populations and those above 8,000 feet elevation in the cooler climate of California's Sierra Nevada (shown in green) are still thriving. These differences in numbers of population extinctions across the geographic range of the butterfly have resulted in the average location shifting northward and to higher elevations over the past century, illustrating how climate change is altering the ranges of many species. Because their change in range is slow, most species are not expected to be able to keep up with the rapid climate change projected in the coming decades.[244]

Large-scale shifts have occurred in the ranges of species and the timing of the seasons and animal migration, and are very likely to continue.

Climate change is already having impacts on animal and plant species throughout the United States. Some of the most obvious changes are related to the timing of the seasons: when plants bud in spring, when birds and other animals migrate, and so on. In the United States, spring now arrives an average of 10 days to two weeks earlier than it did 20 years ago. The growing season is lengthening over much of the continental United States. Many migratory bird species are arriving earlier. For example, a study of northeastern birds that migrate long distances found that birds wintering in the southern United States now arrive back in the Northeast an average of 13 days earlier than they did during the first half of the last century. Birds wintering in South America arrive back in the Northeast an average of four days earlier.[70]

Another major change is in the geographic distribution of species. The ranges of many species in the United States have shifted northward and upward in elevation. For example, the ranges of many butterfly species have expanded northward, contracted at the southern edge, and shifted to higher elevations as warming has continued. A study of Edith's checkerspot butterfly showed that 40 percent of the populations below 2,400 feet have gone extinct, despite the availability of otherwise suitable habitat and food supply. The checkerspot's most southern populations also have gone extinct, while new populations have been established north of the previous northern boundary for the species.[70]

For butterflies, birds, and other species, one of the concerns with such changes in geographic range and timing of migration is the potential for mismatches between species and the resources they need to survive. The rapidly changing landscape, such as new highways and expanding urban areas, can create barriers that limit habitat and increase species loss. Failure of synchronicity between butterflies and the resources they depend upon has led to local population extinctions of the checkerspot butterfly during extreme drought and low-snowpack years in California.[70]

Tree species shifts

Forest tree species also are expected to shift their ranges northward and upslope in response to climate change, although specific quantitative predictions are very difficult to make because of the complexity of human land use and many other factors. This would result in major changes in the character of U.S. forests and the types of forests that will be most prevalent in different regions. In the United States, some common forests types are projected to expand, such as oak-hickory; others are projected to contract, such as maple-beech-birch. Still others, such as spruce-fir, are likely to disappear from the United States altogether.[243]

In Alaska, vegetation changes are already underway due to warming. Tree line is shifting northward into tundra, encroaching on the habitat for many migratory birds and land animals such as caribou that depend on the open tundra landscape.[245]

Marine species shifts and effects on fisheries

The distribution of marine fish and plankton are predominantly determined by climate, so it is not surprising that marine species in U.S. waters are moving northward and that the timing of plankton blooms is shifting. Extensive shifts in the ranges and distributions of both warmwater and coldwater species of fish have been documented.[70] For example, in the waters around Alaska, climate change already is causing significant alterations in marine ecosystems with important implications for fisheries and the people who depend on them (see *Alaska* region).

In the Pacific, climate change is expected to cause an eastward shift in the location of tuna stocks.[246] It is clear that such shifts are related to climate, including natural modes of climate variability such as the cycles of El Niño and La Niña. However, it is unclear how these modes of ocean variability will change as global climate continues to change, and therefore it is very difficult to predict quantitatively how marine fish and plankton species' distributions might shift as a function of climate change.[70]

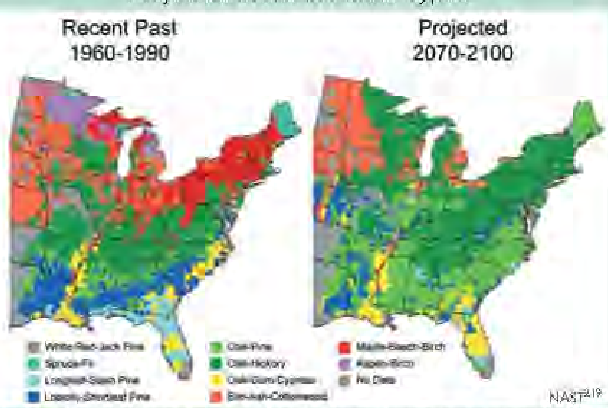
Breaking up of existing ecosystems

As warming drives changes in timing and geographic ranges for various species, it is important to note that entire communities of species do not shift intact. Rather, the range and timing of each species shifts in response to its sensitivity to climate change, its mobility, its lifespan, and the availability of the resources it needs (such as soil, moisture, food, and shelter). The speed with which species can shift their ranges is influenced by factors including their size, lifespan, and seed dispersal techniques in plants. In addition, migratory pathways must be available, such as northward flowing rivers which serve as conduits for fish. Some migratory pathways may be blocked by development and habitat fragmentation. All of these variations result in the breakup of existing ecosystems and formation of new ones, with unknown consequences.[220]

Extinctions and climate change

Interactions among impacts of climate change and other stressors can increase the risk of species extinction. Extinction rates of plants and animals have already risen considerably, with the vast majority of these extinctions attributed to loss of habitat or over-exploitation.[247] Climate change has been identified as a serious risk factor for the fu-

Projected Shifts in Forest Types



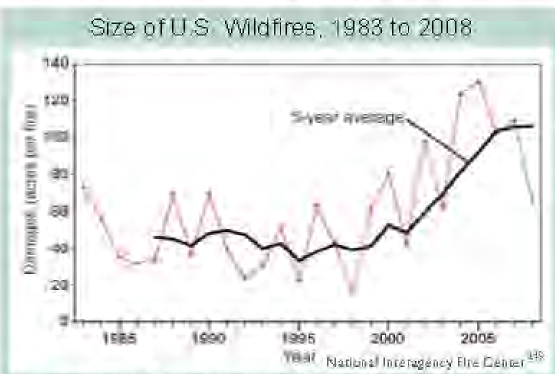
The maps show current and projected forest types. Major changes are projected for many regions. For example, in the Northeast, under a mid-range warming scenario, the currently dominant maple-beech-birch forest type is projected to be completely displaced by other forest types in a warmer future.[243]

ture, however, since it is one of the environmental stresses on species and ecosystems that is continuing to increase.[247] The Intergovernmental Panel on Climate Change has estimated that if a warming of 3.5 to 5.5°F occurs, 20 to 30 percent of species that have been studied would be in climate zones that are far outside of their current ranges, and would therefore likely be at risk of extinction.[248] One reason this percentage is so high is that climate change would be superimposed on other stresses including habitat loss and continued overharvesting of some species, resulting in considerable stress on populations and species.

Fires, insect pests, disease pathogens, and invasive weed species have increased, and these trends are likely to continue.

Forest fires

In the western United States, both the frequency of large wildfires and the length of the fire season have increased substantially in recent decades, due primarily to earlier spring snowmelt and higher spring and summer temperatures.[294] These changes in climate have reduced the availability of moisture, drying out the vegetation that provides the fuel for fires. Alaska also has experienced large increases in fire, with the area burned more than doubling in recent decades. As in the western United States, higher air temperature is a key factor. In Alaska, for example, June air temperatures alone explained approximately 38 percent of the increase in the area burned annually from 1950 to 2003.[243]



Data on wildland fires in the United States show that the number of acres burned per fire has increased since the 1980s.

Insect pests

Insect pests are economically important stresses on forest ecosystems in the United States. Coupled with pathogens, they cost $1.5 billion in damage per year. Forest insect pests are sensitive to climatic variations in many stages of their lives. Changes in climate have contributed significantly to several major insect pest outbreaks in the United States and Canada over the past several decades. The mountain pine beetle has infested lodgepole pine in British Columbia. Over 33 million acres of forest have been affected, by far the largest such outbreak in recorded history. Another 1.5 million acres have been infested by pine beetle in Colorado. Spruce beetle has affected more than 2.5 million acres in Alaska (see *Alaska* region) and western Canada. The combination of drought and high temperatures also has led to serious insect infestations and death of piñon pine in the Southwest, and to various insect pest attacks throughout the forests of the eastern United States.[243]

Rising temperatures increase insect outbreaks in a number of ways. First, winter temperatures above a certain threshold allow more insects to survive the cold season that normally limits their numbers. Second, the longer warm season allows them to develop faster, sometimes completing two life cycles instead of one in a single growing season. Third, warmer conditions help expand their ranges northward. And fourth, drought stress reduces trees' ability to resist insect attack (for example, by pushing back against boring insects with the pressure of their sap). Spruce beetle, pine beetle, spruce budworm, and woolly adelgid (which attacks eastern hemlocks) are just some of the insects that are proliferating in the United States, devastating many forests. These outbreaks are projected to increase with ongoing warming. Trees killed by insects also provide more dry fuel for wildfires.[70,243,250]

Disease pathogens and their carriers

One consequence of a longer, warmer growing season and less extreme cold in winter is that opportunities are created for many insect pests and disease pathogens to flourish. Accumulating evidence links the spread of disease pathogens to a warming climate. For example, a recent study showed that widespread amphibian extinctions in the mountains of Costa Rica are linked to changes in climatic conditions which are thought to have enabled the proliferation of an amphibian disease.[70,251]

Diseases that affect wildlife and the living things that carry these diseases have been expanding their geographic ranges as climate heats up. Depending on their specific adaptations to current climate, many parasites, and the insects, spiders, and scorpions that carry and transmit diseases, die or fail to develop below threshold temperatures. Therefore, as temperatures rise, more of these disease-carrying creatures survive. For some species, rates of reproduction, population growth, and biting, tend to increase with increasing temperatures, up to a limit. Some parasites' development rates and infectivity periods also increase with temperature.[70] An analysis of diseases among marine species found that diseases were increasing for mammals, corals, turtles, and mollusks, while no trends were detected for sharks, rays, crabs, and shrimp.[70]

Invasive plants

Problems involving invasive plant species arise from a mix of human-induced changes, including disturbance of the land surface (such as through over grazing or clearing natural vegetation for development), deliberate or accidental transport of non-native species, the increase in available nitrogen through over-fertilization of crops, and the rising carbon dioxide concentration and the resulting climate change.[243] Human-induced climate change is not generally the initiating factor, nor the most important one, but it is becoming a more important part of the mix.

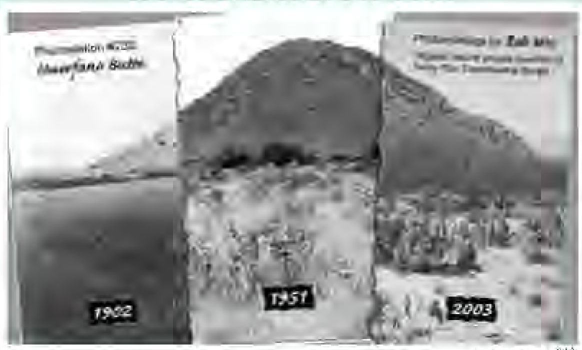
The increasing carbon dioxide concentration stimulates the growth of most plant species, and some invasive plants respond with greater growth rates than native plants. Beyond this, invasive plants appear to better tolerate a wider range of environmental conditions and may be more successful in a warming world because they can migrate and establish themselves in new sites more rapidly than native plants.[70] They are also not usually dependent on external pollinators or seed dispersers to reproduce. For all of these reasons, invasive plant species present a growing problem that is extremely difficult to control once unleashed.[70]

Deserts and drylands are likely to become hotter and drier, feeding a self-reinforcing cycle of invasive plants, fire, and erosion.

The arid Southwest is projected to become even drier in this century. There is emerging evidence that this is already underway.[34] Deserts in the United States are also projected to expand to the north, east, and upward in elevation in response to projected warming and associated changes in climate.

Increased drying in the region contributes to a variety of changes that exacerbate a cycle of desertification. Increased drought conditions cause perennial plants to die due to water stress and increased susceptibility to plant diseases. At the same time, non-native grasses have invaded the region. As these grasses increase in abundance, they provide more fuel for fires, causing fire frequency to increase in a self-reinforcing cycle that leads to further losses of vegetation. When it does rain, the rain tends to come in heavy downpours, and since there is less vegetation to protect the soil, water erosion increases. Higher air temperatures and decreased soil moisture reduce soil stability, further exacerbating erosion. And with a growing population needing water for urban uses, hydroelectric generation, and agriculture, there is increasing pressure on mountain water sources that would otherwise flow to desert river areas.[70,149]

Desertification of Arid Grassland
near Tucson, Arizona, 1902 to 2003



CCSP SAP 4.3[243]

The photo series shows the progression from arid grassland to desert (desertification) over a 100-year period. The change is the result of grazing management and reduced rainfall in the Southwest.[250,252,253]

83

The response of arid lands to climate change also depends on how other factors interact with climate at local scales. Large-scale, unregulated livestock grazing in the Southwest during the late 1800s and early 1900s is widely regarded as having contributed to widespread desertification. Grazing peaked around 1920 on public lands in the West. By the 1970s, grazing had been reduced by about 70 percent, but the arid lands have been very slow to recover from its impacts. Warmer and drier climate conditions are expected to slow recovery even more. In addition, the land resource in the Southwest is currently managed more for providing water for people than for protecting the productivity of the landscape. As a result, the land resource is likely to be further degraded and its recovery hampered.[243]

Coastal and near-shore ecosystems are already under multiple stresses. Climate change and ocean acidification will exacerbate these stresses.

Coastal and near-shore marine ecosystems are vulnerable to a host of climate change-related effects including increasing air and water temperatures, ocean acidification, changes in runoff from the land, sea-level rise, and altered currents. Some of these changes have already led to coral bleaching, shifts in species ranges, increased storm intensity in some regions, dramatic reductions in sea ice extent and thickness along the Alaskan coast,[137] and other significant changes to the nation's coastlines and marine ecosystems.[70]

The interface between land and sea is important, as many species, including many endangered species, depend on it at some point in their life cycle. In addition, coastal areas buffer inland areas from the effects of wave action and storms.[247] Coastal wetlands, intertidal areas, and other near-shore ecosystems are subject to a variety of environmental stresses.[254,255] Sea-level rise, increased coastal storm intensity, and rising temperatures contribute to increased vulnerability of coastal wetland ecosystems. It has been estimated that 3 feet of sea-level rise (within the range of projections for this century) would inundate about 65 percent of the coastal marshlands and swamps in the contiguous United States.[256] The combination of sea-level rise, local land sinking, and related factors already have resulted in substantially higher relative sea-level rise along the Gulf of Mexico and the mid-Atlantic coast, more so than on the Pacific Coast.[43,254] In Louisiana alone, over one-third of the coastal plain that existed a century ago has since been lost,[254] which is mostly due to local land sinking.[70] Barrier islands are also losing land at an increasing rate[257] (see *Southeast* region), and they are particularly important in protecting the coastline in some regions vulnerable to sea-level rise and storm surge.

Coral reefs

Coral reefs are very diverse ecosystems that support many other species by providing food and habitat. In addition to their ecological value, coral reefs provide billions of dollars in services including tourism, fish breeding habitat, and protection of coastlines. Corals face a host of challenges associated with human activities such as poorly regulated tourism, destructive fishing, and pollution, in addition to climate change-related stresses.[70]

Corals are marine animals that host symbiotic algae which help nourish the animals and give the corals their color. When corals are stressed by increases in water temperatures or ultraviolet light, they lose their algae and turn white, a process called coral bleaching. If the stress persists, the corals die. Intensities and frequencies of bleaching events, clearly driven by warming in surface water, have increased substantially over the past 30 years, leading to the death or severe damage of about one-third of the world's corals.[70]

The United States has extensive coral reef ecosystems in the Caribbean, Atlantic, and Pacific oceans. In 2005, the Caribbean basin experienced unprecedented water temperatures that resulted in dramatic coral bleaching with some sites in the U.S. Virgin Islands seeing 90 percent of the coral bleached. Some corals began to recover when water temperatures decreased, but later that year disease appeared, striking the previously bleached and weakened coral. To date, 50 percent of the corals in Virgin Islands National Park have died from the bleaching and disease events. In the Florida Keys, summer bleaching in 2005 was also followed by disease in September.[70]

But rising temperature is not the only stress coral reefs face. As the carbon dioxide concentration in the air increases, more carbon dioxide is absorbed into the world's oceans, leading to their acidification. This makes less calcium carbonate available for corals and other sea life to build their skeletons and shells.[258] If carbon dioxide concentrations continue to rise and the resulting acidification proceeds, eventually, corals and other ocean life that rely on calcium carbonate will not be able to build these skeletons and shells at all. The implications of such extreme changes in ocean ecosystems are not clear, but there is now evidence that in some ocean areas, such as along the Northwest coast, acidification is already occurring[70,259] (see *Coasts* region for more discussion of ocean acidification).

Arctic sea ice ecosystems are already being adversely affected by the loss of summer sea ice and further changes are expected.

Perhaps most vulnerable of all to the impacts of warming are Arctic ecosystems that rely on sea ice, which is vanishing rapidly and is projected to disappear entirely in summertime within this century. Algae that bloom on the underside of the sea ice form the base of a food web linking microscopic animals and fish to seals, whales, polar bears, and people. As the sea ice disappears, so too do these algae. The ice also provides a vital platform for ice-dependent seals (such as the ringed seal) to give birth, nurse their pups, and rest. Polar bears use the ice as a platform from which to hunt their prey. The walrus rests on the ice near the continental shelf between its dives to eat clams and other shellfish. As the ice edge retreats away from the shelves to deeper areas, there will be no clams nearby.[70,132,220]

The Bering Sea, off the west coast of Alaska, produces our nation's largest commercial fish harvests as well as providing food for many Native Alaskan peoples. Ultimately, the fish populations (and animals including seabirds, seals, walruses, and whales) depend on plankton blooms regulated by the extent and location of the ice edge in spring. As the sea ice continues to decline, the location, timing, and species composition of the blooms is changing. The spring melt of sea ice in the Bering Sea has long provided material that feeds the clams, shrimp, and other life forms on the ocean floor that, in turn, provide food for the walruses, gray whales, bearded seals, eider ducks, and many fish. The earlier ice melt resulting from warming, however, leads to later phytoplankton blooms that are largely consumed by microscopic animals near the sea surface, vastly decreasing the amount of food reaching the living things on the ocean floor. This will radically change the species composition of the fish and other creatures, with significant repercussions for both subsistence and commercial fishing.[70]

Ringed seals give birth in snow caves on the sea ice, which protect their pups from extreme cold and predators. Warming leads to earlier snow melt, which causes the snow caves to collapse before the pups are weaned. The small, exposed pups may die of hypothermia or be vulnerable to predation by arctic foxes, polar bears, gulls, and ravens. Gulls and ravens are arriving in the Arctic earlier as springs become warmer, increasing the birds' opportunity to prey on the seal pups.[70]

Polar bears are the top predators of the sea ice ecosystem. Because they prey primarily on ice-associated seals, they are especially vulnerable to the disappearance of sea ice. The bears' ability to catch seals depends on the presence of sea ice. In that habitat, polar bears take advantage of the fact that seals must surface to breathe in limited openings in the ice cover. In the open ocean, bears lack a hunting platform, seals are not restricted in where they can surface, and successful hunting is very rare. On shore, polar bears feed little, if at all.

About two-thirds of the world's polar bears are projected to be gone by the middle of this century. It is projected that there will be no wild polar bears in Alaska in 75 years.[70]

In addition, the rapid rate of warming in Alaska and the rest of the Arctic in recent decades is sharply reducing the snow cover in which polar bears build dens and the sea ice they use as foraging habitat. Female polar bears build snow dens in which they hibernate for four to five months each year and in which they give birth to their cubs. Born weighing only about 1 pound, the tiny cubs depend on the snow den for warmth.

About two-thirds of the world's polar bears are projected to be gone by the middle of this century. It is projected that there will be no wild polar bears left in Alaska in 75 years.[70]

Continued warming will inevitably entail major changes in the sea ice ecosystem, to the point that its viability is in jeopardy. Some species will become extinct, while others might adapt to new habitats. The chances of species surviving the current changes may depend critically on the rate of change. The current rates of change in the sea ice ecosystem are very rapid relative to the life spans of animals including seals, walruses, and polar bears, and as such, are a major threat to their survival.[70]

Forest Species Shift Upslope

Beckage et al.[260]/Adapted from Boston Globe/Landov

As climate warms, hardwood trees out-compete evergreen trees that are adapted to colder conditions.

The pika, pictured above, is a small mammal whose habitat is limited to cold areas near the tops of mountains. As climate warms, little suitable habitat is left. Of 25 pika populations studied in the Great Basin between the Rocky Mountains and the Sierra Nevada, more than one-third have gone extinct in recent decades.[241,242]

The habitats of some mountain species and coldwater fish, such as salmon and trout, are very likely to contract in response to warming.

Animal and plant species that live in the mountains are among those particularly sensitive to rapid climate change. They include animal species such as the grizzly bear, bighorn sheep, pika, mountain goat, and wolverine. Major changes have already been observed in the pika as previously reported populations have disappeared entirely as climate has warmed over recent decades.[70] One reason mountain species are so vulnerable is that their suitable habitats are being compressed as climatic zones shift upward in elevation. Some species try to shift uphill with the changing climate, but may face constraints related to food, other species present, and so on. In addition, as species move up the mountains, those near the top simply run out of habitat.[70]

Fewer wildflowers are projected to grace the slopes of the Rocky Mountains as global warming causes earlier spring snowmelt. Larkspur, aspen fleabane, and aspen sunflower grow at an altitude of about 9,500 feet where the winter snows are deep. Once the snow melts, the flowers form buds and prepare to bloom. But warmer springs mean that the snow melts earlier, leaving the buds exposed to frost. (The percentage of buds that were frosted has doubled over the past decade.) Frost does not kill the plants, but it does make them unable to seed and reproduce, meaning there will be no next generation. Insects and other animal species depend on the flowers for food, and other species depend on those species, so the loss is likely to propagate through the food chain.[236]

Shifts in tree species on mountains in New England, where temperatures have risen 2 to 4°F in the last 40 years, offer another example. Some mountain tree species have shifted uphill by 350 feet in the last 40 years. Tree communities were relatively unchanged at low and high elevations, but in the transition zone in between (at about 2,600 feet elevation) the changes have been dramatic. Cold-loving tree species declined from 43 to 18 percent, while warmer-loving trees increased from 57 to 82 percent. Overall, the transition zone has shifted about 350 feet uphill in just a few decades, a surprisingly rapid rate since these are trees that live for hundreds of years. One possibility is that as trees were damaged or killed by air pollution, it left an opportunity for the warming-induced transition to occur more quickly. These results indicate that the composition of high elevation forests is changing rapidly.[260]

Coldwater fish

Salmon and other coldwater fish species in the United States are at particular risk from warming. Salmon are under threat from a variety of human activities, but global warming is a growing source of stress. Rising temperatures affect salmon in several important ways. As precipitation increasingly falls as rain rather than snow, it feeds floods that wash away salmon eggs incubating in the streambed. Warmer water leads eggs to hatch earlier in the year, so the young are smaller and more vulnerable to predators. Warmer conditions increase the fish's metabolism, taking energy away from growth and forcing the fish to find more food, but earlier hatching of eggs could put them out of sync with the insects they eat. Earlier melting of snow leaves rivers and streams warmer and shallower in summer and fall. Diseases and parasites tend to flourish in warmer water. Studies suggest that up to 40 percent of Northwest salmon populations may be lost by 2050.[263]

Large declines in trout populations are also projected to occur around the United States. Over half of the wild trout populations are likely to disappear from the southern Appalachian Mountains because of the effects of rising stream temperatures. Losses of western trout populations may exceed 60 percent in certain regions. About 90 percent of bull trout, which live in western rivers in some of the country's most wild places, are projected to be lost due to warming. Pennsylvania is predicted to lose 50 percent of its trout habitat in the coming decades. Projected losses of trout habitat for some warmer states, such as North Carolina and Virginia, are up to 90 percent.[264]

Some of the benefits ecosystems provide to society will be threatened by climate change, while others will be enhanced.

Human well-being depends on the Earth's ecosystems and the services that they provide to sustain and fulfill human life.[265] These services are important to human well-being because they contribute to basic material needs, physical and psychological health, security, and economic activity. A recent assessment reported that of 24 vital ecosystem services, 15 were being degraded by human activity.[247] Climate change is one of several human-induced stresses that threaten to intensify and extend these adverse impacts to biodiversity, ecosystems, and the services they provide. Two of many possible examples follow.

Forests and carbon storage

Forests provide many services important to the well-being of Americans: air and water quality maintenance, water flow regulation, and watershed protection; wildlife habitat and biodiversity conservation; recreational opportunities and aesthetic and spiritual fulfillment; raw materials for wood and paper products; and climate regulation and carbon storage. A changing climate will alter forests and the services they provide. Most of these changes are likely to be detrimental.

In the United States, forest growth and long-lived forest products currently offset about 20 percent of U.S. fossil fuel carbon emissions.[140,257] This carbon "sink" is an enormous service provided by forests and its persistence or growth will be important to limiting the atmospheric carbon dioxide concentration. The scale of the challenge of increasing this sink is very large. To offset an additional 10 percent of U.S. emissions through tree planting would require converting one-third of current croplands to forests.[243]

Recreational opportunities

Tourism is one of the largest economic sectors in the world, and it is also one of the fastest growing,[266] the jobs created by recreational tourism provide economic benefits not only to individuals but also to communities. Slightly more than 90 percent of the U.S. population participates in some form of outdoor recreation, representing nearly 270 million participants,[267] and several billion days spent each year in a wide variety of outdoor recreation activities.

Since much recreation and tourism occurs outside, increased temperature and precipitation have a direct effect on the enjoyment of these activities, and on the desired number of visitor days and associated level of visitor spending as well as tourism employment. Weather conditions are an important factor influencing tourism visits. In addition, outdoor recreation and tourism often depends on the availability and quality of natural resources,[268] such as beaches, forests, wetlands, snow, and wildlife, all of which will be affected by climate change.

Thus, climate change can have direct effects on the natural resources that people enjoy. The length of the season for, and desirability of, several of the most popular activities – walking; visiting a beach, lakeshore, or river; sightseeing; swimming; and picnicking[267] – are likely to be enhanced by small near-term increases in temperature. Other activities are likely to be harmed by even small increases in warming, such as snow- and ice-dependent activities including skiing, snowmobiling, and ice fishing.

The net economic effect of near-term climate change on recreational activities is likely to be positive. In the longer term, however, as climate change effects on ecosystems and seasonality become more pronounced, the net economic effect on tourism and recreation is not known with certainty.[172]

Adaptation: Preserving Coastal Wetlands

Coastal wetlands are rich ecosystems that protect the shore from damage during storm surges and provide society with other services. One strategy designed to preserve coastal wetlands as sea level rises is the "rolling easement." Rolling easements allow some development near the shore, but prohibit construction of seawalls or other armoring to protect buildings; they recognize nature's right-of-way to advance inland as sea level rises. Massachusetts and Rhode Island prohibit shoreline armoring along the shores of some estuaries so that ecosystems can migrate inland, and several states limit armoring along ocean shores.[269,270]

Modified from CCSP SAP 4.1[271]

In the case shown here, the coastal marsh would reach the footprint of the house 40 years in the future. Because the house is on pilings, it could still be occupied if it is connected to a community sewage treatment system; a septic system would probably fail due to proximity to the water table. After 80 years, the marsh would have taken over the yard, and the footprint of the house would extend onto public property. The house could still be occupied but reinvestment in the property would be unlikely. After 100 years, this house would be removed, although some other houses in the area could still be occupied. Eventually, the entire area would return to nature. A home with a rolling easement would depreciate in value rather than appreciate like other coastal real estate. But if the loss were expected to occur 100 years from now, it would only reduce the current property value by 1 to 5 percent, for which the owner could be compensated.[271]

Human Health

Key Messages:

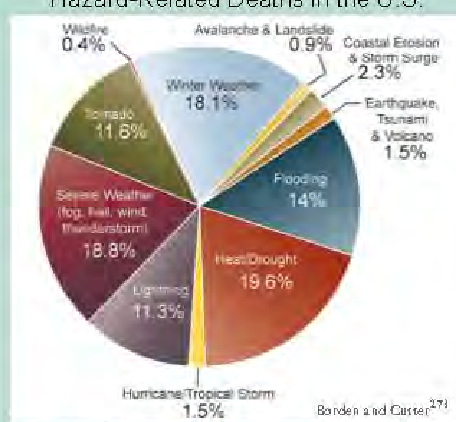
- Increases in the risk of illness and death related to extreme heat and heat waves are very likely. Some reduction in the risk of death related to extreme cold is expected.
- Warming is likely to make it more challenging to meet air quality standards necessary to protect public health.
- Extreme weather events cause physical and mental health problems. Some of these events are projected to increase.
- Some diseases transmitted by food, water, and insects are likely to increase.
- Rising temperature and carbon dioxide concentration increase pollen production and prolong the pollen season in a number of plants with highly allergenic pollen, presenting a health risk.
- Certain groups, including children, the elderly, and the poor, are most vulnerable to a range of climate-related health effects.

Climate change poses unique challenges to human health. Unlike health threats caused by a particular toxin or disease pathogen, there are many ways that climate change can lead to potentially harmful health effects. There are direct health impacts from heat waves and severe storms, ailments caused or exacerbated by air pollution and airborne allergens, and many climate-sensitive infectious diseases.[163]

Realistically assessing the potential health effects of climate change must include consideration of the capacity to manage new and changing climate conditions.[163] Whether or not increased health risks due to climate change are realized will depend largely on societal responses and underlying vulnerability. The probability of exacerbated health risks due to climate change points to a need to maintain a strong public health infrastructure to help limit future impacts.[163]

Increased risks associated with diseases originating outside the United States must also be considered because we live in an increasingly globalized world. Many poor nations are expected to suffer even greater health consequences from climate change.[272] With global trade and travel, disease flare-ups in any part of the world can potentially reach the United States. In addition, weather and climate extremes such as severe storms and drought can undermine public health infrastructure, further stress environmental resources, destabilize economies, and potentially create security risks both within the United States and internationally.[219]

Hazard-Related Deaths in the U.S.



The pie chart shows the distribution of deaths for 11 hazard categories as a percent of the total 19,958 deaths due to these hazards from 1970 to 2004. Heat/drought ranks highest, followed by severe weather, which includes events with multiple causes such as lightning, wind, and rain.[273] This analysis ended prior to the 2005 hurricane season which resulted in approximately 2,000 deaths.[229]

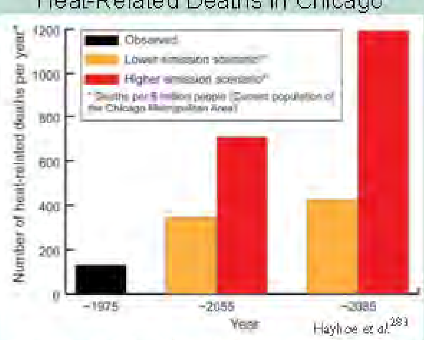
89

Increases in the risk of illness and death related to extreme heat and heat waves are very likely. Some reduction in the risk of death related to extreme cold is expected.

Temperatures are rising and the probability of severe heat waves is increasing. Analyses suggest that currently rare extreme heat waves will become much more common in the future (see *National Climate Change*).[68] At the same time, the U.S. population is aging, and older people are more vulnerable to hot weather and heat waves. The percentage of the U.S. population over age 65 is currently 12 percent and is projected to be 21 percent by 2050 (over 86 million people).[163,274] Diabetics are also at greater risk of heat-related death, and the prevalence of obesity and diabetes is increasing. Heat-related illnesses range from heat exhaustion to kidney stones.[275,276]

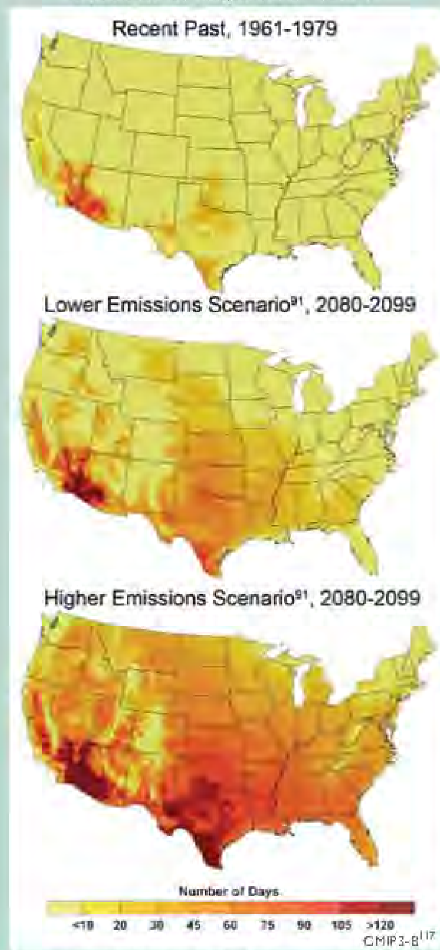
Heat is already the leading cause of weather-related deaths in the United States. More than 3,400 deaths between 1999 and 2003 were reported as resulting from exposure to excessive heat.[277] An analysis of nine U.S. cities shows that deaths due to heat increase with rising temperature and humidity.[278] From the 1970s to the 1990s, however, heat-related deaths declined.[279] This likely resulted from a rapid increase in the use of air conditioning. In 1978, 44 percent of households were without air conditioning, whereas in 2005, only 16 percent of the U.S. population lived without it (and only 3 percent did not have it in the South).[280,281] With air conditioning reaching near saturation, a recent study found that the general decline in heat-related deaths seems to have leveled off since the mid-1990s.[282]

Projected Increase in Heat-Related Deaths in Chicago



Increases in heat-related deaths are projected in cities around the nation, especially under higher emissions scenarios.[91] This analysis included some, but not all possible, adaptation measures. The graph shows the projected number of deaths per year, averaged over a three-decade period around 1975, 2055, and 2085 for the City of Chicago under lower and higher emissions.[91]

Number of Days Over 100°F



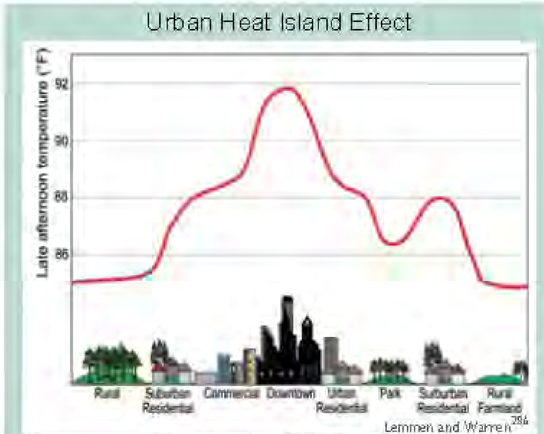
The number of days in which the temperature exceeds 100°F by late this century, compared to the 1960s and 1970s, is projected to increase strongly across the United States. For example, parts of Texas that recently experienced about 10 to 20 days per year over 100°F are expected to experience more than 100 days per year in which the temperature exceeds 100°F by the end of the century under the higher emissions scenario.[91]

As human-induced warming is projected to raise average temperatures by about 6 to 11°F in this century under a higher emissions scenario,[91] heat waves are expected to continue to increase in frequency, severity, and duration.[68,112] For example, by the end of this century, the number of heat-wave days in Los Angeles is projected to double,[284] and the number in Chicago to quadruple,[285] if emissions are not reduced.

Projections for Chicago suggest that the average number of deaths due to heat waves would more than double by 2050 under a lower emissions scenario[91] and quadruple under a high emissions scenario[91] (see figure page 90).[283]

A study of climate change impacts in California projects that, by the 2090s, annual heat-related deaths in Los Angeles would increase by two to three times under a lower emissions scenario and by five to seven times under a higher emissions scenario, compared to a 1990s baseline of about 165 deaths. These estimates assume that people will have become somewhat more accustomed to higher temperatures. Without such acclimatization, these estimates are projected to be about 20 to 25 percent higher.[284]

The full effect of global warming on heat-related illness and death involves a number of factors including actual changes in temperature (averages, highs, and lows); and human population characteristics, such as age, wealth, and fitness. In addition, adaptation at the scale of a city includes options such as heat wave early warning systems, urban design to reduce heat loads, and enhanced services during heat waves.[163]



Large amounts of concrete and asphalt in cities absorb and hold heat. Tall buildings prevent heat from dissipating and reduce air flow. At the same time, there is generally little vegetation to provide shade and evaporative cooling. As a result, parts of cities can be up to 10°F warmer than the surrounding rural areas, compounding the temperature increases that people experience as a result of human-induced warming.[313]

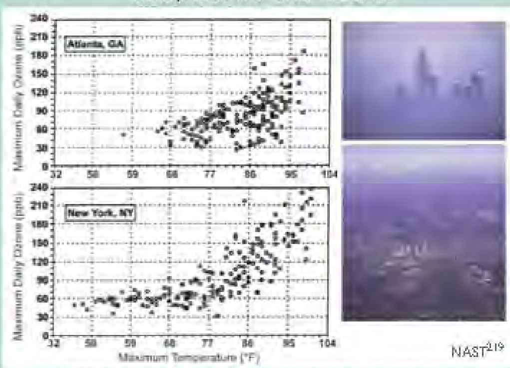
Reduced extreme cold

In a warmer world, the number of deaths caused by extremely low temperatures would be expected to drop, although in general, it is uncertain how climate change will affect net mortality.[163] Nevertheless, a recent study that analyzed daily mortality and weather data with regard to 6,513,330 deaths in 50 U.S. cities between 1989 and 2000 shows a marked difference between deaths resulting from hot and cold temperatures. The researchers found that, on average, cold snaps increased death rates

Adaptation: Reducing Deaths During Heat Waves

In the mid-1990s, Philadelphia became the first U.S. city to implement a system for reducing the risk of death during heat waves. The city focuses its efforts on the elderly, homeless, and poor. During a heat wave, a heat alert is issued and news organizations are provided with tips on how vulnerable people can protect themselves. The health department and thousands of block captains use a buddy system to check on elderly residents in their homes; electric utilities voluntarily refrain from shutting off services for non-payment; and public cooling places extend their hours. The city operates a "Heatline" where nurses are standing by to assist callers experiencing health problems; if callers are deemed "at risk," mobile units are dispatched to the residence. The city has also implemented a "Cool Homes Program" for elderly, low-income residents, which provides measures such as roof coatings and roof insulation that save energy and lower indoor temperatures. Philadelphia's system is estimated to have saved 117 lives over its first 3 years of operation.[287,288]

Temperature and Ozone



NAST[219]

The graphs illustrate the observed association between ground-level ozone (a component of smog) concentration in parts per billion (ppb) and temperature in Atlanta and New York City (May to October 1988 to 1990).[219] The projected higher temperatures across the United States in this century are likely to increase the occurrence of high ozone concentrations, although this will also depend on emissions of ozone precursors and meteorological factors. Ground-level ozone can exacerbate respiratory diseases and cause short-term reductions in lung function.

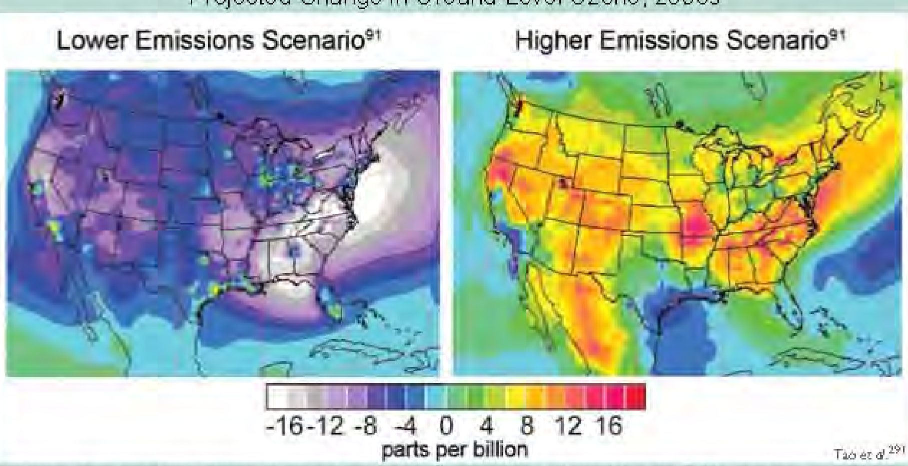
by 1.6 percent, while heat waves triggered a 5.7 percent increase in death rates.[289] The analysis found that the reduction in deaths as a result of relatively milder winters attributable to global warming will be substantially less than the increase in deaths due to summertime heat extremes.

Many factors contribute to winter deaths, including highly seasonal diseases such as influenza and pneumonia. It is unclear how these diseases are affected by temperature.[163]

Warming is likely to make it more challenging to meet air quality standards necessary to protect public health.

Poor air quality, especially in cities, is a serious concern across the United States. Half of all Americans, 158 million people, live in counties where air pollution exceeds national health standards.[290] While the Clean Air Act has improved air quality, higher temperatures and associated stagnant air masses are expected to make it more challenging to meet air quality standards, particularly for ground-level ozone (a component of smog).[13] It

Projected Change in Ground-Level Ozone, 2090s



Tao et al.[291]

The maps show projected changes in ground-level ozone (a component of smog) for the 2090s, averaged over the summer months (June through August), relative to 1996-2000, under lower and higher emissions scenarios, which include both greenhouse gases and emissions that lead to ozone formation (some of which decrease under the lower emissions scenario).[91] By themselves, higher temperatures and other projected climate changes would increase ozone levels under both scenarios. However, the maps indicate that future projections of ozone depend heavily on emissions, with the higher emissions scenario[91] increasing ozone by large amounts, while the lower emissions scenario[91] results in an overall decrease in ground-level ozone by the end of the century.[291]

has been firmly established that breathing ozone results in short-term decreases in lung function and damages the cells lining the lungs. It also increases the incidence of asthma-related hospital visits and premature deaths.[272] Vulnerability to ozone effects is greater for those who spend time outdoors, especially with physical exertion, because this results in a higher cumulative dose to their lungs. As a result, children, outdoor workers, and athletes are at higher risk for these ailments.[163]

Ground-level ozone concentrations are affected by many factors including weather conditions, emissions of gases from vehicles and industry that lead

Spotlight on Air Quality in California

Californians currently experience the worst air quality in the nation. More than 90 percent of the population lives in areas that violate state air quality standards for ground-level ozone or small particles. These pollutants cause an estimated 8,800 deaths and over a billion dollars in health care costs every year in California.[292] Higher temperatures are projected to increase the frequency, intensity, and duration of conditions conducive to air pollution formation, potentially increasing the number of days conducive to air pollution by 75 to 85 percent in Los Angeles and the San Joaquin Valley, toward the end of this century, under a higher emissions scenario, and by 25 to 35 percent under a lower emissions scenario.[293] Air quality could be further compromised by wildfires, which are already increasing as a result of warming.[252,294]

Adaptation: Improving Urban Air Quality

Because ground-level ozone is related to temperature (see figure at top of previous page), air quality is projected to become worse with human-induced climate change. Many areas in the country already have plans in place for responding to air quality problems. For example, the Air Quality Alert program in Rhode Island encourages residents to reduce air pollutant emissions by limiting car travel and the use of small engines, lawn mowers, and charcoal lighter fluids on days when ground-level ozone is high. Television weather reports include alerts when ground-level ozone is high, warning especially susceptible people to limit their time outdoors. To help cut down on the use of cars, all regular bus routes are free on Air Quality Alert days.[295]

Pennsylvania offers the following suggestions for high ozone days:

- Refuel vehicles after dark. Avoid spilling gasoline and stop fueling when the pump shuts off automatically.
- Conserve energy. Do not overcool homes. Turn off lights and appliances that are not in use. Wash clothes and dishes only in full loads.
- Limit daytime driving. Consider carpooling or taking public transportation. Properly maintain vehicles, which also helps to save fuel.
- Limit outdoor activities, such as mowing the lawn or playing sports, to the evening hours.
- Avoid burning leaves, trash, and other materials.

Traffic restrictions imposed during the 1996 summer Olympics in Atlanta quantified the direct respiratory health benefits of reducing the number of cars and the amount of their tailpipe emissions from an urban environment. Peak morning traffic decreased by 23 percent, and peak ozone levels dropped by 28 percent. As a result, childhood asthma-related emergency room visits fell by 42 percent.[296]

93

to ozone formation (especially nitrogen oxides and volatile organic compounds [VOCs]), natural emissions of VOCs from plants, and pollution blown in from other places.[290,297] A warmer climate is projected to increase the natural emissions of VOCs, accelerate ozone formation, and increase the frequency and duration of stagnant air masses that allow pollution to accumulate, which will exacerbate health symptoms.[298] Increased temperatures and water vapor due to human-induced carbon dioxide emissions have been found to increase ozone more in areas with already elevated concentrations, meaning that global warming tends to exacerbate ozone pollution most in already polluted areas. Under constant pollutant emissions, by the middle of this century, Red Ozone Alert Days (when the air is unhealthy for everyone) in the 50 largest cities in the eastern United States are projected to increase by 68 percent due to warming alone.[298] Such conditions would challenge the ability of communities to meet health-based air quality standards such as those in the Clean Air Act.

Health risks from heat waves and air pollution are not necessarily independent. The formation of ground-level ozone occurs under hot and stagnant conditions – essentially the same weather conditions accompanying heat waves (see box page 102). Such interactions among risk factors are likely to increase as climate change continues.

Extreme weather events cause physical and mental health problems. Some of these events are projected to increase.

Injury, illness, emotional trauma, and death are known to result from extreme weather events.[68] The number and intensity of some of these events are already increasing and are projected to increase further in the future.[68,112] Human health impacts in the United States are generally expected to be less severe than in poorer countries where the emergency preparedness and public health infrastructure is less developed. For example, early warning and evacuation systems and effective sanitation lessen the health impacts of extreme events.[68]

This assumes that medical and emergency relief systems in the United States will function well and that timely and effective adaptation measures will be developed and deployed. There have already been serious failures of these systems in the aftermath of hurricanes Katrina and Rita, so coping with future impacts will require significant improvements.

Extreme storms

Over 2,000 Americans were killed in the 2005 hurricane season, more than double the average number of lives lost to hurricanes in the United States over the previous 65 years.[163] But the human health impacts of extreme storms go beyond direct injury and death to indirect effects such as carbon monoxide poisoning from portable electric generators in use following hurricanes, an increase in stomach and intestinal illness among evacuees, and mental health impacts such as depression and post-traumatic stress disorder.[163] Failure to fully account for both direct and indirect health impacts might result in inadequate preparation for and response to future extreme weather events.[163]

Floods

Heavy downpours have increased in recent decades and are projected to increase further as the world continues to warm.[68,112] In the United States, the amount of precipitation falling in the heaviest 1 percent of rain events increased by 20 percent in the past century, while total precipitation increased by 7 percent. Over the last century, there was a 50 percent increase in the frequency of days with precipitation over 4 inches in the upper Midwest.[112] Other regions, notably the South, have also seen strong increases in heavy downpours, with most of these coming in the warm season and almost all of the increase coming in the last few decades.

Heavy rains can lead to flooding, which can cause health impacts including direct injuries as well as increased incidence of waterborne diseases due to pathogens such as *Cryptosporidium* and *Giardia*.[163] Downpours can trigger sewage overflows, contaminating drinking water and endangering beachgoers. The consequences will be particularly severe in the roughly 770 U.S. cities and towns, including New York, Chicago, Washington DC, Milwaukee, and Philadelphia, that have "combined sewer systems;" an older design that carries storm water and sewage in the same pipes.[299] During heavy rains, these systems often cannot handle the volume, and raw sewage spills into lakes or waterways, including drinking-water supplies and places where people swim.[252]

In 1994, the Environmental Protection Agency (EPA) established a policy that mandates that communities substantially reduce or eliminate their combined sewer overflow, but this mandate remains unfulfilled.[300] In 2004, the EPA estimated it would cost $55 billion to correct combined sewer overflow problems in publicly owned wastewater treatment systems.[301]

Using 2.5 inches of precipitation in one day as the threshold for initiating a combined sewer overflow event, the frequency of these events in Chicago is expected to rise by 50 percent to 120 percent by the end of this century,[302] posing further risks to drinking and recreational water quality.

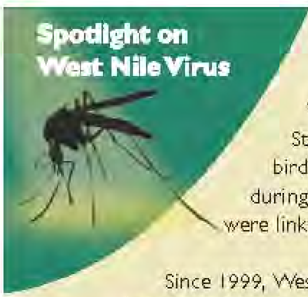
Wildfires

Wildfires in the United States are already increasing due to warming. In the West, there has been a nearly fourfold increase in large wildfires in recent decades, with greater fire frequency, longer fire durations, and longer wildfire seasons. This increase is strongly associated with increased spring and summer temperatures and earlier spring snowmelt, which have caused drying of soils and vegetation.[163,252,294] In addition to direct injuries and deaths due to burns, wildfires can cause eye and respiratory illnesses due to fire-related air pollution.[163]

Some diseases transmitted by food, water, and insects are likely to increase.

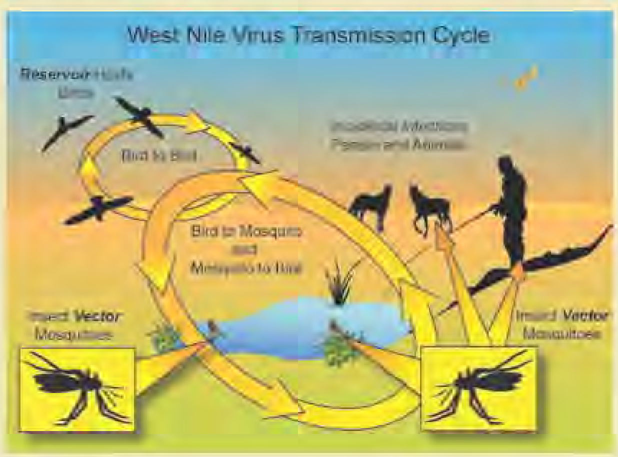
A number of important disease-causing agents (pathogens) commonly transmitted by food, water,

Spotlight on West Nile Virus



The first outbreak of West Nile virus in the United States occurred in the summer of 1999, likely a result of international air transport. Within five years, the disease had spread across the continental United States, transmitted by mosquitoes that acquire the virus from infected birds. While bird migrations were the primary mode of disease spread, during the epidemic summers of 2002 to 2004, epicenters of West Nile virus were linked to locations with either drought or above average temperatures.

Since 1999, West Nile virus has caused over 28,000 reported cases, and over 1,100 Americans have died from it.[303] During 2002, a more virulent strain of West Nile virus emerged in the United States. Recent analyses indicate that this mutated strain responds strongly to higher temperatures, suggesting that greater risks from the disease may result from increases in the frequency of heatwaves,[304] though the risk will also depend on the effectiveness of mosquito control programs.



While West Nile virus causes mild flu-like symptoms in most people, about one in 150 infected people develop serious illness, including the brain inflammation diseases encephalitis and meningitis.

or animals are susceptible to changes in replication, survival, persistence, habitat range, and transmission as a result of changing climatic conditions such as increasing temperature, precipitation, and extreme weather events.[163]

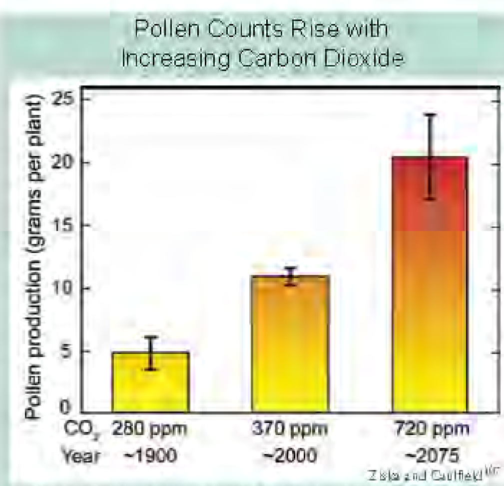
- Cases of food poisoning due to *Salmonella* and other bacteria peak within one to six weeks of the highest reported ambient temperatures.[163]
- Cases of waterborne *Cryptosporidium* and *Giardia* increase following heavy downpours. These parasites can be transmitted in drinking water and through recreational water use.[163]
- Climate change affects the life cycle and distribution of the mosquitoes, ticks, and rodents that carry West Nile virus, equine encephalitis, Lyme disease, and hantavirus. However, moderating factors such as housing quality, land use patterns, pest control programs, and a robust public health infrastructure are likely to prevent the large-scale spread of these diseases in the United States.[163,305]
- Heavy rain and flooding can contaminate certain food crops with feces from nearby livestock or wild animals, increasing the likelihood of food-borne disease associated with fresh produce.[163]
- *Vibrio* sp. (shellfish poisoning) accounts for 20 percent of the illnesses and 95 percent of the deaths associated with eating infected shellfish, although the overall incidence of illness from *Vibrio* infection remains low. There is a close association between temperature, *Vibrio* sp. abundance, and clinical illness. The U.S. infection rate increased 41 percent from 1996 to 2006,[163] concurrent with rising temperatures.
- As temperatures rise, tick populations that carry Rocky Mountain spotted fever are projected to shift from south to north.[306]
- The introduction of disease-causing agents from other regions of the world is an additional threat.[163]

While the United States has programs such as the Safe Drinking Water Act that help protect against some of these problems, climate change will present new challenges.

Rising temperature and carbon dioxide concentration increase pollen production and prolong the pollen season in a number of plants with highly allergenic pollen, presenting a health risk.

Rising carbon dioxide levels have been observed to increase the growth and toxicity of some plants that cause health problems. Climate change has caused an earlier onset of the spring pollen season in the United States.[272] It is reasonable to conclude that allergies caused by pollen have also experienced associated changes in seasonality.[272] Several laboratory studies suggest that increasing carbon dioxide concentrations and temperatures increase ragweed pollen production and prolong the ragweed pollen season.[163,272]

Poison ivy growth and toxicity is also greatly increased by carbon dioxide, with plants growing larger and more allergenic. These increases exceed those of most beneficial plants. For example, poison ivy vines grow twice as much per year in air with a doubled preindustrial carbon dioxide concentration as they do in unaltered air; this is nearly five times the increase reported for tree species in



Pollen production from ragweed grown in chambers at the carbon dioxide concentration of a century ago (about 280 parts per million [ppm]) was about 5 grams per plant; at today's approximate carbon dioxide level, it was about 10 grams; and at a level projected to occur about 2075 under the higher emissions scenario,[91] it was about 20 grams.[107]

Poison ivy

other analyses.[308] Recent and projected increases in carbon dioxide also have been shown to stimulate the growth of stinging nettle and leafy spurge, two weeds that cause rashes when they come into contact with human skin.[309,310]

Certain groups, including children, the elderly, and the poor, are most vulnerable to a range of climate-related health effects.

Infants and children, pregnant women, the elderly, people with chronic medical conditions, outdoor workers, and people living in poverty are especially at risk from a variety of climate related health effects. Examples of these effects include increasing heat stress, air pollution, extreme weather events, and diseases carried by food, water, and insects.[163]

Children's small ratio of body mass to surface area and other factors make them vulnerable to heat-related illness and death. Their increased breathing rate relative to body size, additional time spent outdoors, and developing respiratory tracts, heighten their sensitivity to air pollution. In addition, children's immature immune systems increase their risk of serious consequences from waterborne and food-borne diseases, while developmental factors make them more vulnerable to complications from severe infections such as *E. coli* or *Salmonella*.[163]

The greatest health burdens related to climate change are likely to fall on the poor, especially those lacking adequate shelter and access to other resources such as air conditioning.[163]

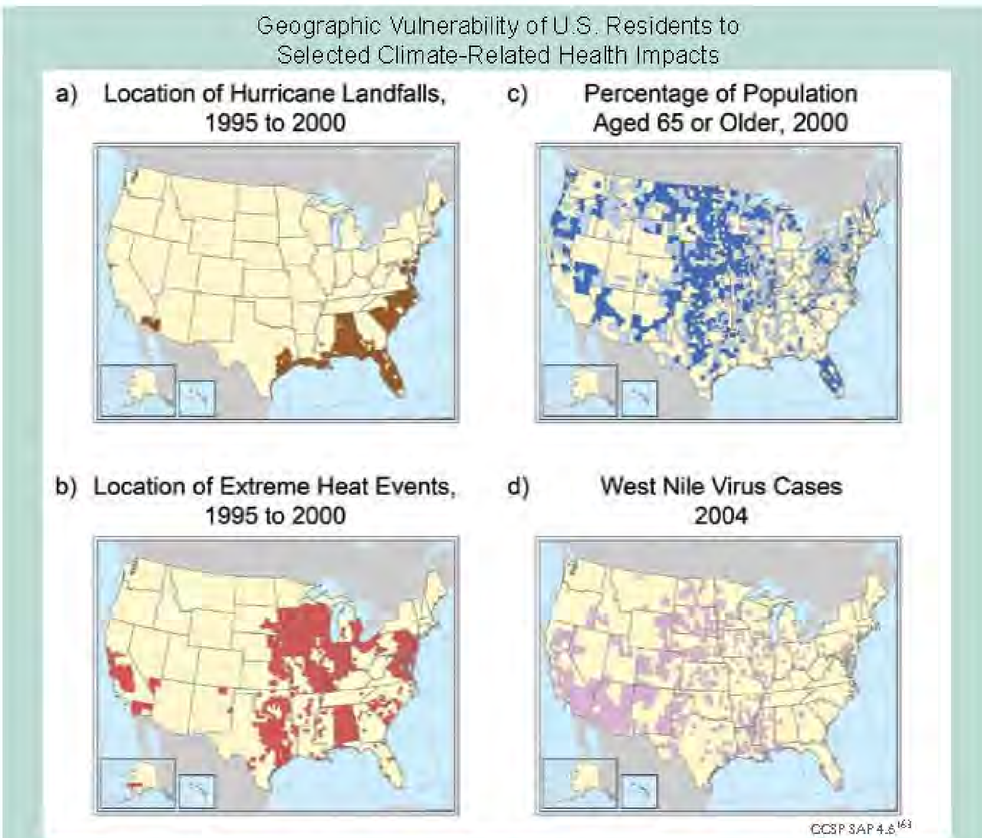
Elderly people are more likely to have debilitating chronic diseases or limited mobility. The elderly are also generally more sensitive to extreme heat for several reasons. They have a reduced ability to regulate their own body temperature or sense when they are too hot. They are at greater risk of heart failure, which is further exacerbated when cardiac demand increases in order to cool the body during a heat wave.[318] Also, people taking medications, such as diuretics for high blood pressure, have a higher risk of dehydration.[163]

The multiple health risks associated with diabetes will increase the vulnerability of the U.S. population to increasing temperatures. The number of Americans with diabetes has grown to about 24 million people, or roughly 8 percent of the U.S. population. Almost 25 percent of the population 60 years and older had diabetes in 2007.[311] Fluid imbalance and dehydration create higher risks for diabetics during heat waves. People with diabetes-related heart disease are at especially increased risk of dying in heat waves.[318]

High obesity rates in the United States are a contributing factor in currently high levels of diabetes. Similarly, a factor in rising obesity rates is a sedentary lifestyle and automobile dependence; 60 percent of Americans do not meet minimum daily exercise requirements. Making cities more walkable and bikeable would thus have multiple benefits: improved personal fitness and weight loss;

reduced local air pollution and associated respiratory illness; and reduced greenhouse gas emissions.[312]

The United States has considerable capacity to adapt to climate change, but during recent extreme weather and climate events, actual practices have not always protected people and property. Vulnerability to extreme events is highly variable, with disadvantaged groups and communities (such as the poor, infirm, and elderly) experiencing considerable damage and disruptions to their lives. Adaptation tends to be reactive, unevenly distributed, and focused on coping rather than preventing problems. Future reduction in vulnerability will require consideration of how best to incorporate planned adaptation into long-term municipal and public service planning, including energy, water, and health services, in the face of changing climate-related risks combined with ongoing changes in population and development patterns.[163,164]



Maps indicating U.S. counties, or in some cases states, with existing vulnerability to climate-sensitive health outcomes: a) location of hurricane landfalls; b) extreme heat events (defined by the Centers for Disease Control as temperatures 10 or more degrees F above the average high temperature for the region and lasting for several weeks); c) percentage of population over age 65 (dark blue indicates that percentage is over 17.6 percent, light blue 14.4 to 17.5 percent); d) locations of West Nile virus cases reported in 2004. These examples demonstrate both the diversity of climate-sensitive health outcomes and the geographic variability of where they occur. Events over short time spans, in particular West Nile virus cases, are not necessarily predictive of future vulnerability.

Society

Key Messages:

- Population shifts and development choices are making more Americans vulnerable to the expected impacts of climate change.
- Vulnerability is greater for those who have few resources and few choices.
- City residents and city infrastructure have unique vulnerabilities to climate change.
- Climate change affects communities through changes in climate-sensitive resources that occur both locally and at great distances.
- Insurance is one of the industries particularly vulnerable to increasing extreme weather events such as severe storms, but it can also help society manage the risks.
- The United States is connected to a world that is unevenly vulnerable to climate change and thus will be affected by impacts in other parts of the world.

Climate change will affect society through impacts on the necessities and comforts of life: water, energy, housing, transportation, food, natural ecosystems, and health. This section focuses on some characteristics of society that make it vulnerable to the potential impacts of climate change and how the risks and costs may be distributed. Many impacts of climate change on society, for example, sea-level rise and increased water scarcity, are covered in other sections of this report. This section is not a comprehensive analysis of societal vulnerabilities, but rather highlights key examples.

Because societies and their built environments have developed under a climate that has fluctuated within a relatively confined range of conditions, most impacts of a rapidly changing climate will present challenges. Society is especially vulnerable to extremes, such as heat waves and floods, many of which are increasing as climate changes.[313] And while there are likely to be some benefits and opportunities in the early stages of warming, as climate continues to change, negative impacts are projected to dominate.[164]

Climate change will affect different segments of society differently because of their varying exposures and adaptive capacities. The impacts of climate change also do not affect society in isolation. Rather, impacts can be exacerbated when climate change occurs in combination with the effects of an aging and growing population, pollution, poverty, and natural environmental fluctuations.[164,172,274] Unequal adaptive capacity in the world as a whole also will pose challenges to the United States. Poorer countries are projected to be disproportionately affected by the impacts of climate change and the United States is strongly connected to the world beyond its borders through markets, trade, investments, shared resources, migrating species, health, travel and tourism, environmental refugees (those fleeing deteriorating environmental conditions), and security.

Cedar Rapids, Iowa, June 12, 2008

Population shifts and development choices are making more Americans vulnerable to the expected impacts of climate change.

Climate is one of the key factors in Americans' choices of where to live. As the U.S. population grows, ages, and becomes further concentrated in cities and coastal areas, society is faced with additional challenges. Climate change is likely to exacerbate these challenges as changes in temperature, precipitation, sea levels, and extreme weather events increasingly affect homes, communities, water supplies, land resources, transportation, urban infrastructure, and regional characteristics that people have come to value and depend on.

Population growth in the United States over the past century has been most rapid in the South, near the coasts, and in large urban areas (see figure on page 55 in the *Energy* sector). The four most populous states in 2000 – California, Texas, Florida, and New York – accounted for 38 percent of the total growth in U.S. population during that time, and share significant vulnerability to coastal storms, severe drought, sea-level rise, air pollution, and urban heat island effects.[313] But migration patterns are now shifting: the population of the Mountain West (Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, and New Mexico) is projected to increase by 65 percent from 2000 to 2030, representing one-third of all U.S. population growth.[274,314] Southern coastal areas on both the Atlantic and the Gulf of Mexico are projected to continue to see population growth.[313]

Overlaying projections of future climate change and its impacts on expected changes in U.S. population and development patterns reveals a critical insight: more Americans will be living in the areas that are most vulnerable to the effects of climate change.[274]

America's coastlines have seen pronounced population growth in regions most at risk of hurricane activity, sea-level rise, and storm surge – putting more people and property in harm's way as the probability of harm increases.[274] On the Atlantic and Gulf coasts where hurricane activity is prevalent, the coastal land in many areas is sinking while sea level is rising. Human activities are exacerbating the loss of coastal wetlands that once helped buffer the coastline from erosion due to storms. The devastation caused by recent hurricanes highlights the vulnerability of these areas.[224]

The most rapidly growing area of the country is the Mountain West, a region projected to face more frequent and severe wildfires and have less water available, particularly during the high-demand period of summer. Continued population growth in these arid and semi-arid regions would stress water supplies. Because of high demand for irrigating agriculture, overuse of rivers and streams is common in the arid West, particularly along the Front Range of the Rocky Mountains in Colorado, in Southern California, and in the Central Valley of California. Rapid population and economic growth in these arid and semi-arid regions has dramatically increased vulnerability to water shortages (see *Water Resources* sector and *Southwest* region).[274]

Many questions are raised by ongoing development patterns in the face of climate change. Will growth continue as projected in vulnerable areas, despite the risks? Will there be a retreat from the coastline as it becomes more difficult to insure vulnerable properties? Will there be pressure for the government to insure properties that private insurers have rejected? How can the vulnerability of new development be minimized? How can we ensure that communities adopt measures to manage the significant changes that are projected in sea level, temperature, rainfall, and extreme weather events?

Development choices are based on people's needs and desires for places to live, economies that provide employment, ecosystems that provide services, and community-based social activities. Thus, the future vulnerability of society will be influenced by how and where people choose to live. Some choices, such as expanded development in coastal regions, can increase vulnerabilities to climate-related events, even without any change in climate.

Vulnerability is greater for those who have few resources and few choices.

Vulnerabilities to climate change depend not only on where people are but also on their circumstances. In general, groups that are especially vulnerable include the very young, the very old, the sick, and the poor. These groups represent a more significant portion of the total population in some regions and localities than others. For example, the elderly more often cite a warm climate as motivating their choice of where to live and thus make up a larger share of the population in warmer areas.[305]

In the future (as in the past), the impacts of climate change are likely to fall disproportionately on the disadvantaged.[313] People with few resources often live in conditions that increase their vulnerability to the effects of climate change.[172] For example, the experience with Hurricane Katrina showed that the poor and elderly were the most vulnerable because of where they lived and their limited ability to get out of harm's way. Thus, those who had the least proportionately lost the most. And it is clear that people with access to financial resources, including insurance, have a greater capacity to adapt to, recover, or escape from adverse impacts of climate change than those who do not have such access.[305,316] The fate of the poor can be permanent dislocation, leading to the loss of social relationships and community support networks provided by schools, churches, and neighborhoods.

Native American communities have unique vulnerabilities. Native Americans who live on established reservations are restricted to reservation boundaries and therefore have limited relocation options.[219] In Alaska, over 100 villages on the coast and in low-lying areas along rivers are subject to increased flooding and erosion due to warming.[315] Warming also reduces the availability and accessibility of many traditional food sources for Native Alaskans, such as seals that live on ice and caribou whose migration patterns depend on being able to cross frozen rivers and wetlands. These vulnerable people face losing their current livelihoods, their communities, and in some cases, their culture, which depends on traditional ways of collecting and sharing food.[132,220] Native cultures in the Southwest are particularly vulnerable to impacts of climate change on water quality and availability.

Chalmette, Louisiana after Hurricane Katrina

City residents and city infrastructure have unique vulnerabilities to climate change.

Over 80 percent of the U.S. population resides in urban areas, which are among the most rapidly changing environments on Earth. In recent decades, cities have become increasingly spread out, complex, and interconnected with regional and national economies and infrastructure.[319] Cities also experience a host of social problems, including neighborhood degradation, traffic congestion, crime, unemployment, poverty, and inequities in health and well-being.[320] Climate-related changes such as increased heat, water shortages, and extreme weather events will add further stress to existing problems. The impacts of climate change on cities are compounded by aging infrastructure, buildings, and populations, as well as air pollution and population growth. Further, infrastructure designed to handle past variations in climate can instill a false confidence in its ability to handle future changes. However, urban areas also present opportunities for adaptation through technology, infrastructure, planning, and design.[313]

As cities grow, they alter local climates through the urban heat island effect. This effect occurs because cities absorb, produce, and retain more heat than the surrounding countryside. The urban heat island effect has raised average urban air temperatures by 2 to 5°F more than surrounding areas over the past 100 years, and by up to 20°F more at night.[321] Such temperature increases, on top of the general increase caused by human-induced warming, affect urban dwellers in many ways, influencing health, comfort, energy costs, air quality, water quality and availability, and even violent crime (which increases at high temperatures) (see *Human Health*, *Energy*, and *Water Resources* sectors).[172,313,322,323]

More frequent heavy downpours and floods in urban areas will cause greater property damage, a heavier burden on emergency management, increased clean-up and rebuilding costs, and a growing financial toll on businesses and homeowners. The Midwest floods of 2008 provide a recent vivid example of such tolls. Heavy downpours and urban floods can also overwhelm combined sewer and storm-water systems and release pollutants to waterways.[313] Unfortunately, for many cities, current planning and existing infrastructure are designed for the historical one-in-100 year event, whereas cities are likely to experience this same flood level much more frequently as a result of the climate change projected over this century.[146,164,324]

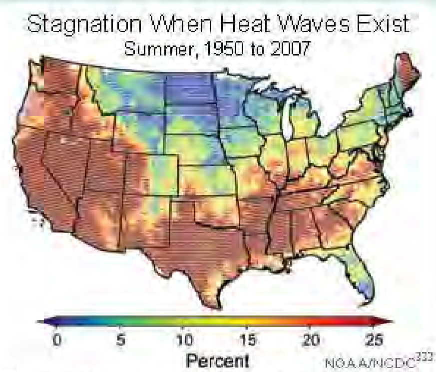
Cities are also likely to be affected by climate change in unforeseen ways, necessitating diversion of city funds for emergency responses to extreme weather.[313] There is the potential for increased summer electricity blackouts owing to greater demand for air conditioning.[325] For example, there were widespread power outages in Chicago during the 1995 heat wave and in some parts of New York City during the 1999 heat wave. In southern California's cities, additional summer electricity demand will intensify conflicts between hydropower and flood-control objectives.[164] Increased costs of repairs and maintenance are projected for transportation systems, including roads, railways, and airports, as they are negatively affected by heavy downpours

Heat, Drought, and Stagnant Air Degrade Air Quality and Quality of Life

Heat waves and poor air quality already threaten the lives of thousands of people each year.[292] Experience and research have shown that these events are interrelated as the atmospheric conditions that produce heat waves are often accompanied by stagnant air and poor air quality.[326] The simultaneous occurrence of heat waves, drought, and stagnant air negatively affects quality of life, especially in cities.

One such event occurred in the United States during the summer of 1988, causing 5,000 to 10,000 deaths and economic losses of more than $70 billion (in 2002 dollars).[229,327] Half of the nation was affected by drought, and 5,994 all-time daily high temperature records were set around the country in July alone (more than three times the most recent 10-year average).[328,329] Poor air quality resulting from the lack of rainfall, high temperatures, and stagnant conditions led to an unprecedented number of unhealthy air quality days throughout large parts of the country.[327,329] Continued climate change is projected to increase the likelihood of such episodes.[68,330]

Interactions such as those between heat wave and drought will affect adaptation planning. For example, electricity use increases during heat waves due to increased air conditioning demand.[330,331] During droughts, cooling water availability is at its lowest. Thus, during a simultaneous heat wave and drought, electricity demand for cooling will be high when power plant cooling water availability is at its lowest.[340]



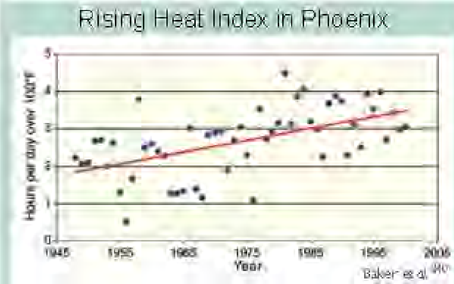
The map shows the frequency of occurrence of stagnant air conditions when heat wave conditions were also present. Since 1950, across the Southeast, southern Great Plains, and most of the West, the air was stagnant more than 25 percent of the time during heat waves.

and extreme heat[190] (see *Transportation* sector). Coping with increased flooding will require replacement or improvements in storm drains, flood channels, levees, and dams.

In addition, coastal cities are also vulnerable to sea-level rise, storm surge, and increased hurricane intensity. Cities such as New Orleans, Miami, and New York are particularly at risk, and would have difficulty coping with the sea-level rise projected by the end of the century under a higher emissions scenario.[91,164] Remnants of hurricanes moving inland also threaten cities of the Appalachian Mountains, which are vulnerable if hurricane frequency or intensity increases. Since most large U.S. cities are on coasts, rivers, or both, climate change will lead to increased potential flood damage. The largest impacts are expected when sea-level rise, heavy runoff, high tides, and storms coincide.[313] Analyses of New York and Boston indicate that the potential impacts of climate change are likely to be negative, but that vulnerability can be reduced by behavioral and policy changes.[313,334-336]

Urban areas concentrate the human activities that are largely responsible for heat-trapping emissions. The demands of urban residents are also associated with a much larger footprint on areas far removed from these population centers.[337] On the other hand, concentrating activities such as transportation can make them more efficient. Cities have a large role to play in reducing heat-trapping emissions, and many are pursuing such actions. For example, over 900 cities have committed to the U.S. Mayors' Climate Protection Agreement to advance emissions reduction goals.[317]

Cities also have considerable potential to adapt to climate change through technological, institutional, structural, and behavioral changes. For example, a number of cities have warning programs in place to reduce heat-related illness and death (see *Human Health* sector). Relocating development away from low-lying areas, building new infrastructure with future sea-level rise in mind, and promoting water conservation are examples of structural and institutional strategies. Choosing road materials that can handle higher temperatures is an adaptation option that relies on new technology (see *Transportation* sector). Cities can reduce heat loads by increasing reflective surfaces and green spaces. Some actions have multiple benefits. For example, increased planting of trees and other vegetation in cities has been shown to be associated with a reduction in crime,[338] in addition to reducing local temperatures, and thus energy demand for air conditioning.



The average number of hours per summer day in Phoenix that the temperature was over 100°F has doubled over the past 50 years, in part as a result of the urban heat island effect. Hot days take a toll on both quality of life and loss of life. Arizona's heat-related deaths are the highest of any state, at three to seven times the national average.[340,341]

Human well-being is influenced by economic conditions, natural resources and amenities, public health and safety, infrastructure, government, and social and cultural resources. Climate change will influence all of these, but an understanding of the many interacting impacts, as well as the ways society can adapt to them, remains in its infancy.[305,339]

Climate change affects communities through changes in climate-sensitive resources that occur both locally and at great distances.

Human communities are intimately connected to resources beyond their geographical boundaries. Thus, communities will be vulnerable to the potential impacts of climate change on sometimes-distant resources. For example, communities that have developed near areas of agricultural production, such as the Midwest corn belt or the wine-producing regions of California and the Northwest, depend on the continued productivity of those regions, which would be compromised by increased temperature or severe weather.[313] Some agricultural production that is linked to cold climates is likely to disappear entirely: recent warming has altered the required temperature patterns for maple syrup production, shifting production northward from New England into Canada. Similarly, cranberries require a long winter chill period, which is shrinking as climate warms[234] (see *Northeast* region). Most cities depend on water supplies from distant watersheds, and those depending on diminishing supplies (such as the Sierra Nevada snowpack) are vulnerable. Northwest communities also depend upon forest resources for their economic base, and many island, coastal, and "sunbelt" communities depend on tourism.

Recreation and tourism play important roles in the economy and quality of life of many Americans. In some regions tourism and recreation are major job creators, bringing billions of dollars to regional economies. Across the nation, fishing, hunting, skiing, snowmobiling, diving, beach-going, and other outdoor activities make important economic contributions and are a part of family traditions that have value that goes beyond financial returns. A changing climate will mean reduced opportunities for some activities and locations and expanded opportunities for others.[305,342] Hunting and fishing will change as animals' habitats shift and as relationships among species in natural communities are disrupted by their different responses to rapid climate change. Water-dependent recreation in areas projected to get drier, such as the Southwest, and beach recreation in areas that are expected to see rising sea levels, will suffer. Some regions will see an expansion of the season for warm weather recreation such as hiking and bicycle riding.

Examples of Impacts On Recreation

Recreational Activity	Potential Impacts of Climate Change	Estimated Economic Impacts
Skiing, Northeast	20 percent reduction in ski season length	$800 million loss per year, potential resort closures[234]
Snowmobiling, Northeast	Reduction of season length under higher emissions scenario[91]	Complete loss of opportunities in New York and Pennsylvania within a few decades, 80 percent reduction in season length for region by end of century[234,342]
Beaches, North Carolina	Many beaches are eroded, and some lost by 2080[341]	Reduced opportunities for beach and fishing trips,[341] without additional costs for adaptation measures

Insurance is one of the industries particularly vulnerable to increasing extreme weather events such as severe storms, but it can also help society manage the risks.

Insurance – the world's largest industry – is one of the primary mechanisms through which the costs of climate change are distributed across society.[344,351]

Most of the climate change impacts described in this report have economic consequences. A significant portion of these flow through public and private insurance markets, which essentially aggregate and distribute society's risk. Insurance thus provides a window into the myriad ways in which the costs of climate change will manifest, and serves as a form of economic adaptation and a messenger of these impacts through the terms and price signals it sends its customers.[344]

In an average year, about 90 percent of insured catastrophe losses worldwide are weather-related. In the United States, about half of all these losses are insured, which amounted to $320 billion between 1980 and 2005 (inflation-adjusted to 2005 dollars). While major events such as hurricanes grab headlines, the aggregate effect of smaller events accounts for at least 60 percent of total insured losses on average.[344] Many of the smallest scale property losses and weather-related life/health losses are unquantified.[345]

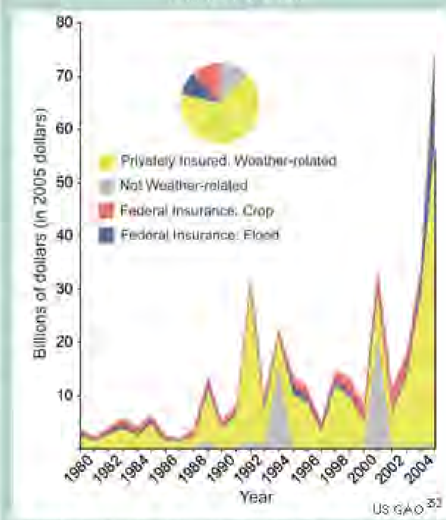
Escalating exposures to catastrophic weather events, coupled with private insurers' withdrawal from various markets, are placing the federal government at increased financial risk as insurer of last resort. The National Flood Insurance Program would have gone bankrupt after the storms of 2005 had they not been given the ability to borrow about $20 billion from the U.S. Treasury.[172] For public and private insurance programs alike, rising losses require a combination of risk-based premiums and improved loss prevention.

While economic and demographic factors have no doubt contributed to observed increases in losses,[346] these factors do not fully explain the upward trend in costs or numbers of events.[344,347] For example, during the time period covered in the figure to the right, population increased by a factor of 1.3 while losses increased by a factor of 15 to 20 in inflation-corrected dollars. Analyses asserting little or no role of climate change in increasing the risk of losses tend to focus on a highly limited set of hazards and locations. They also often fail to account for the vagaries of natural cycles and inflation adjustments, or to normalize for countervailing factors such as improved pre- and post-event loss prevention (such as dikes, building codes, and early warning systems).[348,349]

What is known with far greater certainty is that future increases in losses will be attributable to climate change as it increases the frequency and intensity of many types of extreme weather, such as severe thunderstorms and heat waves.[131,350]

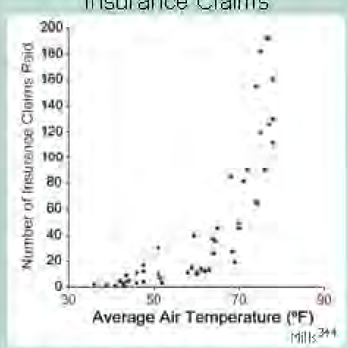
Insurance is emblematic of the increasing globalization of climate risks. Because large U.S.-based companies operate around the world, their customers and assets are exposed to climate impacts wherever they occur. Most of the growth in the insurance industry is in emerging markets, which will structurally increase U.S. insurers' exposure to climate risk because those regions are more vulnerable and are experiencing particularly high rates of population growth and development.[351]

Insured Losses from Catastrophes, 1980 to 2005



Weather-related insurance losses in the United States are increasing. Typical weather-related losses today are similar to those that resulted from the 9/11 attack (shown in gray at 2001 in the graph). About half of all economic losses are insured, so actual losses are roughly twice those shown on the graph. Data on smaller-scale losses (many of which are weather-related) are significant but are not included in this graph as they are not comprehensively reported by the U.S. insurance industry.

Lightning-Related Insurance Claims



There is a strong observed correlation between higher temperatures and the frequency of lightning-induced insured losses in the United States. Each marker represents aggregate monthly U.S. lightning-related insurance claims paid by one large national insurer over a five-year period, 1991-1995. All else being equal, these claims are expected to increase with temperature.[344,353,354]

The movement of populations into harm's way creates a rising baseline of insured losses upon which the consequences of climate change will be superimposed. These observations reinforce a recurring theme in this report: the past can no longer be used as the basis for planning for the future.

It is a challenge to design insurance systems that properly price risks, reward loss prevention, and do not foster risk taking (for example by repeatedly rebuilding flooded homes). This challenge is particularly acute in light of insurance market distortions such as prices that inhibit insurers' ability to recover rising losses, combined with information gaps on the impacts of climate change and adaptation strategies. Rising losses[252] are already affecting the availability and affordability of insurance. Several million customers in the United States, no longer able to purchase private insurance coverage, are taking refuge in state-mandated insurance pools, or going without insurance altogether. Offsetting rising insurance costs is one benefit of mitigation and adaptation investments to reduce the impacts of climate change.

Virtually all segments of the insurance industry are vulnerable to the impacts of climate change. Examples include damage to property, crops, forest products, livestock, and transportation infrastructure; business and supply-chain interruptions caused by weather extremes, water shortages, and electricity outages; legal consequences;[355] and compromised health or loss of life. Increasing risks to insurers and their customers are driven by many factors including reduced periods of time between loss events, increasing variability, shifting types and location of events, and widespread simultaneous losses.

In light of these challenges, insurers are emerging as partners in climate science and the formulation of public policy and adaptation strategies.[356] Some have promoted adaptation by providing premium incentives for customers who fortify their properties, engaging in the process of determining building codes and land-use plans, and participating in the development and financing of new technologies and practices. For example, the Federal Emergency Management Agency (FEMA) Community Rating System is a point system that rewards communities that undertake floodplain management activities to reduce flood risk beyond the minimum requirement set by the National Flood Insurance Program. Everyone in these communities is rewarded with lower flood insurance premiums (−5 to −45 percent).[357] Others have recognized that mitigation and adaptation can work hand in hand in a coordinated climate risk-management strategy and are offering "green" insurance products designed to capture these dual benefits.[90,351]

The United States is connected to a world that is unevenly vulnerable to climate change and thus will be affected by impacts in other parts of the world.

American society will not experience the potential impacts of climate change in isolation. In an increasingly connected world, impacts elsewhere will have political, social, economic, and environmental ramifications for the United States. As in the United States, vulnerability to the potential impacts of climate change worldwide varies by location, population characteristics, and economic status.

The rising concentration of people in cities is occurring globally, but is most prevalent in lower-income countries. Many large cities are located in vulnerable areas such as floodplains and coasts. In most of these cities, the poor often live in the most marginal of these environments, in areas that are susceptible to extreme events, and their ability to adapt is limited by their lack of financial resources.[172]

In addition, over half of the world's population – including most of the world's major cities – depends on glacier melt or snowmelt to supply water for drinking and municipal uses. Today, some locations are experiencing abundant water supplies and even frequent floods due to increases in glacier melt rates due to increased temperatures worldwide. Soon, however, this trend is projected to reverse as even greater temperature increases reduce glacier mass and cause more winter precipitation to fall as rain and less as snow.[90]

As conditions worsen elsewhere, the number of people wanting to immigrate to the United States will increase. The direct cause of potential increased migration, such as extreme climatic events, will be difficult to separate from other forces that drive people to migrate. Climate change also has the potential to alter trade relationships by changing the comparative trade advantages of regions or nations. As with migration, shifts in trade can have multiple causes.

Accelerating emissions in economies that are rapidly expanding, such as China and India, pose future threats to the climate system and already are associated with air pollution episodes that reach the United States.[297]

Meeting the challenge of improving conditions for the world's poor has economic implications for the United States, as does intervention and resolution of intra- and intergroup conflicts. Where climate change exacerbates such challenges, for example by limiting access to scarce resources or increasing incidence of damaging weather events, consequences are likely for the U.S. economy and security.[358]

Northeast

The Northeast has significant geographic and climatic diversity within its relatively small area. The character and economy of the Northeast have been shaped by many aspects of its climate including its snowy winters, colorful autumns, and variety of extreme events such as nor'easters, ice storms, and heat waves. This familiar climate has already begun changing in noticeable ways.

Since 1970, the annual average temperature in the Northeast has increased by 2°F, with winter temperatures rising twice this much.[150] Warming has resulted in many other climate-related changes, including:

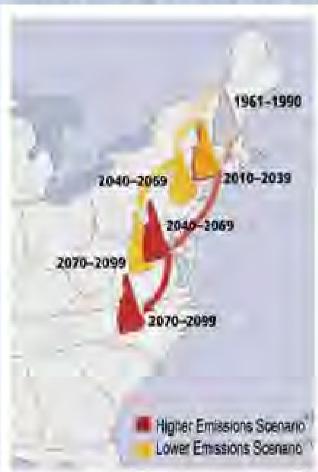
- More frequent days with temperatures above 90°F
- A longer growing season
- Increased heavy precipitation
- Less winter precipitation falling as snow and more as rain
- Reduced snowpack
- Earlier breakup of winter ice on lakes and rivers
- Earlier spring snowmelt resulting in earlier peak river flows
- Rising sea surface temperatures and sea level

Each of these observed changes is consistent with the changes expected in this region from global warming. The Northeast is projected to face continued warming and more extensive climate-related changes, some of which could dramatically alter the region's economy, landscape, character, and quality of life.

Over the next several decades, temperatures in the Northeast are projected to rise an additional 2.5 to 4°F in winter and 1.5 to 3.5°F in summer. By mid-century and beyond, however, today's emissions choices would generate starkly different climate futures; the lower the emissions, the smaller the climatic changes and resulting impacts.[150,359] By late this century, under a higher emissions scenario[91]:

- Winters in the Northeast are projected to be much shorter with fewer cold days and more precipitation.
- The length of the winter snow season would be cut in half across northern New York, Vermont, New Hampshire, and Maine, and reduced to a week or two in southern parts of the region.
- Cities that today experience few days above 100°F each summer would average 20 such days per summer, while certain cities, such as Hartford and Philadelphia, would average nearly 30 days over 100°F.
- Short-term (one- to three-month) droughts are projected to occur as frequently as once each summer in the Catskill and Adirondack Mountains, and across the New England states.
- Hot summer conditions would arrive three weeks earlier and last three weeks longer into the fall.
- Sea level in this region is projected to rise more than the global average, see *Global* and *National Climate Change* and *Coasts* sections for more information on sea-level rise (pages 25, 37, 150).

Climate on the Move:
Changing Summers in New Hampshire



Hayhoe et al.[359] Fig. from Frumhoff et al.[214]

Yellow arrows track what summers are projected to feel like under a lower emissions scenario,[91] while red arrows track projections for a higher emissions scenario[91] (referred to as "even higher" on page 23). For example, under the higher emission scenario,[91] by late this century residents of New Hampshire would experience a summer climate more like what occurs today in North Carolina.[359]

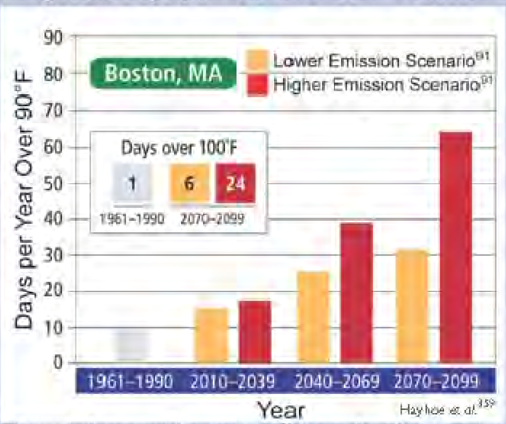
Extreme heat and declining air quality are likely to pose increasing problems for human health, especially in urban areas.

Heat waves, which are currently rare in the region, are projected to become much more commonplace in a warmer future, with major implications for human health (see *Human Health* sector).[163,68]

In addition to the physiological stresses associated with hotter days and nights,[360] for cities that now experience ozone pollution problems, the number of days that fail to meet federal air quality standards is projected to increase with rising temperatures if there are no additional controls on ozone-causing pollutants[163,361] (see *Human Health* sector). Sharp reductions in emissions will be needed to keep ozone within existing standards.

Projected changes in summer heat (see figure below) provide a clear sense of how different the climate of the Northeast is projected to be under lower versus higher emissions scenarios. Changes of this kind will require greater use of air conditioning (see *Energy* sector).

Projected Days per Year over 90°F in Boston



The graph shows model projections of the number of summer days with temperatures over 90°F in Boston, Massachusetts, under lower and higher (referred to as "even higher" on page 23) emissions scenarios.[91] The inset shows projected days over 100°F.[359]

Projected Shifts in Tree Species

Adapted from Iverson et al.[164]

Much of the Northeast's forest is composed of the hardwoods maple, beech, and birch, while mountain areas and more northern parts of the region are dominated by spruce/fir forests. As climate changes over this century, suitable habitat for spruce and fir is expected to contract dramatically. Suitable maple/beech/birch habitat is projected to shift significantly northward under a higher emissions scenario (referred to as "even higher" on page 23),[91] but to shift far less under a lower emissions scenario.[91,342] Other studies of tree species shifts suggest even more dramatic changes than those shown here (see page 81).

Agricultural production, including dairy, fruit, and maple syrup, are likely to be adversely affected as favorable climates shift.

Large portions of the Northeast are likely to become unsuitable for growing popular varieties of apples, blueberries, and cranberries under a higher emissions scenario.[91,362,363] Climate conditions suitable for maple/beech/birch forests are projected to shift dramatically northward (see figure above), eventually leaving only a small portion of the Northeast with a maple sugar business.[364]

The dairy industry is the most important agricultural sector in this region, with annual production worth $3.6 billion.[365] Heat stress in dairy cows depresses both milk production and birth rates for periods of weeks to months.[193,366] By late this century, all but the northern parts of Maine, New Hampshire, New York, and Vermont are projected to suffer declines in July milk production under the higher emissions scenario. In parts of Connecticut, Massachusetts, New Jersey, New York, and Pennsylvania, a large decline in milk production, up to 20 percent or greater, is projected. Under the lower emissions scenario, however, reductions in milk production of up to 10 percent remain confined primarily to the southern parts of the region.

This analysis used average monthly temperature and humidity data that do not capture daily variations in heat stress and projected increases in extreme heat. Nor did the analysis directly consider farmer responses, such as installation of potentially costly cooling systems. On balance, these projections are likely to underestimate impacts on the dairy industry.[150]

Increased Flood Risk in New York City

The light blue area above depicts today's FEMA 100-year flood zone for the city (the area of the city that is expected to be flooded once every 100 years). With rising sea levels, a 100-year flood at the end of this century (not mapped here) is projected to inundate a far larger area of New York City, especially under the higher emissions scenario.[91] Critical transportation infrastructure located in the Battery area of lower Manhattan could be flooded far more frequently unless protected. The increased likelihood of flooding is causing planners to look into building storm-surge barriers in New York Harbor to protect downtown New York City.[234,370,371]

Severe flooding due to sea-level rise and heavy downpours is likely to occur more frequently.

The densely populated coasts of the Northeast face substantial increases in the extent and frequency of storm surge, coastal flooding, erosion, property damage, and loss of wetlands.[367,369] New York state alone has more than $2.3 trillion in insured coastal property.[368] Much of this coastline is exceptionally vulnerable to sea-level rise and related impacts. Some major insurers have withdrawn coverage from thousands of homeowners in coastal areas of the Northeast, including New York City.

Rising sea level is projected to increase the frequency and severity of damaging storm surges and flooding. Under a higher emissions scenario,[91] what is now considered a once-in-a-century coastal flood in New York City is projected to occur at least twice as often by mid-century, and 10 times as often (or once per decade

Adaptation: Raising a Sewage Treatment Plant in Boston

Boston's Deer Island sewage treatment plant was designed and built taking future sea-level rise into consideration. Because the level of the plant relative to the level of the ocean at the outfall is critical to the amount of rainwater and sewage that can be treated, the plant was built 1.9 feet higher than it would otherwise have been to accommodate the amount of sea-level rise projected to occur by 2050, the planned life of the facility.

The planners recognized that the future would be different from the past and they decided to plan for the future based on the best available information. They assessed what could be easily and inexpensively changed at a later date versus those things that would be more difficult and expensive to change later. For example, increasing the plant's height would be less costly to incorporate in the original design, while protective barriers could be added at a later date, as needed, at a relatively small cost.

on average) by late this century. With a lower emissions scenario,[91] today's 100-year flood is projected to occur once every 22 years on average by late this century.[369]

The projected reduction in snow cover will adversely affect winter recreation and the industries that rely upon it.

Winter snow and ice sports, which contribute some $7.6 billion annually to the regional economy, will be particularly affected by warming.[342] Of this total, alpine skiing and other snow sports (not including snowmobiling) account for $4.6 billion annually. Snowmobiling, which now rivals skiing as the largest winter recreation industry in the nation, accounts for the remaining $3 billion.[372] Other winter traditions, ranging from skating and ice fishing on frozen ponds and lakes, to cross-country (Nordic) skiing, snowshoeing, and dog sledding, are integral to the character of the Northeast, and for many residents and visitors, its desirable quality of life.

Warmer winters will shorten the average ski and snowboard seasons, increase artificial snowmaking requirements, and drive up operating costs. While snowmaking can enhance the prospects for ski resort success, it requires a great deal of water and energy, as well as very cold nights, which are becoming less frequent. Without the opportunity to benefit from snowmaking, the prospects for the snowmobiling industry are even worse. Most of the region is likely to have a marginal or non-existent snowmobile season by mid-century.

Ski Areas at Risk
under Higher Emissions Scenario[91]

Scott et al.[342]; Fig. from Frumhoff et al.[234]

The ski resorts in the Northeast have three climate-related criteria that need to be met for them to remain viable: the average length of the ski season must be at least 100 days; there must be a good probability of being open during the lucrative winter holiday week between Christmas and the New Year; and there must be enough nights that are sufficiently cold to enable snowmaking operations. By these standards, only one area in the region (not surprisingly, the one located farthest north) is projected to be able to support viable ski resorts by the end of this century under a higher emissions scenario (referred to as "even higher" on page 23).[91,373]

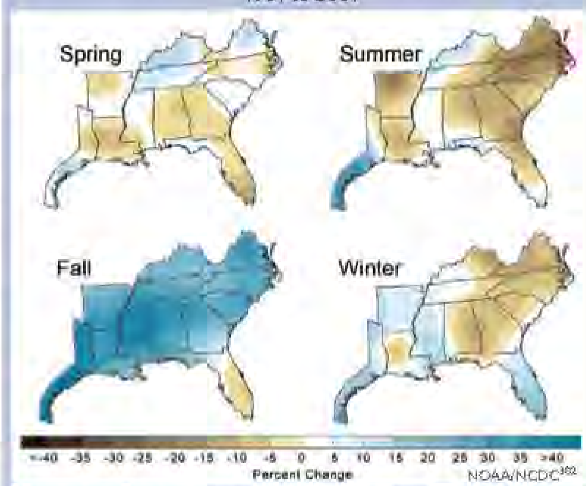
The center of lobster fisheries is projected to continue its northward shift and the cod fishery on Georges Bank is likely to be diminished.

Lobster catch has increased dramatically in the Northeast as a whole over the past three decades, though not uniformly.[374,375] Catches in the southern part of the region peaked in the mid-1990s, and have since declined sharply, beginning with a 1997 die-off in Rhode Island and Buzzards Bay (Massachusetts) associated with the onset of a temperature-sensitive bacterial shell disease, and accelerated by a 1999 lobster die-off in Long Island Sound. Currently, the southern extent of the commercial lobster harvest appears to be limited by this temperature-sensitive shell disease, and these effects are expected to increase as near-shore water temperatures rise above the threshold for this disease. Analyses also suggest that lobster survival and settlement in northern regions of the Gulf of Maine could be increased by warming water, a longer growing season, more rapid growth, an earlier hatching season, an increase in nursery grounds suitable for larvae, and faster development of plankton.[376]

Cod populations throughout the North Atlantic are adapted to a wide range of seasonal ocean temperatures, including average annual temperatures near the seafloor ranging from 36 to 54°F. Large populations of cod are generally not found above the 54°F threshold.[377] Temperature also influences both the location and timing of spawning, which in turn affects the subsequent growth and survival of young cod. Increases in average annual bottom temperatures above 47°F lead to a decline in growth and survival.[378,379] Projections of warming indicate that both the 47°F and the 54°F thresholds will be met or exceeded in this century under a higher emissions scenario.[234] Climate change will thus introduce an additional stress to an already-stressed fishery.[377]

Southeast

Observed Changes in Precipitation
1901 to 2007



While average fall precipitation in the Southeast increased by 30 percent since the early 1900s, summer and winter precipitation declined by nearly 10 percent in the eastern part of the region. Southern Florida has experienced a nearly 10 percent drop in precipitation in spring, summer, and fall. The percentage of the Southeast region in drought has increased over recent decades.

The climate of the Southeast is uniquely warm and wet, with mild winters and high humidity, compared with the rest of the continental United States. The average annual temperature of the Southeast did not change significantly over the past century as a whole. Since 1970, however, annual average temperature has risen about 2°F, with the greatest seasonal increase in temperature occurring during the winter months. The number of freezing days in the Southeast has declined by four to seven days per year for most of the region since the mid-1970s.

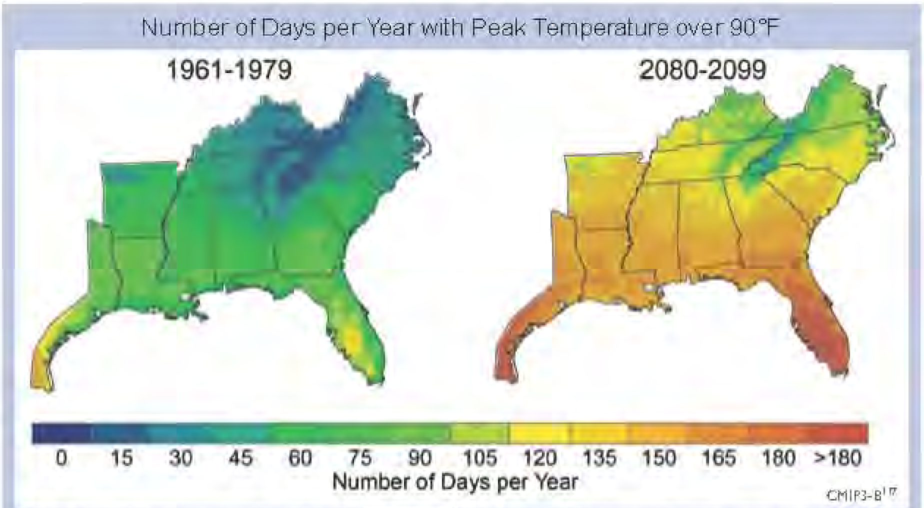
Average autumn precipitation has increased by 30 percent for the region since 1901. The decline in fall precipitation in South Florida contrasts strongly with the regional average. There has been an increase in heavy downpours in many parts of the region,[380,381] while the percentage of the region experiencing moderate to severe drought increased over the past three decades. The area of moderate to severe spring and summer drought has increased by 12 percent and 14 percent, respectively, since the mid-1970s. Even in the fall months, when precipitation tended to increase in most of the region, the extent of drought increased by 9 percent.

Climate models project continued warming in all seasons across the Southeast and an increase in the rate of warming through the end of this century. The projected rates of warming are more than double those experienced in the Southeast since 1975, with the greatest temperature increases projected to occur in the summer months. The number of very hot days is projected to rise at a greater rate than the average temperature. Under a lower emissions scenario,[91] average temperatures in the region are projected to rise by about 4.5°F by the 2080s, while a higher emissions scenario[91] yields about 9°F of average warming (with about a 10.5°F increase in summer, and a much higher heat index). Spring and summer rainfall is projected to decline in South Florida during this century. Except for indications that the amount of rainfall from individual hurricanes will increase,[68] climate models provide divergent

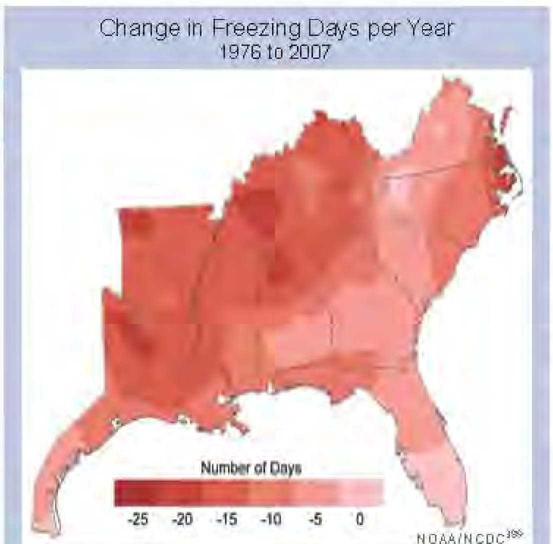
Average Change in Temperature and Precipitation in the Southeast					
	Temperature Change in °F			Precipitation change in %	
	1901-2008	1970-2008		1901-2008	1970-2008
Annual	0.3	1.6	Annual	6.0	-7.7
Winter	0.2	2.7	Winter	1.2	-9.6
Spring	0.4	1.2	Spring	1.7	-29.2
Summer	0.4	1.6	Summer	-4.0	3.6
Fall	0.2	1.1	Fall	27.4	0.1

Observed temperature and precipitation changes in the Southeast are summarized above for two different periods.[383] Southeast average temperature declined from 1901 to 1970 and then increased strongly since 1970.

111



The number of days per year with peak temperature over 90°F is expected to rise significantly, especially under a higher emissions scenario[91] as shown in the map above. By the end of the century, projections indicate that North Florida will have more than 165 days (nearly six months) per year over 90°F, up from roughly 60 days in the 1960s and 1970s. The increase in very hot days will have consequences for human health, drought, and wildfires.



Since the mid-1970s, the number of days per year in which the temperature falls below freezing has declined by four to seven days over much of the Southeast. Some areas, such as western Louisiana, have experienced more than 20 fewer freezing days. Climate models project continued warming across the region, with the greatest increases in temperature expected in summer, and the number of very hot days increasing at a greater rate than the average temperature.

results for future precipitation for the remainder of the Southeast. Models project that Gulf Coast states will tend to have less rainfall in winter and spring, compared with the more northern states in the region (see map on page 31 in the *National Climate Change* section). Because higher temperatures lead to more evaporation of moisture from soils and water loss from plants, the frequency, duration, and intensity of droughts are likely to continue to increase.

The destructive potential of Atlantic hurricanes has increased since 1970, correlated with an increase in sea surface temperature. A similar relationship with the frequency of landfalling hurricanes has not been established[98,384-387] (see *National Climate Change* section for a discussion of past trends and future projections). An increase in average summer wave heights along the U.S. Atlantic coastline since 1975 has been attributed to a progressive increase in hurricane power.[112,388] The intensity of Atlantic hurricanes is likely to increase during this century with higher peak wind speeds, rainfall intensity, and storm surge height and strength.[90,112] Even with no increase in hurricane intensity, coastal inundation and shoreline retreat would increase as sea-level rise accelerates, which is one of the most certain and most costly consequences of a warming climate.[164]

Projected increases in air and water temperatures will cause heat-related stresses for people, plants, and animals.

The warming projected for the Southeast during the next 50 to 100 years will create heat-related stress for people, agricultural crops, livestock, trees, transportation and other infrastructure, fish, and wildlife. The average temperature change is not as important for all of these sectors and natural systems as the projected increase in maximum and minimum temperatures. Examples of potential impacts include:

- Increased illness and death due to greater summer heat stress, unless effective adaptation measures are implemented.[164]
- Decline in forest growth and agricultural crop production due to the combined effects of thermal stress and declining soil moisture.[390]
- Increased buckling of pavement and railways.[217,222]
- Decline in dissolved oxygen in stream, lakes, and shallow aquatic habitats leading to fish kills and loss of aquatic species diversity.
- Decline in production of cattle and other rangeland livestock.[391] Significant impacts on beef cattle occur at continuous temperatures in the 90 to 100°F range, increasing in danger as the humidity level increases (see *Agriculture* sector).[391] Poultry and swine are primarily raised in indoor operations, so warming would increase energy requirements.[193]

A reduction in very cold days is likely to reduce the loss of human life due to cold-related stress, while heat stress and related deaths in the summer months are likely to increase. The reduction in cold-related deaths is not expected to offset the increase in heat-related deaths (see *Human Health* sector). Other effects of the projected increases in temperature include more frequent outbreaks of shellfish-borne diseases in coastal waters, altered distribution of native plants and animals, local loss of many threatened and endangered species, displacement of native species by invasive species, and more frequent and intense wildfires.

Decreased water availability is very likely to affect the region's economy as well as its natural systems.

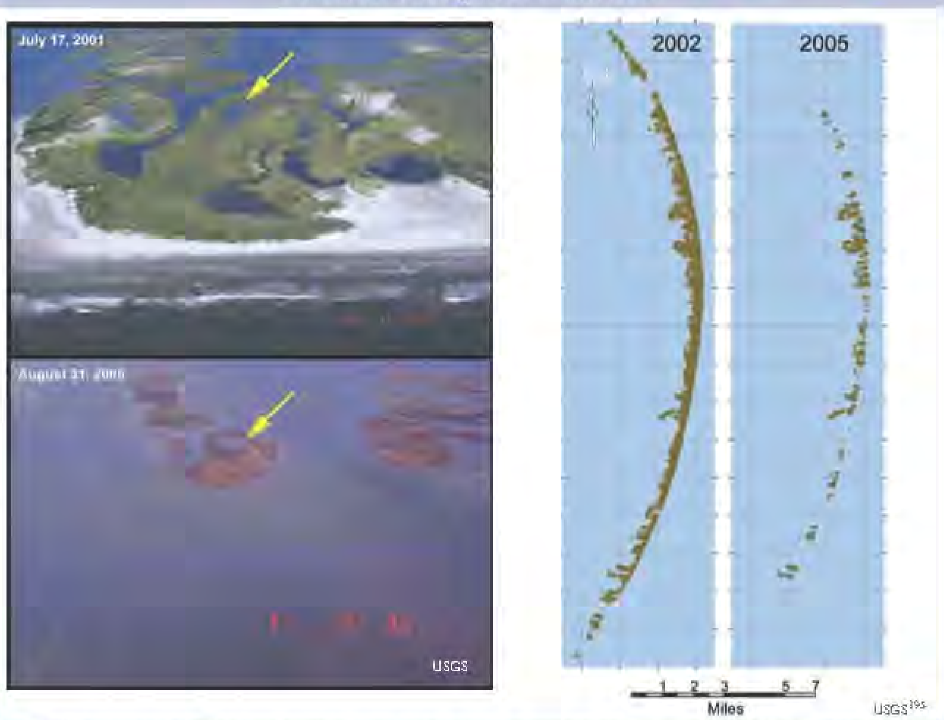
Decreased water availability due to increased temperature and longer periods of time between rainfall events, coupled with an increase in societal demand is very likely to affect many sectors of the Southeast's economy. The amount and timing of water available to natural systems is also affected by climate change, as well as by human response strategies such as increasing storage capacity (dams)[142] and increasing acreage of irrigated cropland.[392] The 2007 water shortage in the Atlanta region created serious conflicts between three states, the U.S. Army Corps of Engineers (which operates the dam at Lake Lanier), and the U.S. Fish and Wildlife Service, which is charged with protecting endangered species. As humans seek to adapt to climate change by manipulating water resources, streamflow and biological diversity are likely to be reduced.[142] During droughts, recharge of groundwater will decline as the temperature and spacing between rainfall events increase. Responding by increasing groundwater pumping will further stress or deplete aquifers and place increasing strain on surface water resources. Increasing evaporation and plant water loss rates alter the balance of runoff and groundwater recharge, which is likely to lead to saltwater intrusion into shallow aquifers in many parts of the Southeast.[142]

In Atlanta and Athens, Georgia, 2007 was the second driest year on record. Among the numerous effects of the rainfall shortage were restrictions on water use in some cities and low water levels in area lakes. In the photo, a dock lies on dry land near Aqualand Marina on Lake Lanier (located northeast of Atlanta) in December 2007.

U.S. Global Change Research Program

Global Climate Change Impacts in the United States

Land Lost During 2005 Hurricanes



In 2005, 217 square miles of land and wetlands were lost to open water during hurricanes Rita and Katrina. The photos and maps show the Chandeleur Islands, east of New Orleans, before and after the 2005 hurricanes; 85 percent of the islands' above-water land mass was eliminated.

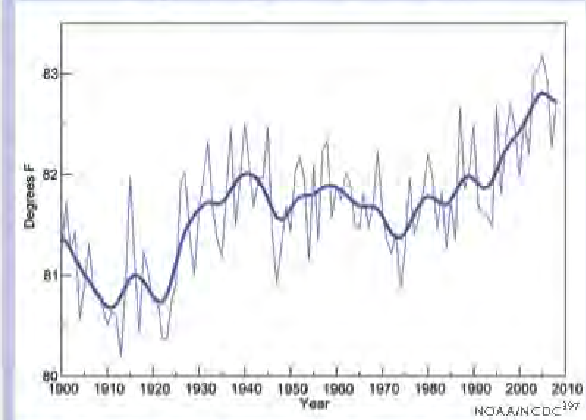
Sea-level rise and the likely increase in hurricane intensity and associated storm surge will be among the most serious consequences of climate change.

An increase in average sea level of up to 2 feet or more and the likelihood of increased hurricane intensity and associated storm surge are likely to be among the most costly consequences of climate change for this region (see *National Climate Change* section). As sea level rises, coastal shorelines will retreat. Wetlands will be inundated and eroded away, and low-lying areas including some communities will be inundated more frequently – some permanently – by the advancing sea. Current buildings and infrastructure were not designed to withstand the intensity of the projected storm surge, which would cause catastrophic damage. As temperature increases and rainfall patterns change, soil moisture and runoff to the coast are likely to be more variable. The salinity of estuaries, coastal wetlands, and tidal rivers is likely to increase in the southeastern coastal zone, thereby altering coastal ecosystems and displacing them farther inland if no barriers exist. More frequent storm surge flooding and permanent inundation of coastal ecosystems and communities is likely in some low-lying areas, particularly along the central Gulf Coast where the land surface is sinking.[393,394] Rapid acceleration in the rate of increase in sea-level rise could threaten a large portion of the Southeast coastal zone. The likelihood of a catastrophic increase in the rate of sea-level rise is dependent upon ice sheet response to warming, which is the subject of much scientific uncertainty (see *Global Climate Change* section).[90] Such rapid rise in sea level is likely to result in the destruction of barrier islands and wetlands.[257,390]

114

Compared to the present coastal situation, for which vulnerability is quite high, an increase in hurricane intensity will further affect low-lying coastal ecosystems and coastal communities along the Gulf and South Atlantic coastal margin. An increase in intensity is very likely to increase inland and coastal flooding, coastal erosion rates, wind damage to coastal forests, and wetland loss. Major hurricanes also pose a severe risk to people, personal property, and public infrastructure in the Southeast, and this risk is likely to be exacerbated.[393,394] Hurricanes have their greatest impact at the coastal margin where they make landfall, causing storm surge, severe beach erosion, inland flooding, and wind-related casualties for both cultural and natural resources. Some of these impacts extend farther inland, affecting larger areas. Recent examples of societal vulnerability to severe hurricanes include Katrina and Rita in 2005, which were responsible for the loss of more than 1,800 lives and the net loss of 217 square miles of low-lying coastal marshes and barrier islands in southern Louisiana.[390,396]

Sea Surface Temperature
Atlantic Hurricane Main Development Region
August through October, 1900 to 2008



Ocean surface temperature during the peak hurricane season, August through October, in the main development region for Atlantic hurricanes.[397] Higher sea surface temperatures in this region of the ocean have been associated with more intense hurricanes. As ocean temperatures continue to increase in the future, it is likely that hurricane rainfall and wind speeds will increase in response to human-caused warming (see *National Climate Change* section).[44]

Ecological thresholds are expected to be crossed throughout the region, causing major disruptions to ecosystems and to the benefits they provide to people.

Ecological systems provide numerous important services that have high economic and cultural value in the Southeast. Ecological effects cascade among both living and physical systems, as illustrated in the following examples of ecological disturbances that result in abrupt responses, as opposed to gradual and proportional responses to warming:

- The sudden loss of coastal landforms that serve as a storm-surge barrier for natural resources and as a homeland for coastal communities (such as in a major hurricane).[254,390]
- An increase in sea level can have no apparent effect until an elevation is reached that allows widespread, rapid saltwater intrusion into coastal forests and freshwater aquifers.[398]
- Lower soil moisture and higher temperatures leading to intense wildfires or pest outbreaks (such as the southern pine beetle) in southeastern forests;[399] intense droughts leading to the drying of lakes, ponds, and wetlands; and the local or global extinction of riparian and aquatic species.[142]

Flooding damage in Louisiana due to Hurricane Katrina

115

- A precipitous decline of wetland-dependent coastal fish and shellfish populations due to the rapid loss of coastal marsh.[400]

Quality of life will be affected by increasing heat stress, water scarcity, severe weather events, and reduced availability of insurance for at-risk properties.

Over the past century, the southeastern "sunbelt" has attracted people, industry, and investment. The population of Florida more than doubled during the past three decades, and growth rates in most other southeastern states were in the range of 45 to 75 percent (see population map, page 55). Future population growth and the quality of life for existing residents is likely to be affected by the many challenges associated with climate change, such as reduced insurance availability, increased insurance cost, and increases in water scarcity, sea-level rise, extreme weather events, and heat stress. Some of these problems, such as increasing heat and declining air quality, will be especially acute in cities.

Adaptation: Reducing Exposure to Flooding and Storm Surge

Three different types of adaptation to sea-level rise are available for low-lying coastal areas.[173,269] One is to move buildings and infrastructure farther inland to get out of the way of the rising sea. Another is to accommodate rising water through changes in building design and construction, such as elevating buildings on stilts. Flood insurance programs even require this in some areas with high probabilities of floods. The third adaptation option is to try to protect existing development by building levees and river flood control structures. This option is being pursued in some highly vulnerable areas of the Gulf and South Atlantic coasts. Flood control structures can be designed to be effective in the face of higher sea level and storm surge. Some hurricane levees and floodwalls were not just replaced after Hurricane Katrina, they were redesigned to withstand higher storm surge and wave action.[401]

Recent upgrades that raised the height of this earthen levee increased protection against storm surge in the New Orleans area.

The costs and environmental impacts of building such structures can be significant. Furthermore, building levees can actually increase future risks.[269] This is sometimes referred to as the levee effect or the safe-development paradox. Levees that provide protection from, for example, the storm surge from a Category 3 hurricane, increase real and perceived safety and thereby lead to increased development. This increased development means there will be greater damage if and when the storm surge from a Category 5 hurricane tops the levee than there would have been if no levee had been constructed.[252]

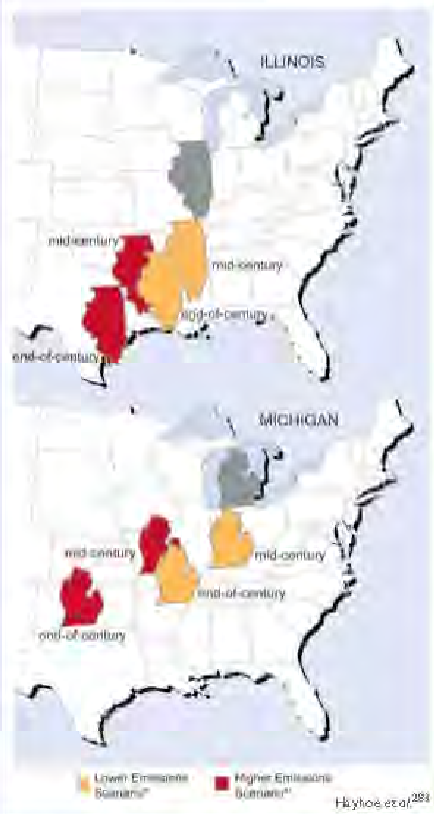
In addition to levees, enhancement of key highways used as hurricane evacuation routes and improved hurricane evacuation planning is a common adaptation underway in all Gulf Coast states.[217] Other protection options that are being practiced along low-lying coasts include the enhancement and protection of natural features such as forested wetlands, saltmarshes, and barrier islands.[390]

Midwest

The Midwest's climate is shaped by the presence of the Great Lakes and the region's location in the middle of the North American continent. This location, far from the temperature-moderating effects of the oceans, contributes to large seasonal swings in air temperature from hot, humid summers to cold winters. In recent decades, a noticeable increase in average temperatures in the Midwest has been observed, despite the strong year-to-year variations. The largest increase has been measured in winter, extending the length of the frost-free or growing season by more than one week, mainly due to earlier dates for the last spring frost. Heavy downpours are now twice as frequent as they were a century ago. Both summer and winter precipitation have been above average for the last three decades, the wettest period in a century. The Midwest has experienced two record-breaking floods in the past 15 years.[213] There has also been a decrease in lake ice, including on the Great Lakes. Since the 1980s, large heat waves have been more frequent in the Midwest than any time in the last century, other than the Dust Bowl years of the 1930s.[112,283,402-404]

During the summer, public health and quality of life, especially in cities, will be negatively affected by increasing heat waves, reduced air quality, and insect and waterborne diseases. In the winter, warming will have mixed impacts.

Climate on the Move:
Changing Summers in the Midwest



Model projections of summer average temperature and precipitation changes in Illinois and Michigan for mid-century (2040-2059), and end-of-century (2080-2099), indicate that summers in these states are expected to feel progressively more like summers currently experienced in states south and west. Both states are projected to get considerably warmer and have less summer precipitation.

Heat waves that are more frequent, more severe, and longer lasting are projected. The frequency of hot days and the length of the heat-wave season both will be more than twice as great under the higher emissions scenario[91] compared to the lower emissions scenario.[91,283,402,403,405] Events such as the Chicago heat wave of 1995, which resulted in over 700 deaths, will become more common. Under the lower emissions scenario,[91] such a heat wave is projected to occur every other year in Chicago by the end of the century, while under the higher emissions scenario,[91] there would be about three such heat waves per year. Even more severe heat waves, such as the one that claimed tens of thousands of lives in Europe in 2003, are projected to become more frequent in a warmer world, occurring as often as every other year in the Midwest by the end of this century under the higher emissions scenario.[91,283,403,406] Some health impacts can be reduced by better preparation for such events.[288]

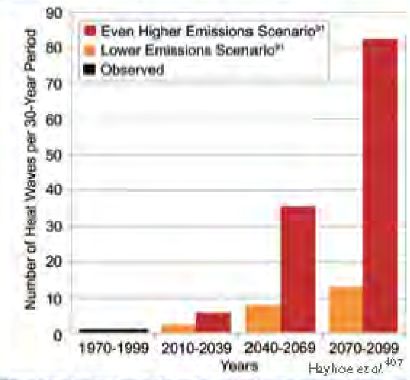
117

During heat waves, high electricity demand combines with climate-related limitations on energy production capabilities (see *Energy Supply and Use* sector), increasing the likelihood of electricity shortages and resulting in brownouts or even blackouts. This combination can leave people without air conditioning and ventilation when they need it most, as occurred during the 1995 Chicago/Milwaukee heat wave. In general, electricity demand for air conditioning is projected to significantly increase in summer. Improved energy planning could reduce electricity disruptions.

The urban heat island effect can further add to high local daytime and nighttime temperatures (see *Human Health* sector). Heat waves take a greater toll in illness and death when there is little relief from the heat at night.

Another health-related issue arises from the fact that climate change can affect air quality. A warmer climate generally means more ground-level ozone (a component of smog), which can cause respiratory problems, especially for those who are young, old, or have asthma or allergies. Unless the emissions of pollutants that lead to ozone formation are reduced significantly, there will be more ground-level ozone as a result of the projected climate changes in the Midwest due to increased air temperatures, more stagnant air, and increased emissions from vegetation.[283,291,402,403,408-410]

Number of 1995-like Chicago Heat Waves

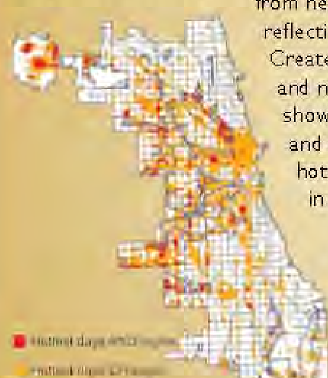


Over the last three decades of this century, heat waves like the one that occurred in Chicago in 1995 are projected to occur about once every three years under the lower emissions scenario.[91] Under the even higher emissions scenario, such events are projected to occur an average of nearly three times a year. In this analysis, heat waves were defined as at least one week of daily maximum temperatures greater than 90°F and nighttime minimum temperatures greater than 70°F, with at least two consecutive days with daily temperatures greater than 100°F and nighttime temperatures greater than 80°F.

Insects such as ticks and mosquitoes that carry diseases will survive winters more easily and produce larger populations in a warmer Midwest.[283,402,403] One potential risk is an increasing incidence of diseases such as West Nile

Adaptation: Chicago Tries to Cool the Urban Heat Island

Efforts to reduce urban heat island effects become even more important in a warming climate. The City of Chicago has produced a map of urban hotspots to use as a planning tool to target areas that could most benefit from heat-island reduction initiatives such as reflective or green roofing, and tree planting. Created using satellite images of daytime and nighttime temperatures, the map shows the hottest 10 percent of both day and night temperatures in red, and the hottest 10 percent of either day or night in orange.



Chicago's urban hot spots

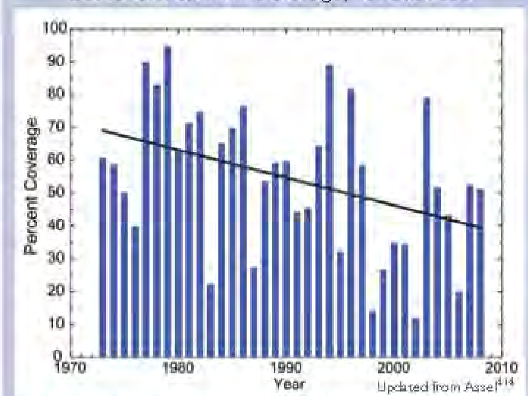
"Green roofs" are cooler than the surrounding conventional roofs.

The City is working to reduce urban heat buildup and the need for air conditioning by using reflective roofing materials. This thermal image shows that the radiating temperature of the City Hall's "green roof" – covered with soil and vegetation – is up to 77°F cooler than the nearby conventional roofs.[411]

virus. Waterborne diseases will present an increasing risk to public health because many pathogens thrive in warmer conditions.[163]

In winter, oil and gas demand for heating will decline. Warming will also decrease the number of days with snow on the ground, which is expected to improve traffic safety.[222] On the other hand, warming will decrease outdoor winter recreational opportunities such as skiing, snowmobiling, ice skating, and ice fishing.

Observed Changes in Great Lakes Ice Cover
Seasonal Maximum Coverage, 1973 to 2008

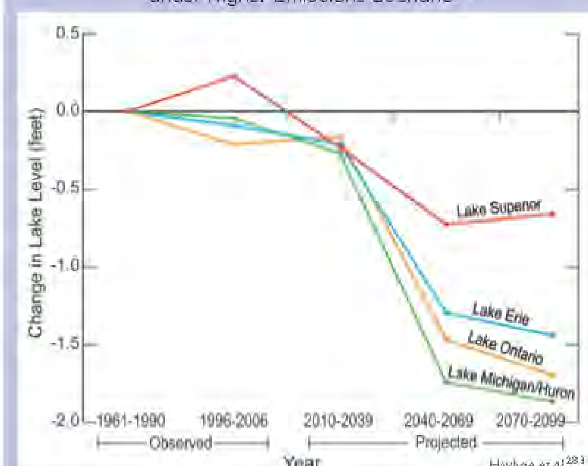


Reductions in winter ice cover lead to more evaporation, causing lake levels to drop even farther. While the graph indicates large year-to-year variations, there is a clear decrease in the extent of Great Lakes ice coverage, as shown by the black trend line.

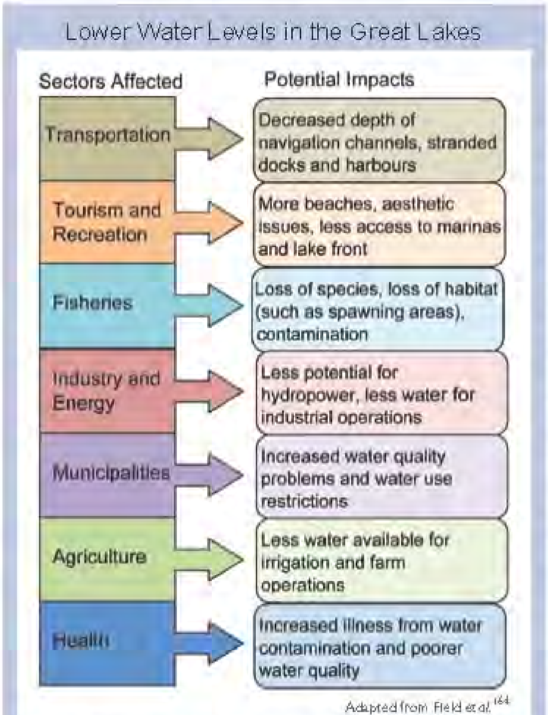
Significant reductions in Great Lakes water levels, which are projected under higher emissions scenarios, lead to impacts on shipping, infrastructure, beaches, and ecosystems.

The Great Lakes are a natural resource of tremendous significance, containing 20 percent of the planet's fresh surface water and serving as the dominant feature of the industrial heartland of the nation. Higher temperatures will mean more evaporation and hence a likely reduction in the Great Lakes water levels. Reduced lake ice increases evaporation in winter, contributing to the decline. Under a lower emissions scenario,[91] water levels in the Great Lakes are projected to fall no more than 1 foot by the end of the century, but under a higher emissions scenario,[91] they are projected to fall between 1 and 2 feet.[283] The greater the temperature rise, the higher the likelihood of a larger decrease in lake levels.[412] Even a decrease of 1 foot, combined with normal fluctuations, can result in significant lengthening of the distance to the lakeshore in many places. There are also potential impacts on beaches, coastal ecosystems, dredging requirements, infrastructure, and shipping. For example, lower lake levels reduce "draft," or the distance between the waterline and the bottom of a ship, which lessens a ship's ability to carry freight. Large vessels, sized for passage through the St. Lawrence Seaway, lose up to 240 tons of capacity for each inch of draft lost.[283,402,403,413] These impacts will have costs, including increased shipping, repair and maintenance costs, and lost recreation and tourism dollars.

Projected Changes in Great Lakes Levels
under Higher Emissions Scenario[91]



Average Great Lakes levels depend on the balance between precipitation (and corresponding runoff) in the Great Lakes Basin on one hand, and evaporation and outflow on the other. As a result, lower emissions scenarios[91] with less warming show less reduction in lake levels than higher emissions scenarios.[91] Projected changes in lake levels are based on simulations by the NOAA Great Lakes model for projected climate changes under a higher emissions scenario.[91]



Reduced water levels in the Great Lakes will have interconnected impacts across many sectors, creating mismatches between water supply and demand, and necessitating trade-offs. Regions outside the Midwest will also be affected. For example, a reduction in hydropower potential would affect the Northeast, and a reduction in irrigation water would affect regions that depend on agricultural produce from the Midwest.

The Great Flood of 1993 caused flooding along 500 miles of the Mississippi and Missouri river systems. The photo shows the flood's effects on U.S. Highway 54, just north of Jefferson City, Missouri.

The likely increase in precipitation in winter and spring, more heavy downpours, and greater evaporation in summer would lead to more periods of both floods and water deficits.

Precipitation is projected to increase in winter and spring, and to become more intense throughout the year. This pattern is expected to lead to more frequent flooding, increasing infrastructure damage, and impacts on human health. Such heavy downpours can overload drainage systems and water treatment facilities, increasing the risk of waterborne diseases. Such an incident occurred in Milwaukee in 1993 when the water supply was contaminated with the parasite *Cryptosporidium*, causing 403,000 reported cases of gastrointestinal illness and 54 deaths.

In Chicago, rainfall of more than 2.5 inches per day is an approximate threshold beyond which combined water and sewer systems overflow into Lake Michigan (such events occurred 2.5 times per decade from 1961 to 1990). This generally results in beach closures to reduce the risk of disease transmission. Rainfall above this threshold is projected to occur twice as often by the end of this century under the lower emissions scenario[91] and three times as often under the higher emissions scenario.[91,283,403] Similar increases are expected across the Midwest.

More intense rainfall can lead to floods that cause significant impacts regionally and even nationally. For example, the Great Flood of 1993 caused catastrophic flooding along 500 miles of the Mississippi and Missouri river systems, affecting one-quarter of all U.S. freight (see *Transportation* sector).[222,415-417] Another example was a record-breaking 24-hour rainstorm in July 1996, which resulted in flash flooding in Chicago and its suburbs, causing extensive damage and disruptions, with some commuters not being able to reach Chicago for three days (see *Transportation* sector).[222] There was also a record-breaking storm in August 2007. Increases in such events are likely to cause greater property damage, higher insurance rates, a heavier burden on emergency management, increased clean-up and rebuilding costs, and a growing financial toll on businesses, homeowners, and insurers.

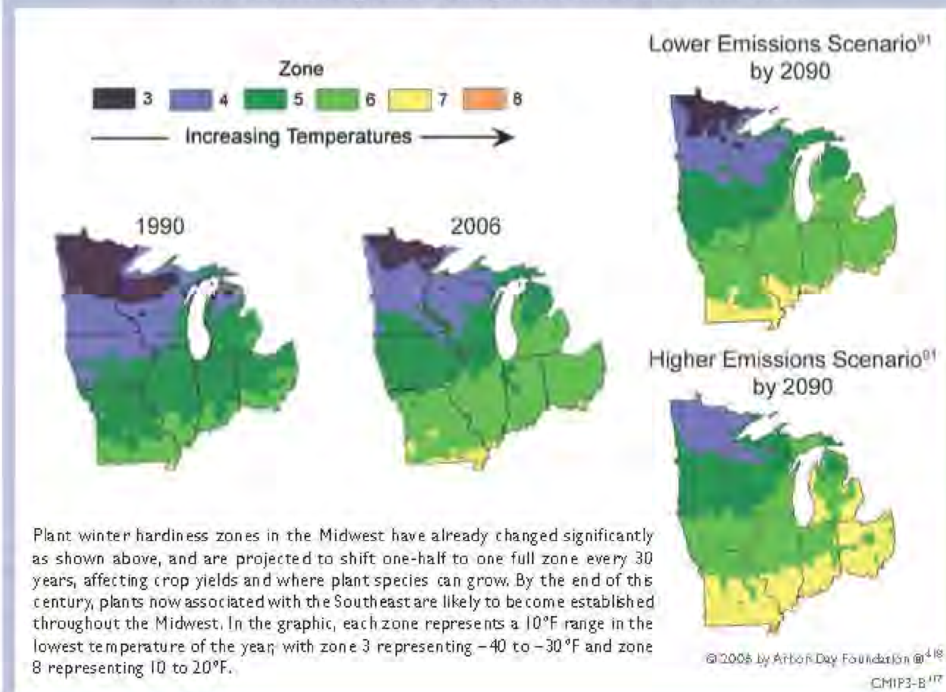
In the summer, with increasing evaporation rates and longer periods between rainfalls, the likelihood of drought will increase and water levels in rivers, streams, and wetlands are likely to decline. Lower water levels also could create problems for river traffic, reminiscent of the stranding of more than 4,000 barges on the Mississippi River during the 1988 drought. Reduced summer water levels are also likely to reduce the recharge of groundwater, cause small streams to dry up (reducing native fish populations), and reduce the area of wetlands in the Midwest.

While the longer growing season provides the potential for increased crop yields, increases in heat waves, floods, droughts, insects, and weeds will present increasing challenges to managing crops, livestock, and forests.

The projected increase in winter and spring precipitation and flooding is likely to delay planting and crop establishment. Longer growing seasons and increased carbon dioxide have positive effects on some crop yields, but this is likely to be counterbalanced in part by the negative effects of additional disease-causing pathogens, insect pests, and weeds (including invasive weeds).[193] Livestock production is expected to become more costly as higher temperatures stress livestock, decreasing productivity and increasing costs associated with the needed ventilation and cooling equipment.[193]

Plant winter hardiness zones (each zone represents a 10°F change in minimum temperature) in the Midwest are likely to shift one-half to one full zone

Observed and Projected Changes in Plant Hardiness Zones



Plant winter hardiness zones in the Midwest have already changed significantly as shown above, and are projected to shift one-half to one full zone every 30 years, affecting crop yields and where plant species can grow. By the end of this century, plants now associated with the Southeast are likely to become established throughout the Midwest. In the graphic, each zone represents a 10°F range in the lowest temperature of the year, with zone 3 representing –40 to –30°F and zone 8 representing 10 to 20°F.

121

about every 30 years. By the end of the century, plants now associated with the Southeast are likely to become established throughout the Midwest.

Impacts on forests are likely to be mixed, with the positive effects of higher carbon dioxide and nitrogen levels acting as fertilizers potentially negated by the negative effects of decreasing air quality.[243] In addition, more frequent droughts, and hence fire hazards, and an increase in destructive insect pests, such as gypsy moths, hinder plant growth. Insects, historically controlled by cold winters, more easily survive milder winters and produce larger populations in a warmer climate (see *Agriculture* and *Ecosystems* sectors).

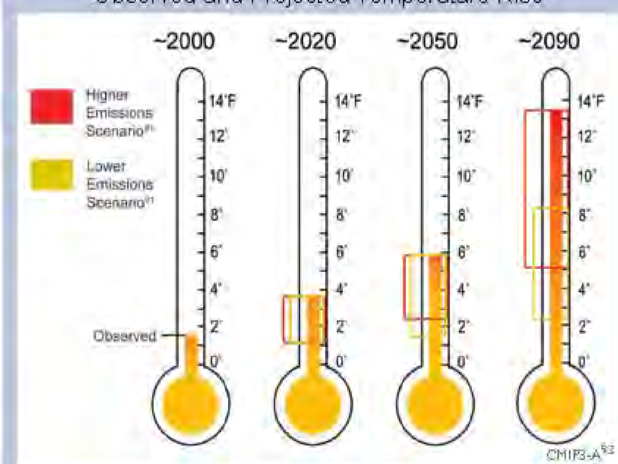
Native species are very likely to face increasing threats from rapidly changing climate conditions, pests, diseases, and invasive species moving in from warmer regions.

As air temperatures increase, so will water temperatures. In some lakes, this will lead to an earlier and longer period in summer during which mixing of the relatively warm surface lake water with the colder water below is reduced.[564] In such cases, this stratification can cut off oxygen from bottom layers, increasing the risk of oxygen-poor or oxygen-free "dead zones" that kill fish and other living things. In lakes with contaminated sediment, warmer water and low-oxygen conditions can more readily mobilize mercury and other persistent pollutants.[565] In such cases, where these increasing quantities of contaminants are taken up in the aquatic food chain, there will be additional potential for health hazards for species that eat fish from the lakes, including people.[566]

Populations of coldwater fish, such as brook trout, lake trout, and whitefish, are expected to decline dramatically, while populations of coolwater fish such as muskie, and warmwater species such as smallmouth bass and bluegill, will take their place. Aquatic ecosystem disruptions are likely to be compounded by invasions by non-native species, which tend to thrive under a wide range of environmental conditions. Native species, adapted to a narrower range of conditions, are expected to decline.

All major groups of animals, including birds, mammals, amphibians, reptiles, and insects, will be affected by impacts on local populations, and by competition from other species moving into the Midwest region.[70] The potential for animals to shift their ranges to keep pace with the changing climate will be inhibited by major urban areas and the presence of the Great Lakes.

Great Plains

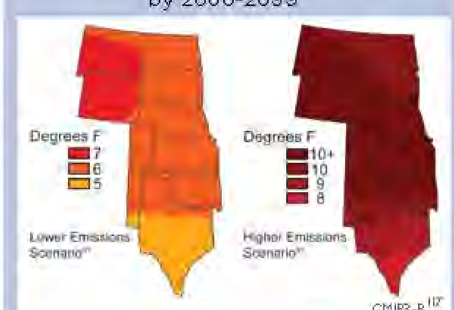


The average temperature in the Great Plains already has increased roughly 1.5°F relative to a 1960s and 1970s baseline. By the end of the century, temperatures are projected to continue to increase by 2.5°F to more than 13°F compared with the 1960 to 1979 baseline, depending on future emissions of heat-trapping gases. The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible.

The Great Plains is characterized by strong seasonal climate variations. Over thousands of years, records preserved in tree rings, sediments, and sand deposits provide evidence of recurring periods of extended drought (such as the Dust Bowl of the 1930s) alternating with wetter conditions.[97,419]

Today, semi-arid conditions in the western Great Plains gradually transition to a moister climate in the eastern parts of the region. To the north, winter days in North Dakota average 25°F, while it is not unusual to have a West Texas winter day over 75°F. In West Texas, there are between 70 and 100 days per year over 90°F, whereas North Dakota has only 10 to 20 such days on average.

Significant trends in regional climate are apparent over the last few decades. Average temperatures have increased throughout the region, with the largest changes occurring in winter months and over the northern states. Relatively cold days are becoming less frequent and relatively hot days more frequent.[420] Precipitation has also increased over most of the area.[149,421]



Temperatures in the Great Plains are projected to increase significantly by the end of this century, with the northern part of the region experiencing the greatest projected increase in temperature.

Temperatures are projected to continue to increase over this century, with larger changes expected under scenarios of higher heat-trapping emissions as compared to lower heat-trapping emissions. Summer changes are projected to be larger than those in winter in the southern and central Great Plains.[108] Precipitation is also projected to change, particularly in winter and spring. Conditions are anticipated to become wetter in the north and drier in the south.

Projected changes in long-term climate and more frequent extreme events such as heat waves, droughts, and heavy rainfall will affect many aspects of life in the Great Plains. These include the region's already threatened water resources, essential agricultural and ranching activities, unique natural and protected areas, and the health and prosperity of its inhabitants.

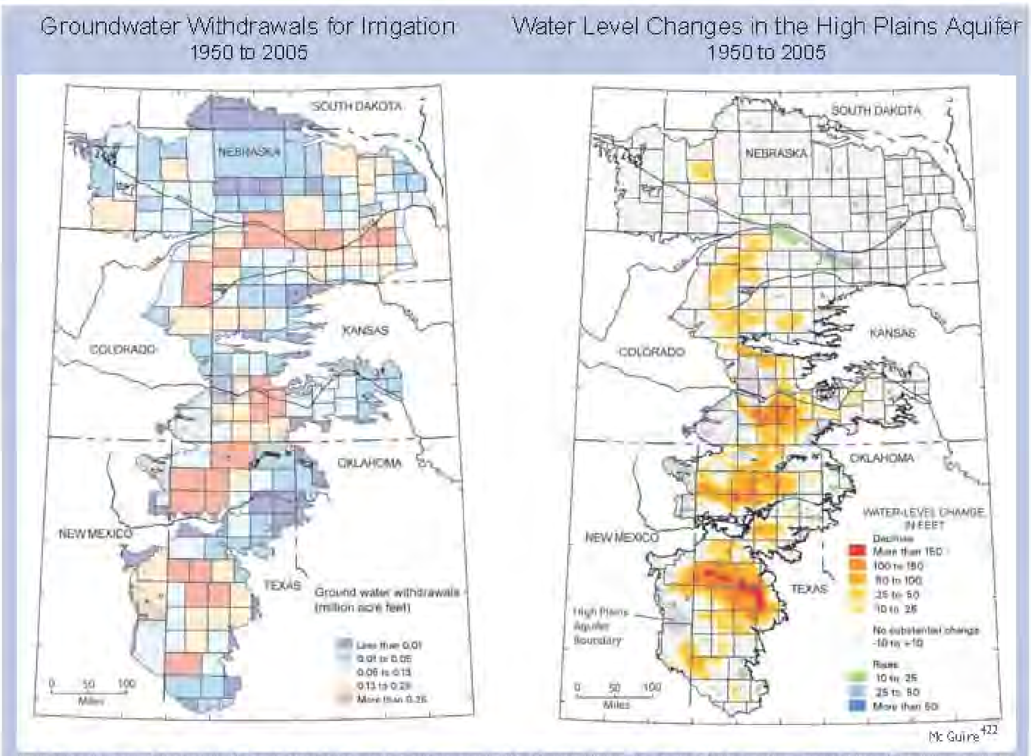
Projected increases in temperature, evaporation, and drought frequency add to concerns about the region's declining water resources.

Water is the most important factor affecting activities on the Great Plains. Most of the water used in the Great Plains comes from the High Plains aquifer (sometimes referred to by the name of its largest formation, the Ogallala aquifer), which stretches from South Dakota to Texas. The aquifer holds both current recharge from precipitation and so-called "ancient" water, water trapped by silt and soil washed down from the Rocky Mountains during the last ice age.

As population increased in the Great Plains and irrigation became widespread, annual water withdrawals began to outpace natural recharge.[422]

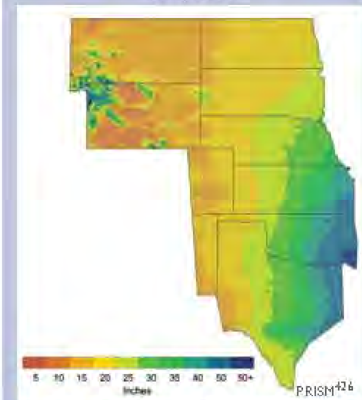
Today, an average of 19 billion gallons of groundwater are pumped from the aquifer each day. This water irrigates 13 million acres of land and provides drinking water to over 80 percent of the region's population.[423] Since 1950, aquifer water levels have dropped an average of 13 feet, equivalent to a 9 percent decrease in aquifer storage. In heavily irrigated parts of Texas, Oklahoma, and Kansas, reductions are much larger, from 100 feet to over 250 feet.

Projections of increasing temperatures, faster evaporation rates, and more sustained droughts brought on by climate change will only add more stress to overtaxed water sources.[149,253,424,425] Current water use on the Great Plains is unsustainable, as the High Plains aquifer continues to be tapped faster than the rate of recharge.



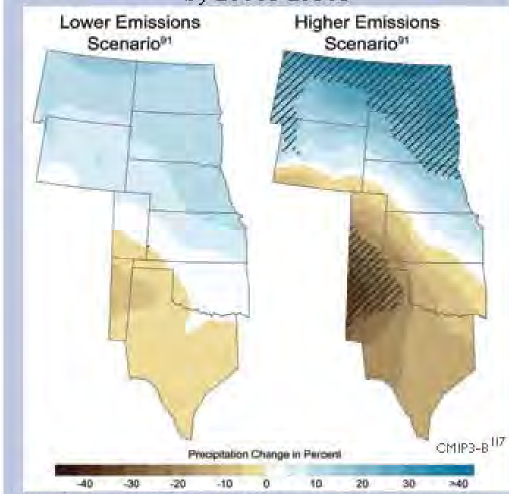
Irrigation is one of the main factors stressing water resources in the Great Plains. In parts of the region, more than 81 trillion gallons of water (pink areas on the left hand map) were withdrawn for irrigation in Texas, Oklahoma, and Kansas from 1950 to 2005. During the same time period, water levels in parts of the High Plains aquifer in those states decreased by more than 150 feet (red areas on the right hand map).

Average Annual Observed Precipitation 1971-2000



The Great Plains currently experiences a sharp precipitation gradient from east to west, from more than 50 inches of precipitation per year in eastern Oklahoma and Texas to less than 10 inches in some of the western parts of the region.

Projected Spring Precipitation Change by 2080s-2090s



Northern areas of the Great Plains are projected to experience a wetter climate by the end of this century, while southern areas are projected to experience a drier climate. The change in precipitation is compared with a 1960-1979 baseline. Confidence in the projected changes is highest in the hatched areas.

The Dust Bowl: Combined Effects of Land Use and Climate

Over the past century, large-scale conversion of grasslands to crops and ranchland has altered the natural environment of the Great Plains.[149] Irrigated fields have increased evaporation rates, reducing summer temperatures, and increasing local precipitation.[427,428]

Dust Bowl of 1935 in Stratford, Texas

The Dust Bowl of the 1930s epitomizes what can happen as a result of interactions between climate and human activity. In the 1920s, increasing demand for food encouraged poor agricultural practices. Small-scale producers ploughed under native grasses to plant wheat, removing the protective cover the land required to retain its moisture.

Variations in ocean temperature contributed to a slight increase in air temperatures, just enough to disrupt the winds that typically draw moisture from the south into the Great Plains. As the intensively tilled soils dried up, topsoil from an estimated 100 million acres of the Great Plains blew across the continent.

The Dust Bowl dramatically demonstrated the potentially devastating effects of poor land-use practices combined with climate variability and change.[429] Today, climate change is interacting with a different set of poor land-use practices. Water is being pumped from the Ogallala aquifer faster than it can recharge. In many areas, playa lakes are poorly managed (see page 127). Existing stresses on water resources in the Great Plains due to unsustainable water usage are likely to be exacerbated by future changes in temperature and precipitation, this time largely due to human-induced climate change.

Agriculture, ranching, and natural lands, already under pressure due to an increasingly limited water supply, are very likely to also be stressed by rising temperatures.

Agricultural, range, and croplands cover more than 70 percent of the Great Plains, producing wheat, hay, corn, barley, cattle, and cotton. Agriculture is fundamentally sensitive to climate. Heat and water stress from droughts and heat waves can decrease yields and wither crops.[430,431] The influence of long-term trends in temperature and precipitation can be just as great.[431]

As temperatures increase over this century, optimal zones for growing particular crops will shift. Pests that were historically unable to survive in the Great Plains' cooler areas are expected to spread northward. Milder winters and earlier springs also will encourage greater numbers and earlier emergence of insects.[149] Rising carbon dioxide levels in the atmosphere can increase crop growth, but also make some types of weeds grow even faster (see *Agriculture* sector).[432]

Projected increases in precipitation are unlikely to be sufficient to offset decreasing soil moisture and water availability in the Great Plains due to rising temperatures and aquifer depletion. In some areas, there is not expected to be enough water for agriculture to sustain even current usage.

With limited water supply comes increased vulnerability of agriculture to climate change. Further stresses on water supply for agriculture and ranching are likely as the region's cities continue to grow, increasing competition between urban and rural users.[433] The largest impacts are expected in heavily irrigated areas in the southern Great Plains, already plagued by unsustainable water use and greater frequency of extreme heat.[149]

Successful adaptation will require diversification of crops and livestock, as well as transitions from irrigated to rain-fed agriculture.[434-436] Producers who can adapt to changing climate conditions are likely to see their businesses survive; some might even thrive. Others, without resources or ability to adapt effectively, will lose out.

Climate change is likely to affect native plant and animal species by altering key habitats such as the wetland ecosystems known as prairie potholes or playa lakes.

Ten percent of the Great Plains is protected lands, home to unique ecosystems and wildlife. The region is a haven for hunters and anglers, with its ample supplies of wild game such as moose, elk, and deer; birds such as goose, quail, and duck; and fish such as walleye and bass.

Climate-driven changes are likely to combine with other human-induced stresses to further increase the vulnerability of natural ecosystems to pests, invasive species, and loss of native species. Changes in temperature and precipitation affect the composition and diversity of native animals and plants through altering their breeding patterns, water and food supply, and habitat availability.[149] In a changing climate, populations of some pests such as red fire ants and rodents, better adapted to a warmer climate, are projected to increase.[437,438] Grassland and plains birds, already besieged by habitat fragmentation, could experience significant shifts and reductions in their ranges.[439]

Urban sprawl, agriculture, and ranching practices already threaten the Great Plains' distinctive wetlands. Many of these are home to endangered and iconic species. In particular, prairie wetland ecosystems provide crucial habitat for migratory waterfowl and shorebirds.

Mallard ducks are one of the many species that inhabit the playa lakes, also known as prairie potholes.

Ongoing shifts in the region's population from rural areas to urban centers will interact with a changing climate, resulting in a variety of consequences.

Inhabitants of the Great Plains include a rising number of urban dwellers, a long tradition of rural communities, and extensive Native American

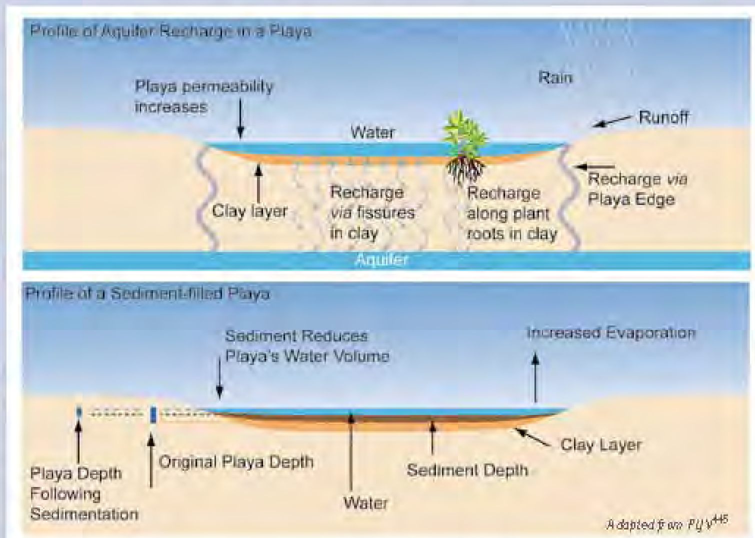
Playa Lakes and Prairie Potholes

Shallow ephemeral lakes dot the Great Plains, anomalies of water in the arid landscape. In the north they are known as prairie potholes; in the south, playa lakes. These lakes create unique microclimates that support diverse wildlife and plant communities. A playa can lie with little or no water for long periods, or have several wet/dry cycles each year. When it rains, what appeared to be only a few clumps of short, dry grasses just a few days earlier suddenly teems with frogs, toads, clam shrimp, and aquatic plants.

Playa lakes in west Texas fill up after a heavy spring rain.

The playas provide a perfect home for migrating birds to feed, mate, and raise their young. Millions of shorebirds and waterfowl, including Canada geese, mallard ducks, and Sandhill cranes, depend on the playas for their breeding grounds. From the prairie potholes of North Dakota to the playa lakes of West Texas, the abundance and diversity of native bird species directly depends on these lakes.[440,441]

Despite their small size, playa lakes and prairie potholes also play a critical role in supplying water to the Great Plains. The contribution of the playa lakes to this sensitively balanced ecosystem needs to be monitored and maintained in order to avoid unforeseen impacts on our natural resources. Before cultivation, water from these lakes was the primary source of recharge to the High Plains aquifer.[442] But many playas are disappearing and others are threatened by growing urban populations, extensive agriculture, and other filling and tilling practices.[443] In recent years, agricultural demands have drawn down the playas to irrigate crops. Agricultural waste and fertilizer residues drain into playas, decreasing the quality of the water, or clogging them so the water cannot trickle down to refill the aquifer. Climate change is expected to add to these stresses, with increasing temperatures and changing rainfall patterns altering rates of evaporation, recharge, and runoff to the playa lake systems.[444]



populations. Although farming and ranching remain primary uses of the land – taking up much of the region's geographical area – growing cities provide housing and jobs for more than two-thirds of the population. For everyone on the Great Plains, though, a changing climate and a limited water supply are likely to challenge their ability to thrive, leading to conflicting interests in the allocation of increasingly scarce water resources.[313,433]

Native American communities

The Great Plains region is home to 65 Native American tribes. Native populations on rural tribal lands have limited capacities to respond to climate change.[313] Many reservations already face severe problems with water quantity and quality – problems likely to be exacerbated by climate change and other human-induced stresses.

Rural communities

As young adults move out of small, rural communities, the towns are increasingly populated by a vulnerable demographic of very old and very young people, placing them more at risk for health issues than urban communities. Combined effects of changing demographics and climate are likely to make it more difficult to supply adequate and efficient public health services and educational opportunities to rural areas. Climate-driven shifts in optimal crop types and increased risk of drought, pests, and extreme events will add more economic stress and tension to traditional communities.[430,433]

Urban populations

Although the Great Plains is not yet known for large cities, many mid-sized towns throughout the region are growing rapidly. One in four of the most rapidly growing cities in the nation is located in the Great Plains[446] (see *Society* sector). Most of these growing centers can be found in the southern parts of the region, where water resources are already seriously constrained. Urban populations, particularly the young, elderly, and economically disadvantaged, may also be disproportionately affected by heat.[447]

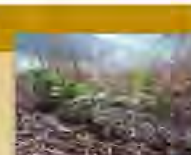
New opportunities

There is growing recognition that the enormous wind power potential of the Great Plains could provide new avenues for future employment and land use. Texas already produces the most wind power of any state. Wind energy production is also prominent in Oklahoma. North and South Dakota have rich wind potential.[191]

As climate change creates new environmental conditions, effective adaptation strategies become increasingly essential to ecological and socioeconomic survival. A great deal of the Great Plains' adaptation potential might be realized through agriculture. For example, plant species that mature earlier and are more resistant to disease and pests are more likely to thrive under warmer conditions.

Other emerging adaptation strategies include dynamic cropping systems and increased crop diversity. In particular, mixed cropping-livestock systems maximize available resources while minimizing the need for external inputs such as irrigation that draws down precious water supplies.[436] In many parts of the region, diverse cropping systems and improved water use efficiency will be key to sustaining crop and rangeland systems.[448] Reduced water supplies might cause some farmers to alter the intensive cropping systems currently in use.[193,219]

Adaptation: Agricultural Practices to Reduce Water Loss and Soil Erosion



Conservation of water is critical to efficient crop production in areas where water can be scarce. Following the Dust Bowl in the 1930s, Great Plains farmers implemented a number of improved farming practices to increase the effectiveness of rainfall capture and retention in the soil and protect the soil against water and wind erosion. Examples include rotating crops, retaining crop residues, increasing vegetative cover, and altering plowing techniques.

With observed and projected increases in summer temperatures and in the frequency and intensity of heavy downpours, it will become even more important to protect against increasing loss of water and soil. Across the upper Great Plains, where strong storms are projected to occur more frequently, producers are being encouraged to increase the amount of crop residue left on the soil or to plant cover crops in the fall to protect the soil in the spring before crops are planted.

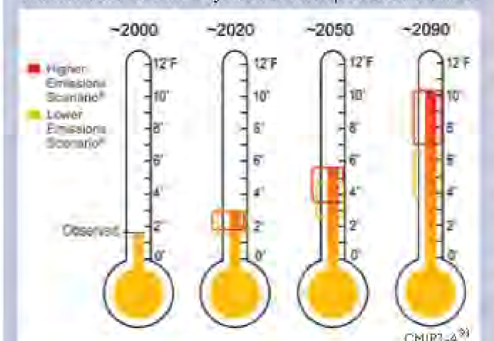
Across the southern Great Plains, some farmers are returning to dryland farming rather than relying on irrigation for their crops. Preserving crop residue helps the soil absorb more moisture from rain and eases the burden on already-stressed groundwater. These efforts have been promoted by the U.S. Department of Agriculture through research and extension efforts such as Kansas State University's Center for Sustainable Agriculture and Alternative Crops.

Southwest

The Southwest region stretches from the southern Rocky Mountains to the Pacific Coast. Elevations range from the lowest in the country to among the highest, with climates ranging from the driest to some of the wettest. Past climate records based on changes in Colorado River flows indicate that drought is a frequent feature of the Southwest, with some of the longest documented "megadroughts" on Earth. Since the 1940s, the region has experienced its most rapid population and urban growth. During this time, there were both unusually wet periods (including much of 1980s and 1990s) and dry periods (including much of 1950s and 1960s).[449] The prospect of future droughts becoming more severe as a result of global warming is a significant concern, especially because the Southwest continues to lead the nation in population growth.

Human-induced climate change appears to be well underway in the Southwest. Recent warming is among the most rapid in the nation, significantly more than the global average in some areas. This is driving declines in spring snowpack and Colorado River flow.[34,160,161] Projections suggest continued strong warming, with much larger increases under higher emissions scenarios[91] compared to lower emissions scenarios. Projected summertime temperature increases are greater than the annual average increases in some parts of the region, and are likely to be exacerbated locally by expanding urban heat island effects.[450] Further water cycle changes are projected, which, combined with increasing temperatures, signal a serious water supply challenge in the decades and centuries ahead.[34,159]

Observed and Projected Temperature Rise



The average temperature in the Southwest has already increased roughly 1.5°F compared to a 1960-1979 baseline period. By the end of the century, average annual temperature is projected to rise approximately 4°F to 10°F above the historical baseline, averaged over the Southwest region. The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible.

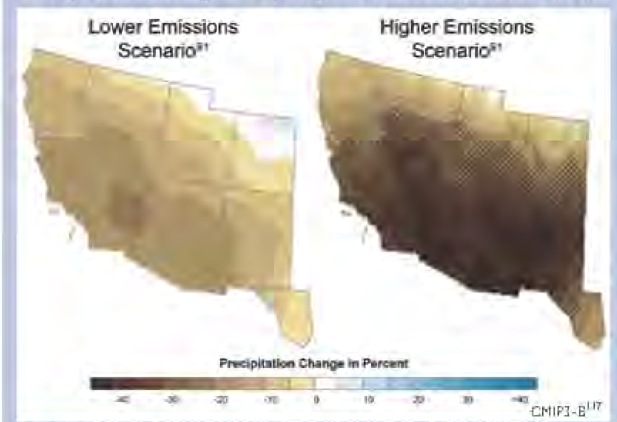
Water supplies are projected to become increasingly scarce, calling for trade-offs among competing uses, and potentially leading to conflict.

Water is, quite literally, the lifeblood of the Southwest. The largest use of water in the region is associated with agriculture, including some of the nation's most important crop-producing areas in California. Water is also an important source of hydroelectric power, and water is required for the large population growth in the region, particularly that of major cities such as Phoenix and Las Vegas. Water also plays a critical role in supporting healthy ecosystems across the region, both on land and in rivers and lakes.

Water supplies in some areas of the Southwest are already becoming limited, and this trend toward scarcity is likely to be a harbinger of future water shortages.[34,451] Groundwater pumping is lowering water tables, while rising temperatures reduce river flows in vital rivers including the Colorado.[34] Limitations imposed on water supply by projected temperature increases are likely to be made worse by substantial reductions in rain and snowfall in the spring months, when precipitation is most needed to fill reservoirs to meet summer demand.[151]

A warmer and drier future means extra care will be needed in planning the allocation of water for the coming decades. The Colorado Compact, negotiated in the 1920s, allocated the Colorado River's water among the seven basin states. It was based, however, on unrealistic assumptions about how much water was available because the observations of runoff during the early 1900s turned out to be part of the greatest and longest high-flow period of the last five centuries.[452] Today, even in normal decades, the Colorado River does not have enough water to meet the agreed-upon allocations. During droughts and under projected future conditions, the situation looks even bleaker.

Projected Change in Spring Precipitation, 2080-2099

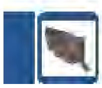


Percentage change in March-April-May precipitation for 2080-2099 compared to 1961-1979 for a lower emissions scenario[91] (left) and a higher emissions scenario[91] (right). Confidence in the projected changes is highest in the hatched areas.

During droughts, water designated for agriculture could provide a temporary back-up supply for urban water needs. Similarly, non-renewable groundwater could be tapped during especially dry periods. Both of these options, however, come at the cost of either current or future agricultural production.

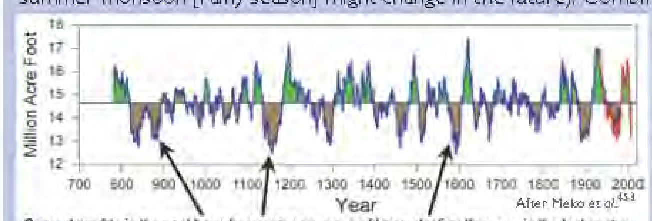
Water is already a subject of contention in the Southwest, and climate change – coupled with rapid population growth – promises to increase the likelihood of water-related

Future of Drought in the Southwest



Droughts are a long-standing feature of the Southwest's climate. The droughts of the last 110 years pale in comparison to some of the decades-long "megadroughts" that the region has experienced over the last 2000 years.[419] During the closing decades of the 1500s, for example, major droughts gripped parts of the Southwest.[189] These droughts sharply reduced the flow of the Colorado River[452,453] and the all-important Sierra Nevada headwaters for California,[454] and dried out the region as a whole. As of 2009, much of the Southwest remains in a drought that began around 1999. This event is the most severe western drought of the last 110 years, and is being exacerbated by record warming.[455]

Over this century, projections point to an increasing probability of drought for the region.[90,115] Many aspects of these projections, including a northward shift in winter and spring storm tracks, are consistent with observed trends over recent decades.[76,456,457] Thus, the most likely future for the Southwest is a substantially drier one (although there is presently no consensus on how the region's summer monsoon [rainy season] might change in the future). Combined with the historical record of severe droughts and the current uncertainty regarding the exact causes and drivers of these past events, the Southwest must be prepared for droughts that could potentially result from multiple causes. The combined effects of natural climate variability and human-induced climate change could turn out to be a devastating "one-two punch" for the region.



Colorado River flow has been reconstructed back over 1200 years based primarily on tree-ring data. These data reveal that some droughts in the past have been more severe and longer lasting than any experienced in the last 100 years. The red line indicates actual measurements of river flow during the last 100 years. Models indicate that, in the future, droughts will continue to occur, but will become hotter, and thus more severe, over time.[91]

130

conflict. Projected temperature increases, combined with river-flow reductions, will increase the risk of water conflicts between sectors, states, and even nations. In recent years, negotiations regarding existing water supplies have taken place among the seven states sharing the Colorado River and the two states (New Mexico and Texas) sharing the Rio Grande. Mexico and the United States already disagree on meeting their treaty allocations of Rio Grande and Colorado River water.

In addition, many water settlements between the U.S. Government and Native American tribes have yet to be fully worked out. The Southwest is home to dozens of Native communities whose status as sovereign nations means they hold rights to the water for use on their land. However, the amount of water actually available to each nation is determined through negotiations and litigation. Increasing water demand in the Southwest is driving current negotiations and litigation of tribal water rights. While several nations have legally settled their water rights, many other tribal negotiations are either currently underway or pending. Competing demands from treaty rights, rapid development, and changes in agriculture in the region, exacerbated by years of drought and climate change, have the potential to spark significant conflict over an already over-allocated and dwindling resource.

Increasing temperature, drought, wildfire, and invasive species will accelerate transformation of the landscape.

Climate change already appears to be influencing both natural and managed ecosystems of the Southwest.[455,458] Future landscape impacts are likely to be substantial, threatening biodiversity, protected areas, and ranching and agricultural lands. These changes are often driven by multiple factors, including changes in temperature and drought patterns, wildfire, invasive species, and pests.

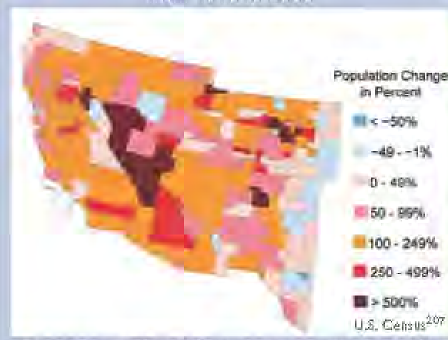
Conditions observed in recent years can serve as indicators for future change. For example, temperature increases have made the current drought in the region more severe than the natural droughts of the last several centuries. As a result, about 4,600 square miles of piñon-juniper woodland in the Four Corners region of the Southwest have experienced substantial die-off of piñon pine trees.[455] Record wildfires are also being driven by rising temperatures and related reductions in spring snowpack and soil moisture.[458]

How climate change will affect fire in the Southwest varies according to location. In general, total area burned is projected to increase.[459] How this plays out at individual locations, however, depends on regional changes in temperature and precipitation, as well as on whether fire in the area is currently limited by fuel availability or by rainfall.[460] For example, fires in wetter, forested areas are expected to increase in frequency, while areas where fire is limited by the availability of fine fuels experience decreases.[460] Climate changes could also create subtle shifts in fire behavior, allowing more "runaway fires" – fires that are thought to have been brought under control, but then rekindle.[461] The magnitude of fire damages, in terms of economic impacts as well as direct endangerment, also increases as urban development increasingly impinges on forested areas.[460,462]

Climate-fire dynamics will also be affected by changes in the distribution of ecosystems across the Southwest. Increasing temperatures and shifting precipitation patterns will drive declines in high-elevation ecosystems such as alpine forests and tundra.[459,463] Under higher emissions scenarios,[91] high-elevation forests in California, for example, are projected to decline by 60 to 90 percent before the end of the century.[284,459] At the same time, grasslands are projected to expand, another factor likely to increase fire risk.

As temperatures rise, some iconic landscapes of the Southwest will be greatly altered as species shift their ranges northward and upward to cooler climates, and fires attack unaccustomed ecosystems which lack natural defenses. The Sonoran Desert, for example, famous for the saguaro cactus, would look very different if more woody species spread northward from Mexico into areas currently dominated by succulents (such as cacti) or native grasses.[464] The desert is already being invaded by red brome and buffle grasses that do well in high temperatures and are native to Africa and the

Change in Population
from 1970 to 2008



The map above of percentage changes in county population between 1970 and 2008 shows that the Southwest has experienced very rapid growth in recent decades (indicated in orange, red, and maroon).

Mediterranean. Not only do these noxious weeds out-compete some native species in the Sonoran Desert, they also fuel hot, cactus-killing fires. With these invasive plant species and climate change, the Saguaro and Joshua Tree national parks could end up with far fewer of their namesake plants.[465] In California, two-thirds of the more than 5,500 native plant species are projected to experience range reductions up to 80 percent before the end of this century under projected warming.[466] In their search for optimal conditions, some species will move uphill, others northward, breaking up present-day ecosystems; those species moving southward to higher elevations might cut off future migration options as temperatures continue to increase.

The potential for successful plant and animal adaptation to coming change is further hampered by existing regional threats such as human-caused fragmentation of the landscape, invasive species, river-flow reductions, and pollution. Given the mountainous nature of the Southwest, and the associated impediments to species shifting their ranges, climate change likely places other species at risk. Some areas have already been identified as possible refuges where species at risk could continue to live if these areas were preserved for this purpose.[466] Other rapidly changing landscapes will require major adjustments, not only from plant and animal species, but also by the region's ranchers, foresters, and other inhabitants.

Increased frequency and altered timing of flooding will increase risks to people, ecosystems, and infrastructure.

Paradoxically, a warmer atmosphere and an intensified water cycle are likely to mean not only a greater likelihood of drought for the Southwest, but also an increased risk of flooding. Winter precipitation in Arizona, for example, is already

A Biodiversity Hotspot

The Southwest is home to two of the world's 34 designated "biodiversity hotspots." These at-risk regions have two special qualities: they hold unusually large numbers of plant and animal species that are endemic (found nowhere else), and they have already lost over 70 percent of their native vegetation.[467,468] About half the world's species of plants and land animals occur only in these 34 locations, though they cover just 2.3 percent of the Earth's land surface.

One of these biodiversity hotspots is the Madrean Pine-Oak Woodlands. Once covering 178 square miles, only isolated patches remain in the United States, mainly on mountaintops in southern Arizona, New Mexico, and West Texas. The greatest diversity of pine species in the world grows in this area: 44 of the 110 varieties,[469] as well as more than 150 species of oak.[470] Some 5,300 to 6,700 flowering plant species inhabit the ecosystem, and over 500 bird species, 23 of which are endemic. More hummingbirds are found here than anywhere else in the United States. There are 384 species of reptiles, 37 of which are endemic, and 328 species of mammals, six of which are endemic. There are 84 fish species, 18 of which are endemic. Some 200 species of butterfly thrive here, of which 45 are endemic, including the Monarch that migrates 2,500 miles north to Canada each year.[471] Ecotourism has become the economic driver in many parts of this region, but logging, land clearing for agriculture, urban development, and now climate change threaten the region's viability.

becoming more variable, with a trend toward both more frequent extremely dry and extremely wet winters.[472] Some water systems rely on smaller reservoirs being filled up each year. More frequent dry winters suggest an increased risk of these systems running short of water. However, a greater potential for flooding also means reservoirs cannot be filled to capacity as safely in years where that is possible. Flooding also causes reservoirs to fill with sediment at a faster rate, thus reducing their water-storage capacities.

On the global and national scales, precipitation patterns are already observed to be shifting, with more rain falling in heavy downpours that can lead to flooding.[90,473] Rapid landscape transformation due to vegetation die-off and wildfire as well as loss of wetlands along rivers is also likely to reduce flood-buffering capacity. Moreover, increased flood risk in the Southwest is likely to result from a combination of decreased snow cover on the lower slopes of high mountains, and an increased fraction of winter precipitation falling as rain and therefore running off more rapidly.[154] The increase in rain on snow events will also result in rapid runoff and flooding.[474]

The most obvious impact of more frequent flooding is a greater risk to human beings and their infrastructure. This applies to locations along major rivers, but also to much broader and highly vulnerable areas such as the Sacramento–San Joaquin River Delta system. Stretching from the San Francisco Bay nearly to the state capital of Sacramento, the Sacramento–San Joaquin River Delta and Suisun Marsh make up the largest estuary on the West Coast of North America. With its rich soils and rapid subsidence rates – in some locations as high as 2 or more feet per decade – the entire Delta region is now below sea level, protected by more than a thousand miles of levees and dams.[475] Projected changes in the timing and amount of river flow, particularly in winter and spring, is estimated to more than double the risk of Delta flooding events by mid-century, and result in an eight-fold increase before the end of the century.[476] Taking into account the additional risk of a major seismic event and increases in sea level due to climate change over this century, the California Bay–Delta Authority has concluded that the Delta and Suisun Marsh are not sustainable under current practices; efforts are underway to identify and implement adaptation strategies aimed at reducing these risks.[476]

Unique tourism and recreation opportunities are likely to suffer.

Tourism and recreation are important aspects of the region's economy. Increasing temperatures will affect important winter activities such as downhill and cross-country skiing, snowshoeing, and snowmobiling, which require snow on the ground. Projections indicate later snow and less snow coverage in ski resort areas, particularly those at lower elevations and in the southern part of the region.[284] Decreases from 40 to almost 90 percent are likely in end-of-season snowpack under a higher emissions scenario[91] in counties with major ski resorts from New Mexico to California.[477] In addition to shorter seasons, earlier wet snow avalanches – more than six weeks earlier by the end of this century under a higher emissions scenario[91] – could force ski areas to shut down affected runs before the season would otherwise end.[478] Resorts require a certain number of days just to break even, cutting the season short by even a few weeks, particularly if those occur during the lucrative holiday season, could easily render a resort unprofitable.

Even in non-winter months, ecosystem degradation will affect the quality of the experience for hikers, bikers, birders, and others who enjoy the Southwest's natural beauty. Water sports that depend on the flows of rivers and sufficient water in lakes and reservoirs are already being affected, and much larger changes are expected.

Cities and agriculture face increasing risks from a changing climate.

Resource use in the Southwest is involved in a constant three-way tug-of-war among preserving natural ecosystems, supplying the needs of rapidly expanding urban areas, and protecting the lucrative agricultural sector, which, particularly in California, is largely based on highly temperature- and water-sensitive specialty crops. Urban areas are also sensitive to temperature-related impacts on air quality, electricity demand, and the health of their inhabitants.

The magnitude of projected temperature increases for the Southwest, particularly when combined with urban heat island effects for major cities such as Phoenix, Albuquerque, Las Vegas, and many California cities, represent significant stresses to health, electricity, and water supply in a region that already experiences very high summer temperatures.[284,325,450]

If present-day levels of ozone-producing emissions are maintained, rising temperatures also imply declining air quality in urban areas such as those in California which already experience some of the worst air quality in the nation (see *Society* sector).[479] Continued rapid population growth is expected to exacerbate these concerns.

With more intense, longer-lasting heat wave events projected to occur over this century, demands for air conditioning are expected to deplete electricity supplies, increasing risks of brownouts and blackouts.[325] Electricity supplies will also be affected by changes in the timing of river flows and where hydroelectric systems have limited storage capacity and reservoirs (see *Energy* sector).[480,481]

Much of the region's agriculture will experience detrimental impacts in a warmer future, particularly specialty crops in California such as apricots, almonds, artichokes, figs, kiwis, olives, and walnuts.[482,483] These and other specialty crops require a minimum number of hours at a chilling temperature threshold in the winter to become dormant and set fruit for the following year.[482] Accumulated winter chilling hours have already decreased across central California and its coastal valleys. This trend is projected to continue to the point where chilling thresholds for many key crops would no longer be met. A steady reduction in winter chilling could have serious economic impacts on fruit and nut production in the region. California's losses due to future climate change are estimated between zero and 40 percent for wine and table grapes, almonds, oranges, walnuts, and avocadoes, varying significantly by location.[483]

Adaptation strategies for agriculture in California include more efficient irrigation and shifts in cropping patterns, which have the potential to help compensate for climate-driven increases in water demand for agriculture due to rising temperatures.[484] The ability to use groundwater and/or water designated for agriculture as backup supplies for urban uses in times of severe drought is expected to become more important in the future as climate change dries out the Southwest; however, these supplies are at risk of being depleted as urban populations swell (see *Water* sector).

Adaptation: Strategies for Fire

Living with present-day levels of fire risk, along with projected increases in risk, involves actions by residents along the urban-forest interface as well as fire and land management officials. Some basic strategies for reducing damage to structures due to fires are being encouraged by groups like National Firewise Communities, an interagency program that encourages wildfire preparedness measures such as creating defensible space around residential structures by thinning trees and brush, choosing fire-resistant plants, selecting ignition-resistant building materials and design features, positioning structures away from slopes, and working with firefighters to develop emergency plans.

Additional strategies for responding to the increased risk of fire as climate continues to change could include adding firefighting resources[461] and improving evacuation procedures and communications infrastructure. Also important would be regularly updated insights into what the latest climate science implies for changes in types, locations, timing, and potential severity of fire risks over seasons to decades and beyond; implications for related political, legal, economic, and social institutions; and improving predictions for regeneration of burnt-over areas and the implications for subsequent fire risks. Reconsideration of policies that encourage growth of residential developments in or near forests is another potential avenue for adaptive strategies.[462]

Northwest

The Northwest's rapidly growing population, as well as its forests, mountains, rivers, and coastlines, are already experiencing human-induced climate change and its impacts.[34] Regionally averaged temperature rose about 1.5°F over the past century[485] (with some areas experiencing increases up to 4°F) and is projected to increase another 3 to 10°F during this century.[486] Higher emissions scenarios would result in warming in the upper end of the projected range. Increases in winter precipitation and decreases in summer precipitation are projected by many climate models,[487] though these projections are less certain than those for temperature. Impacts related to changes in snowpack, streamflows, sea level, forests, and other important aspects of life in the Northwest are already underway, with more severe impacts expected over coming decades in response to continued and more rapid warming.

Declining springtime snowpack leads to reduced summer streamflows, straining water supplies.

The Northwest is highly dependent on temperature-sensitive springtime snowpack to meet growing, and often competing, water demands such as municipal and industrial uses, agricultural irrigation, hydropower production, navigation, recreation, and in-stream flows that protect aquatic ecosystems including threatened and endangered species. Higher cool season (October through March) temperatures cause more precipitation to fall as rain rather than snow and contribute to earlier snowmelt. April 1 snowpack, a key indicator of natural water storage available for the warm season, has already declined substantially throughout the region. The average decline in the Cascade Mountains, for example, was about 25 percent over the past 40 to 70 years, with most of this due to the 2.5°F increase in cool season temperatures over that period.[108,488] Further declines in Northwest snowpack are projected to result from additional warming over this century, varying with latitude, elevation, and proximity to the coast. April 1 snowpack is projected to decline as much as 40 percent in the Cascades by the 2040s.[489] Throughout the region, earlier snowmelt will cause a reduction in the amount of water available during the warm season.[68]

In areas where it snows, a warmer climate means major changes in the timing of runoff: streamflow increases in winter and early spring, and then decreases in late spring, summer, and fall. This shift in streamflow timing has already been observed over the past 50 years,[252] with the peak of spring runoff shifting from a few days earlier in some places to as much as 25 to 30 days earlier in others.[157]

This trend is projected to continue, with runoff shifting 20 to 40 days earlier within this century.[157] Reductions in summer water availability will vary with the temperatures experienced in different parts of the region. In relatively warm areas on the western slopes of the Cascade Mountains, for example, reductions in warm season (April through September) runoff of 30 percent or more are projected by mid-century, whereas colder areas in the Rocky Mountains are expected to see reductions of about 10 percent. Areas dominated by rain rather than snow are not expected to see major shifts in the timing of runoff.[492]

Trends in April 1 Snow Water Equivalent
1950 to 2002

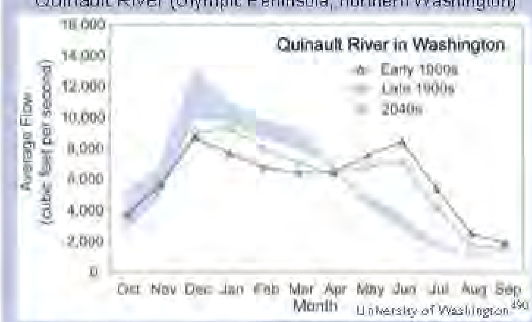
April 1 snowpack (a key indicator of natural water storage available for the warm season) has declined throughout the Northwest. In the Cascade Mountains, April 1 snowpack declined by an average of 25 percent, with some areas experiencing up to 60 percent declines. On the map, decreasing trends are in red and increasing trends are in blue.[491]

Extreme high and low streamflows also are expected to change with warming. Increasing winter rainfall (as opposed to snowfall) is expected to lead to more winter flooding in relatively warm watersheds on the west side of the Cascades. The already low flows of late summer are projected to decrease further due to both earlier snowmelt and increased evaporation and water loss from vegetation. Projected decreases in summer precipitation would exacerbate these effects. Some sensitive watersheds are projected to experience both increased flood risk in winter and increased drought risk in summer due to warming.

The region's water supply infrastructure was built based on the assumption that most of the water needed for summer uses would be stored naturally in snowpack. For example, the storage capacity in Columbia Basin reservoirs is only 30 percent of the annual runoff, and many small urban water supply systems on the west side of the Cascades store less than 10 percent of their annual flow.[493] Besides providing water supply and managing flows for hydropower, the region's reservoirs are operated for flood-protection purposes and, as such, might have to release (rather than store) large amounts of runoff during the winter and early spring to maintain enough space for flood protection. Earlier flows would thus place more of the year's runoff into the category of hazard rather than resource. An advance in the timing of snowmelt runoff would also

Shift to Earlier Peak Streamflow

Quinault River (Olympic Peninsula, northern Washington)



As precipitation continues to shift from snow to rain, by the 2040s, peak flow on the Quinault River is projected to occur in December, and flows in June are projected to be reduced to about half of what they were over the past century. On the graph, the blue swath represents the range of projected streamflows based on an increase in temperature of 3.6 to 5.4°F. The other lines represent streamflows in the early and late 1900s.[487,494]

increase the length of the summer dry period, with important consequences for water supply, ecosystems, and wildfire management.[157]

One of the largest demands on water resources in the region is hydroelectric power production. About 70 percent of the Northwest's electricity is provided by hydropower, a far greater percentage than in any other region. Warmer summers will increase electricity demands for air conditioning and refrigeration at the same time of year that lower streamflows will lead to reduced hydropower generation. At the same time, water is needed for irrigated agriculture, protecting fish species, reservoir and river recreation, and urban uses. Conflicts between all of these water uses are expected to increase, forcing complex trade-offs between competing objectives (see *Energy* and *Water* sectors).[487,494]

Increased insect outbreaks, wildfires, and changing species composition in forests will pose challenges for ecosystems and the forest products industry.

Higher summer temperatures and earlier spring snowmelt are expected to increase the risk of forest fires in the Northwest by increasing summer moisture deficits; this pattern has already been observed in recent decades. Drought stress and higher temperatures will decrease tree growth in most low- and mid-elevation forests. They will also increase the frequency and intensity of mountain pine beetle and other insect attacks,[243] further increasing fire risk and reducing timber production, an important part of the regional economy. The mountain pine beetle outbreak in British Columbia has destroyed 33 million acres of trees so far, about 40 percent of the marketable pine trees in the province. By 2018, it is projected that the infestation will have run its course and over 78 percent of the mature pines will have been killed; this will affect more than one-third of the total area of British Columbia's forests[495] (see *Ecosystems* sector). Forest and fire management practices are also factors in these insect outbreaks.[252] Idaho's Sawtooth Mountains are also now threatened by pine beetle infestation.

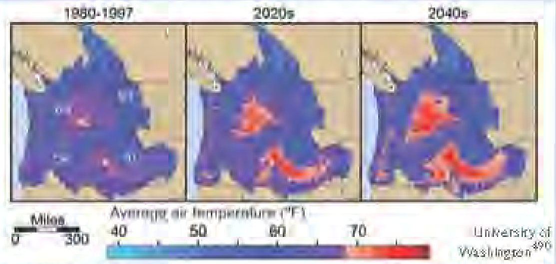
In the short term, high elevation forests on the west side of the Cascade Mountains are expected to see increased growth. In the longer term, forest growth is expected to decrease as summertime soil moisture deficits limit forest productivity, with low-elevation forests experiencing these changes first. The extent and species composition of forests are also expected to change as tree species respond to climate change. There is also the potential for extinction of local populations and loss of biological diversity if environmental changes outpace species' ability to shift their ranges and form successful new ecosystems.

Agriculture, especially production of tree fruit such as apples, is also an important part of the regional economy. Decreasing irrigation supplies, increasing pests and disease, and increased competition from weeds are likely to have negative effects on agricultural production.

Salmon and other coldwater species will experience additional stresses as a result of rising water temperatures and declining summer streamflows.

Northwest salmon populations are at historically low levels due to stresses imposed by a variety of human activities including dam building, logging, pollution, and over-fishing. Climate change affects salmon throughout their life stages and poses an additional stress. As more winter precipitation falls as rain rather than snow, higher winter streamflows scour streambeds, damaging spawning nests and washing away incubating eggs. Earlier peak streamflows flush young salmon from rivers to estuaries before they are physically mature enough for the transition, increasing a variety of stresses including the risk of being eaten by predators. Lower summer streamflows and warmer water temperatures create less favorable summer stream conditions for salmon and other coldwater fish species in many parts of the Northwest. In addition, diseases and parasites that infect salmon tend to flourish in warmer water. Climate change also impacts the ocean environment, where salmon spend several years of their lives. Historically, warm periods in the coastal ocean have coincided with relatively low abundances of salmon, while cooler ocean periods have coincided with relatively high salmon numbers.[70, 563]

Decreasing Habitat for Coldwater Fish



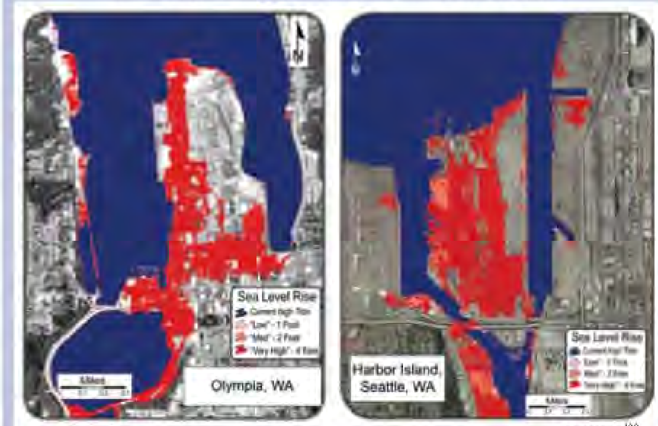
Increasing air temperatures lead to rising water temperatures, which increase stress on coldwater fish such as trout, salmon, and steelhead. August average air temperature above 70°F is a threshold above which these fish are severely stressed. Projected temperatures for the 2020s and 2040s under a higher emissions scenario suggest that the habitat for these fish is likely to decrease dramatically.[494,497,563,564]

Most wild Pacific salmon populations are extinct or imperiled in 56 percent of their historical range in the Northwest and California,[496] and populations are down more than 90 percent in the Columbia River system. Many species are listed as either threatened or endangered under the Federal Endangered Species Act. Studies suggest that about one-third of the current habitat for the Northwest's salmon and other coldwater fish will no longer be suitable for them by the end of this century as key temperature thresholds are exceeded. Because climate change impacts on their habitat are projected to be negative, climate change is expected to hamper efforts to restore depleted salmon populations.

Sea-level rise along vulnerable coastlines will result in increased erosion and the loss of land.

Climate change is projected to exacerbate many of the stresses and hazards currently facing the coastal zone. Sea-level rise will increase erosion of the Northwest coast and cause the loss of beaches and significant coastal land areas. Among the most vulnerable parts of the coast is the heavily populated south Puget Sound region, which includes the cities of Olympia, Tacoma, and Seattle, Washington. Some climate models project changes in atmospheric pressure patterns that suggest a more southwesterly direction of future winter winds. Combined with higher sea levels, this would accelerate coastal erosion all along the Pacific Coast. Sea-level rise in the Northwest (as elsewhere) is determined by global rates of sea-level rise, changes in coastal elevation associated with local vertical movement of the land, and atmospheric circulation patterns that influence wind-driven "pile-up" of water along the coast. A mid-range estimate of relative sea-level rise for the Puget Sound basin is about 13 inches by 2100. However, higher levels of up to 50 inches by 2100 in more rapidly subsiding (sinking) portions of the basin are also possible given the large uncertainties about accelerating rates of ice melt from Greenland and Antarctica in recent years (see *Global* and *National Climate Change* sections).[498]

Northwest Cities at Risk to Sea-Level Rise



Petersen[499]

Highly populated coastal areas throughout Puget Sound, Washington, are vulnerable to sea-level rise. The maps show regions of Olympia and Harbor Island (both located in Puget Sound) that are likely to be lost to sea-level rise by the end of this century based on moderate and high estimates.

An additional concern is landslides on coastal bluffs. The projected heavier winter rainfall suggests an increase in saturated soils and, therefore, an increased number of landslides. Increased frequency and/or severity of landslides is expected to be especially problematic in areas where there has been intensive development on unstable slopes. Within Puget Sound, the cycle of beach erosion and bluff landslides will be exacerbated by sea-level rise, increasing beach erosion, and decreasing slope stability.

Adaptation: Improved Planning to Cope with Future Changes

States, counties, and cities in the Northwest are beginning to develop strategies to adapt to climate change. In 2007, Washington state convened stakeholders to develop adaptation strategies for water, agriculture, forests, coasts, infrastructure, and human health. Recommendations included improved drought planning, improved monitoring of diseases and pests, incorporating sea-level rise in coastal planning, and public education. An implementation strategy is under development.

In response to concerns about increasing flood risk, King County, Washington, approved plans in 2007 to fund repairs to the county's aging levee system. The county also will replace more than 57 "short-span" bridges with wider span structures that allow more debris and floodwater to pass underneath rather than backing up and causing the river to flood. The county has begun incorporating porous concrete and rain gardens into road projects to manage the effects of stormwater runoff during heavy rains, which are increasing as climate changes. King County has also published an adaptation guidebook that is becoming a model that other local governments can refer to in order to organize adaptation actions within their municipal planning processes.[500]

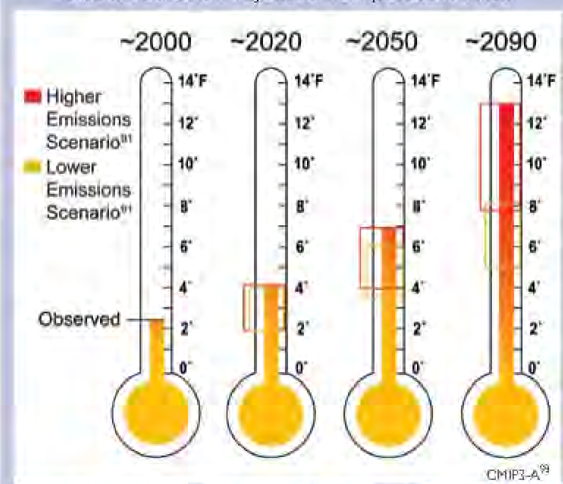
Concern about sea-level rise in Olympia, Washington, contributed to the city's decision to relocate its primary drinking water source from a low-lying surface water source to wells on higher ground. The city adjusted its plans for construction of a new City Hall to locate the building in an area less vulnerable to sea-level rise than the original proposed location. The building's foundation also was raised by 1 foot.

Alaska

Over the past 50 years, Alaska has warmed at more than twice the rate of the rest of the United States' average. Its annual average temperature has increased 3.4°F, while winters have warmed even more, by 6.3°F.[501] As a result, climate change impacts are much more pronounced than in other regions of the United States. The higher temperatures are already contributing to earlier spring snowmelt, reduced sea ice, widespread glacier retreat, and permafrost warming.[220,501] These observed changes are consistent with climate model projections of greater warming over Alaska, especially in winter, as compared to the rest of the country.

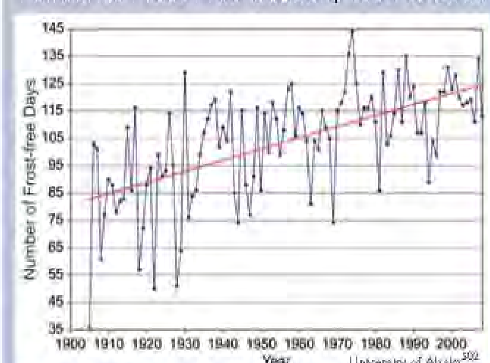
Climate models also project increases in precipitation over Alaska. Simultaneous increases in evaporation due to higher air temperatures, however, are expected to lead to drier conditions overall, with reduced soil moisture.[90] In the future, therefore, model projections suggest a longer summer growing season combined with an increased likelihood of summer drought and wildfires.

Observed and Projected Temperature Rise



Alaska's annual average temperature has increased 3.4°F over the past 50 years. The observed increase shown above compares the average temperature of 1993-2007 with a 1960s-1970s baseline, an increase of over 2°F. The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible. By the end of this century, the average temperature is projected to rise by 5 to 13°F above the 1960s-1970s baseline.

Fairbanks Frost-Free Season, 1904 to 2008



Over the past 100 years, the length of the frost-free season in Fairbanks, Alaska, has increased by 50 percent. The trend toward a longer frost-free season is projected to produce benefits in some sectors and detriments in others.

Average annual temperatures in Alaska are projected to rise about 3.5 to 7°F by the middle of this century. How much temperatures rise later in the century depends strongly on global emissions choices, with increases of 5 to 8°F projected with lower emissions, and increases of 8 to 13°F with higher emissions.[91] Higher temperatures are expected to continue to reduce Arctic sea ice coverage. Reduced sea ice provides opportunities for increased shipping and resource extraction. At the same time, it increases coastal erosion[522] and flooding associated with coastal storms. Reduced sea ice also alters the timing and location of plankton blooms, which is expected to drive major shifts of marine species such as pollock and other commercial fish stocks.[527]

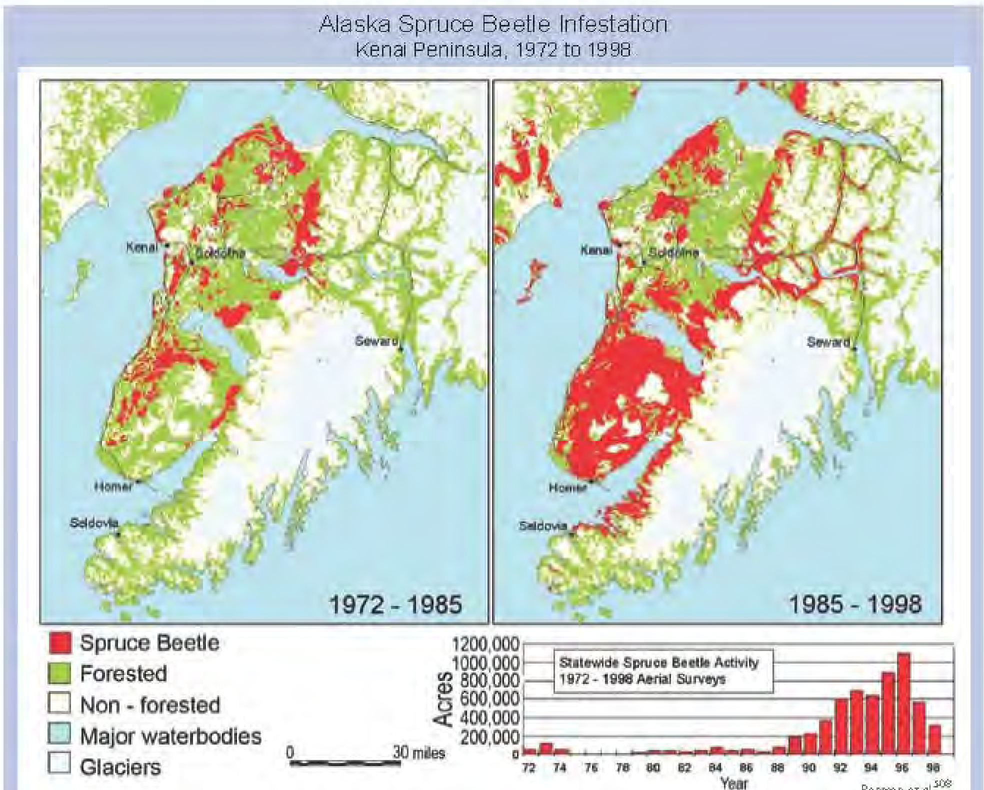
139

Longer summers and higher temperatures are causing drier conditions, even in the absence of strong trends in precipitation.

Between 1970 and 2000, the snow-free season increased by approximately 10 days across Alaska, primarily due to earlier snowmelt in the spring.[503,504] A longer growing season has potential economic benefits, providing a longer period of outdoor and commercial activity such as tourism. However, there are also downsides. For example, white spruce forests in Alaska's interior are experiencing declining growth due to drought stress[505] and continued warming could lead to widespread death of trees.[506] The decreased soil moisture in Alaska also suggests that agriculture in Alaska might not benefit from the longer growing season.

Insect outbreaks and wildfires are increasing with warming.

Climate plays a key role in determining the extent and severity of insect outbreaks and wildfires.[506,507] During the 1990s, for example, south-central Alaska experienced the largest outbreak of spruce beetles in the world.[243,506] This outbreak occurred because rising temperatures allowed the spruce beetle to survive over the winter and to complete its life cycle in just one year instead of the normal two years. Healthy trees ordinarily defend themselves by pushing back against burrowing beetles with their pitch. From 1989 to 1997, however, the region experienced an extended drought, leaving the trees too stressed to fight off the infestation.



Warming in Alaska has caused insect outbreaks to increase. Red areas indicate spruce beetle infestations on the Kenai Peninsula. Over 5 million acres of Alaska spruce forests were destroyed.

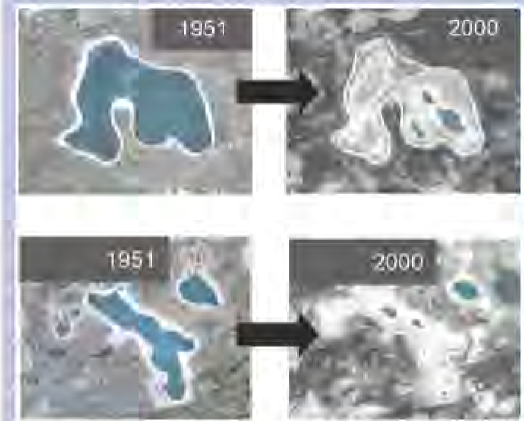
Prior to 1990, the spruce budworm was not able to reproduce in interior Alaska.[506] Hotter, drier summers, however, now mean that the forests there are threatened by an outbreak of spruce budworms.[509] This trend is expected to increase in the future if summers in Alaska become hotter and drier.[506] Large areas of dead trees, such as those left behind by pest infestations, are highly flammable and thus much more vulnerable to wildfire than living trees.

The area burned in North America's northern forest that spans Alaska and Canada tripled from the 1960s to the 1990s. Two of the three most extensive wildfire seasons in Alaska's 56-year record occurred in 2004 and 2005, and half of the most severe fire years on record have occurred since 1990.[510] Under changing climate conditions, the average area burned per year in Alaska is projected to double by the middle of this century.[507] By the end of this century, area burned by fire is projected to triple under a moderate greenhouse gas emissions scenario and to quadruple under a higher emissions scenario.[91] Such increases in area burned would result in numerous impacts, including hazardous air quality conditions such as those suffered by residents of Fairbanks during the summers of 2004 and 2005, as well as increased risks to rural Native Alaskan communities because of reduced availability of the fish and game that make up their diet. This would cause them to adopt a more "Western" diet,[511] known to be associated with increased risk of cancers, diabetes, and cardiovascular disease.[512]

Lakes are declining in area.

Across the southern two-thirds of Alaska, the area of closed-basin lakes (lakes without stream inputs and outputs) has decreased over the past 50 years. This is likely due to the greater evaporation and thawing of permafrost that result from warming.[513,514] A continued decline in the area of surface water would present challenges for the management of natural resources and ecosystems on National Wildlife Refuges in Alaska. These refuges, which cover over 77 million acres (21 percent of Alaska) and comprise 81 percent of the U.S. National Wildlife Refuge System, provide breeding habitat for millions of waterfowl and shorebirds that winter in the lower 48 states. Wetlands are

Ponds in Alaska are Shrinking (1951 to 2000)
Yukon Flats National Wildlife Refuge



Riordan et al.[514]

Ponds across Alaska, including those shown above in the northeastern interior of the state, have shrunk as a result of increased evaporation and permafrost thawing. The pond in the top pair of images shrunk from 180 to 10 acres; the larger pond in the bottom pair of images shrunk from 90 to 4 acres.

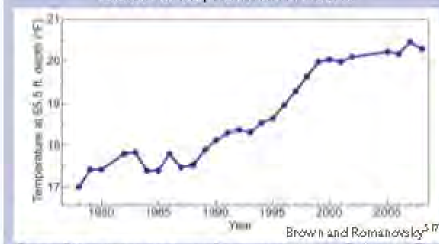
also important to Native peoples who hunt and fish for their food in interior Alaska. Many villages are located adjacent to wetlands that support an abundance of wildlife resources. The sustainability of these traditional lifestyles is thus threatened by a loss of wetlands.

Thawing permafrost damages roads, runways, water and sewer systems, and other infrastructure.

Permafrost temperatures have increased throughout Alaska since the late 1970s.[149] The largest increases have been measured in the northern part of the state.[515] While permafrost in interior Alaska so far has experienced less warming than permafrost in northern Alaska, it is more vulnerable to thawing during this century because it is generally just below the freezing point, while permafrost in northern Alaska is colder.

Land subsidence (sinking) associated with the thawing of permafrost presents substantial challenges to engineers attempting to preserve infrastructure in Alaska.[516] Public infrastructure at risk for damage includes roads, runways, and water and sewer systems. It is estimated that thawing

Permafrost Temperature, 1978 to 2008
Deadhorse, northern Alaska



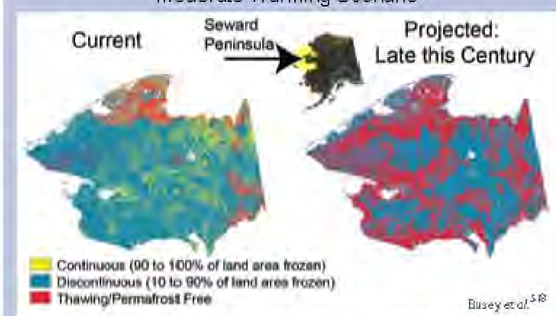
Permafrost temperatures have risen throughout Alaska, with the largest increases in the northern part of the state.

permafrost would add between $3.6 billion and $6.1 billion (10 to 20 percent) to future costs for publicly owned infrastructure by 2030 and between $5.6 billion and $7.6 billion (10 to 12 percent) by 2080.[230] Analyses of the additional costs of permafrost thawing to private property have not yet been conducted.

Thawing ground also has implications for oil and gas drilling. As one example, the number of days per year in which travel on the tundra is allowed under Alaska Department of Natural Resources standards has dropped from more than 200 to about 100 days in the past 30 years. This results in a 50 percent reduction in days that oil and gas exploration and extraction equipment can be used.[220,245]

Thawing permafrost can push natural ecosystems across thresholds. Some forests in Alaska are literally toppling over as the permafrost beneath them thaws, undermining the root systems of trees (see photo next page).

Changing Permafrost Distribution
Moderate Warming Scenario



The maps show projected thawing on the Seward Peninsula by the end of this century under a moderate warming scenario approximately halfway between the lower and higher emissions scenarios[91] described on page 23.

Coastal storms increase risks to villages and fishing fleets.

Alaska has more coastline than the other 49 states combined. Frequent storms in the Gulf of Alaska and the Bering, Chukchi, and Beaufort Seas already affect the coasts during much of the year. Alaska's coastlines, many of which are low in elevation, are increasingly threatened by a combination of the loss of their protective sea ice buffer, increasing storm activity, and thawing coastal permafrost.

Increasing storm activity in autumn in recent years[520] has delayed or prevented barge operations

Adaptation: Keeping Soil Around the Pipeline Cool

When permafrost thaws, it can cause the soil to sink or settle, damaging structures built upon or within that soil. A warming climate and burial of supports for the Trans-Alaska Pipeline System both contribute to thawing of the permafrost around the pipeline. In locations on the pipeline route where soils were ice-rich, a unique above-ground system was developed to keep the ground cool. Thermal siphons were designed to disperse heat to the air that would otherwise be transferred to the soil, and these siphons were placed on the pilings that support the pipeline. While this unique technology added significant expense to the pipeline construction, it helps to greatly increase the useful lifetime of this structure.[519]

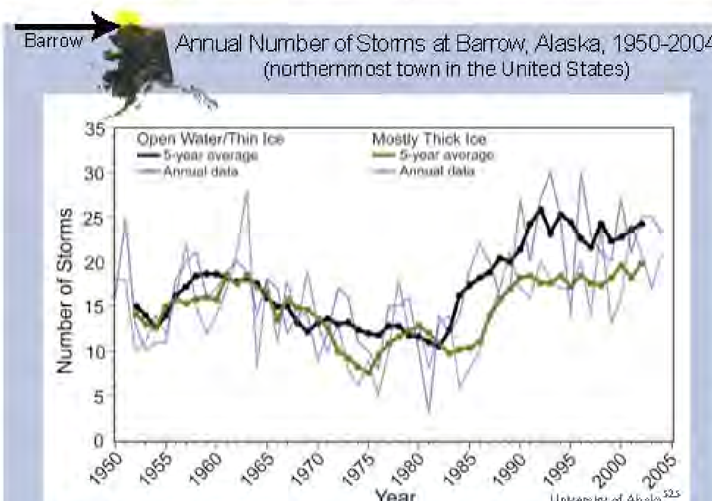
Leaning trees in this Alaska forest tilt because the ground beneath them, which used to be permanently frozen, has thawed. Forests like this are named "drunken forests."

Projected Coastal Erosion, 2007 to 2027
Newtok, western Alaska

Many of Alaska's coastlines are eroding rapidly; the disappearance of coastal land is forcing communities to relocate. The 2007 line on the image indicates where Newtok, Alaska's shoreline had eroded to by 2007. The other lines are projected assuming a conservative erosion rate of 36 to 83 feet per year; however, Newtok residents reported a July 2003 erosion rate of 110 feet per year.

that supply coastal communities with fuel. Commercial fishing fleets and other marine traffic are also strongly affected by Bering Sea storms. High-wind events have become more frequent along the western and northern coasts. The same regions are experiencing increasingly long sea-ice-free seasons and hence longer periods during which coastal areas are especially vulnerable to wind and wave damage. Downtown streets in Nome, Alaska, have flooded in recent years. Coastal erosion is causing the shorelines of some areas to retreat at average rates of tens of feet per year. The ground beneath several native communities is literally crumbling into the sea, forcing residents to confront difficult and expensive choices between relocation and engineering strategies that require continuing investments despite their uncertain effectiveness (see *Society* sector). The rate of erosion along Alaska's northeastern coastline has doubled over the past 50 years.[522]

Annual Number of Storms at Barrow, Alaska, 1950-2004
(northernmost town in the United States)



The number of coastal storms has generally increased as the amount of ice along the coast has decreased. This increase threatens commercial activity and communities in Alaska. The blue line indicates the annual number of open-water storms, those occurring in primarily ice-free water (July to December). The purple line indicates the number of storms occurring when thick sea ice is present (January to June). The black and green lines are smoothed using 5-year averages.

Over this century, an increase of sea surface temperatures and a reduction of ice cover are likely to lead to northward shifts in the Pacific storm track and increased impacts on coastal Alaska.[523,524] Climate models project the Bering Sea to experience the largest decreases in atmospheric pressure in the Northern Hemisphere, suggesting an increase in storm activity in the region.[90] In addition, the longer ice-free season is likely to make more heat and moisture available for storms in the Arctic Ocean, increasing their frequency and/or intensity.

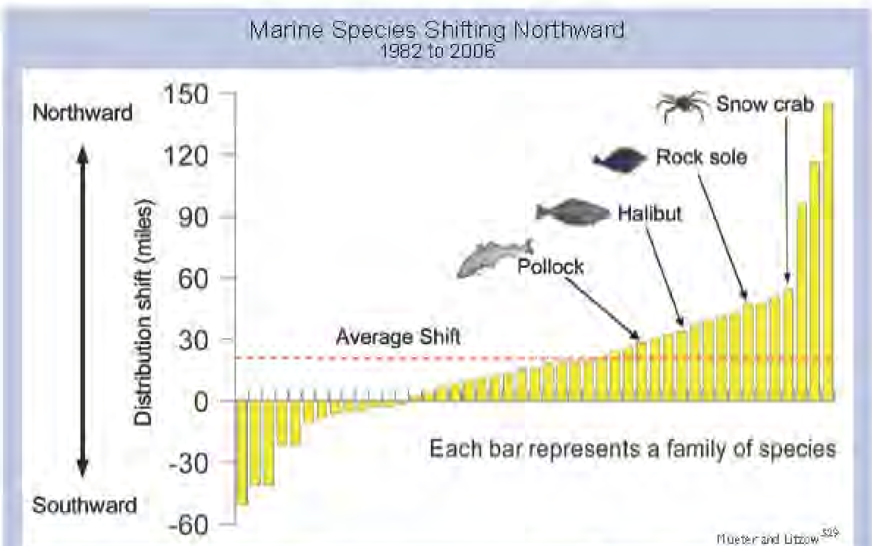
143

Displacement of marine species will affect key fisheries.

Alaska leads the United States in the value of its commercial fishing catch. Most of the nation's salmon, crab, halibut, and herring come from Alaska. In addition, many Native communities depend on local harvests of fish, walruses, seals, whales, seabirds, and other marine species for their food supply. Climate change causes significant alterations in marine ecosystems with important implications for fisheries. Ocean acidification associated with a rising carbon dioxide concentration represents an additional threat to coldwater marine ecosystems[23,526] (see *Ecosystems* sector and *Coasts* region).

One of the most productive areas for Alaska fisheries is the northern Bering Sea off Alaska's west coast. The world's largest single fishery is the Bering Sea pollock fishery, which has undergone major declines in recent years. Over much of the past decade, as air and water temperatures rose, sea ice in this region declined sharply. Populations of fish, seabirds, seals, walruses, and other species depend on plankton blooms that are regulated by the extent and location of the ice edge in spring. As the sea ice retreats, the location, timing, and species composition of the plankton blooms changes, reducing the amount of food reaching the living things on the ocean floor. This radically changes the species composition and populations of fish and other marine life forms, with significant repercussions for fisheries[527] (see *Ecosystems* sector).

Over the course of this century, changes already observed on the shallow shelf of the northern Bering Sea are likely to affect a much broader portion of the Pacific-influenced sector of the Arctic Ocean. As such changes occur, the most productive commercial fisheries are likely to become more distant from existing fishing ports and processing infrastructure, requiring either relocation or greater investment in transportation time and fuel costs. These changes will also affect the ability of Native Peoples to successfully hunt and fish for the food they need to survive. Coastal communities are already noticing a displacement of walrus and seal populations. Bottom-feeding walrus populations are threatened when their sea ice platform retreats from the shallow coastal feeding grounds on which they depend.[528]



As air and water temperatures rise, marine species are moving northward, affecting fisheries, ecosystems, and coastal communities that depend on the food source. On average, by 2006, the center of the range for the examined species moved 19 miles north of their 1982 locations.

Islands

Climate change presents the Pacific and Caribbean islands with unique challenges. The U.S. affiliated Pacific Islands are home to approximately 1.7 million people in the Hawaiian Islands; Palau; the Samoan Islands of Tutuila, Manua, Rose, and Swains; and islands in the Micronesian archipelago, the Carolines, Marshalls, and Marianas.[530] These include volcanic, continental, and limestone islands, atolls, and islands of mixed geologies.[530] The degree to which climate change and variability will affect each of the roughly 30,000 islands in the Pacific depends upon a variety of factors, including the island's geology, area, height above sea level, extent of reef formation, and the size of its freshwater aquifer.[531]

In addition to Puerto Rico and the U.S. Virgin Islands, there are 40 island nations in the Caribbean that are home to approximately 38 million people.[532] Population growth, often concentrated in coastal areas, escalates the vulnerability of both Pacific and Caribbean island communities to the effects of climate change, as do weakened traditional support systems. Tourism and fisheries, both of which are climate-sensitive, play a large economic role in these communities.[530]

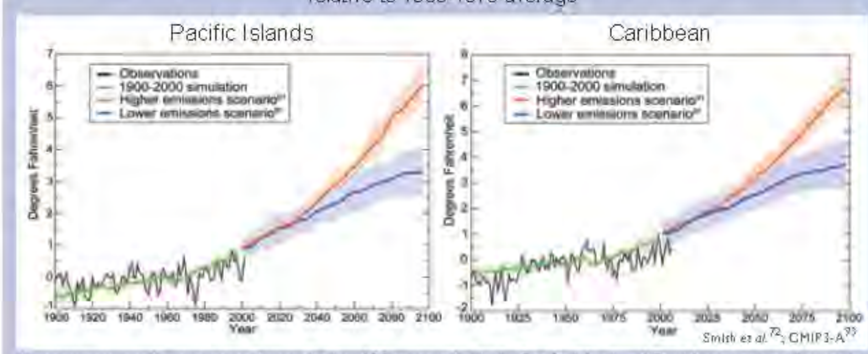
Small islands are considered among the most vulnerable to climate change because extreme events have major impacts on them. Changes in weather patterns and the frequency and intensity of extreme events, sea-level rise, coastal erosion, coral reef bleaching, ocean acidification, and contamination of freshwater resources by salt water are among the impacts small islands face.[533]

Islands have experienced rising temperatures and sea levels in recent decades. Projections for the rest of this century suggest:

- Increases in air and ocean surface temperatures in both the Pacific and Caribbean;[90]
- An overall decrease in rainfall in the Caribbean; and
- An increased frequency of heavy downpours and increased rainfall during summer months (rather than the normal rainy season in winter months) for the Pacific (although the range of projections regarding rainfall in the Pacific is still quite large).

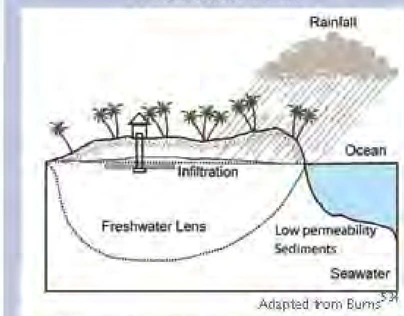
The number of heavy rain events is very likely to increase.[90] Hurricane (typhoon) wind speeds and rainfall rates are likely to increase with continued

Air Temperature Change, Observed and Projected, 1900 to 2100
relative to 1960-1979 average



Air temperatures have increased over the last 100 years in both the Pacific Island and Caribbean regions. Larger increases are projected in the future, with higher emissions scenarios[91] producing considerably greater increases. The shaded areas show the likely ranges while the lines show the central projections from a set of climate models.

Freshwater Lens



Many island communities depend on freshwater lenses, which are recharged by precipitation. The amount of water a freshwater lens contains is determined by the size of the island, the amount of rainfall, rates of water withdrawal, the permeability of the rock beneath the island, and salt mixing due to storm- or tide-induced pressure. Freshwater lenses can be as shallow as 4 to 8 inches or as deep as 65 feet.[534]

warming.[68] Islands and other low-lying coastal areas will be at increased risk from coastal inundation due to sea-level rise and storm surge, with major implications for coastal communities, infrastructure, natural habitats, and resources.

The availability of freshwater is likely to be reduced, with significant implications for island communities, economies, and resources.

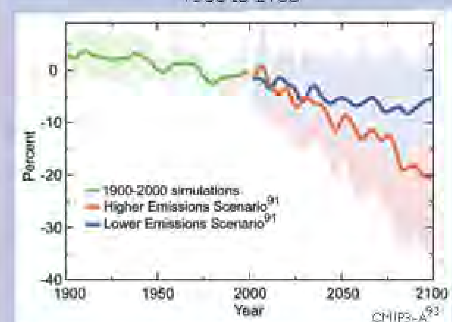
Most island communities in the Pacific and the Caribbean have limited sources of the freshwater needed to support unique ecosystems and biodiversity, public health, agriculture, and tourism. Conventional freshwater resources include rainwater collection, groundwater, and surface water.[534] For drinking and bathing, smaller Pacific islands primarily rely on individual rainwater catchment systems, while groundwater from the freshwater lens is used for irrigation. The size of freshwater lenses in atolls is influenced by factors such as rates of recharge (through precipitation), rates of use, and extent of tidal inundation.[531] Since rainfall triggers the formation of the freshwater lens, changes in precipitation, such as the significant decreases projected for the Caribbean, can significantly affect the availability of water. Because tropical storms replenish water supplies, potential changes in these storms are a great concern.

While it might initially be seen as a benefit, increased rainfall in the Pacific Islands during the summer months is likely to result in increased flooding, which would reduce drinking water quality and crop yields.[534] In addition, many islands have weak distribution systems and old infrastructure, which result in significant water leakage, decreasing their ability to use freshwater efficiently. Water pollution (such as from agriculture or sewage), exacerbated by storms and floods, can contaminate the freshwater supply, affecting public health. Sea-level rise also affects island water supplies by causing salt water to contaminate the freshwater lens and by causing an increased frequency of flooding due to storm high tides.[531] Finally, a rapidly rising population is straining the limited water resources, as would an increased incidence and/or intensity of storms[534] or periods of prolonged drought.

Island communities, infrastructure, and ecosystems are vulnerable to coastal inundation due to sea-level rise and coastal storms.

Sea-level rise will have enormous effects on many island nations. Flooding will become more frequent due to higher storm tides, and coastal land will be permanently lost as the sea inundates low-lying areas and the shorelines erode. Loss of land

Caribbean Precipitation Change
1900 to 2100

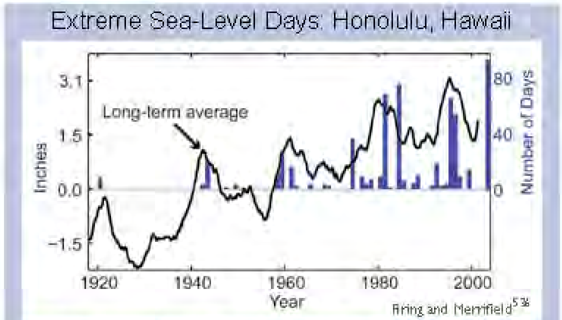


Total annual precipitation has declined in the Caribbean and climate models project stronger declines in the future, particularly under higher emission scenarios.[91] Such decreases threaten island communities that rely on rainfall for replenishing their freshwater supplies. The shaded areas show the likely ranges while the lines show the central projections from a set of climate models.

will reduce freshwater supplies[531] and affect living things in coastal ecosystems. For example, the Northwestern Hawaiian Islands, which are low-lying and therefore at great risk from increasing sea level, have a high concentration of endangered and threatened species, some of which exist nowhere else.[535] The loss of nesting and nursing habitat is expected to threaten the survival of already vulnerable species.[535]

In addition to gradual sea-level rise, extreme high water level events can result from a combination of coastal processes.[271] For example, the harbor in Honolulu, Hawaii, experienced the highest daily average sea level ever recorded in September 2003. This resulted from the combination of long-term sea-level rise, normal seasonal heating (which causes the volume of water to expand and thus the level of the sea to rise), seasonal high tide, and an ocean circulation event which temporarily raised local sea level.[536] The interval between such extreme events has decreased from more than 20 years to approximately 5 years as average sea level has risen.[536]

Hurricanes, typhoons, and other storm events, with their intense precipitation and storm surge, cause major impacts to Pacific and Caribbean island communities, including loss of life, damage to infrastructure and property, and contamination of freshwater supplies.[537] As the climate continues to warm, the peak wind intensities and near-storm precipitation from future tropical cyclones are likely to increase,[90] which, combined with sea-level rise, is expected to cause higher storm surge levels. If such events occur frequently, communities would face challenges in recovering between events, resulting in long-term deterioration of infrastructure, freshwater and agricultural resources, and other impacts.[246]



Sea-level rise will result in permanent land loss and reductions in freshwater supplies, as well as threaten coastal ecosystems. "Extreme" sea-level days (with a daily average of more than 6 inches above the long-term average[90]) can result from the combined effects of gradual sea-level rise due to warming and other phenomena, including seasonal heating and high tides.

Adaptation: Securing Water Resources

A billboard on Pohnpei, in the Federated States of Micronesia, encourages water conservation in preparation for the 1997 to 1998 El Niño.

In the islands, "water is gold." Effective adaptation to climate-related changes in the availability of freshwater is thus a high priority. While island communities cannot completely counter the threats to water supplies posed by global warming, effective adaptation approaches can help reduce the damage.

When existing resources fall short, managers look to unconventional resources, such as desalinating seawater, importing water by ship, and using treated wastewater for non-drinking uses. Desalination costs are declining, though concerns remain about the impact on marine life, the disposal of concentrated brines that may contain chemical waste, and the large energy use (and associated carbon footprint) of the process.[146] With limited natural resources, the key to successful water resource management in the islands will continue to be "conserve, recover, and reuse."[530]

Pacific Island communities are also making use of the latest science. This effort started during the 1997 to 1998 El Niño, when managers began using seasonal forecasts to prepare for droughts by increasing public awareness and encouraging water conservation. In addition, resource managers can improve infrastructure, such as by fixing water distribution systems to minimize leakage and by increasing freshwater storage capacity.[530]

Final Draft for Internal Review, May 2009
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Coastal houses and an airport in the U.S.-affiliated Federated States of Micronesia rely on mangroves' protection from erosion and damage due to rising sea level, waves, storm surges, and wind.

Critical infrastructure, including homes, airports, and roads, tends to be located along the coast. Flooding related to sea-level rise and hurricanes and typhoons negatively affects port facilities and harbors, and causes closures of roads, airports, and bridges.[538] Long-term infrastructure damage would affect social services such as disaster risk management, health care, education, management of freshwater resources, and economic activity in sectors such as tourism and agriculture.

Climate changes affecting coastal and marine ecosystems will have major implications for tourism and fisheries.

Marine and coastal ecosystems of the islands are particularly vulnerable to the impacts of climate change. Sea-level rise, increasing water temperatures, rising storm intensity, coastal inundation and flooding from extreme events, beach erosion, ocean acidification, increased incidences of coral disease, and increased invasions by non-native species are among the threats that endanger the ecosystems that provide safety, sustenance, economic viability, and cultural and traditional values to island communities.[539]

Tourism is a vital part of the economy for many islands. In 1999, the Caribbean had tourism-based gross earnings of $17 billion, providing 900,000 jobs and making the Caribbean one of the most tourism dependent regions in the world.[532] In the South Pacific, tourism can contribute as much as 47 percent of gross domestic product.[540] In Hawaii, tourism generated $12.4 billion for the state in 2006, with over 7 million visitors.[541]

Sea-level rise can erode beaches, and along with increasing water temperatures, can destroy or degrade natural resources such as mangroves and coral reef ecosystems that attract tourists.[246] Extreme weather events can affect transportation systems and interrupt communications. The availability of freshwater is critical to sustaining tourism, but is subject to the climate-related impacts described on the previous page. Public health concerns about diseases would also negatively affect tourism.

Coral reefs sustain fisheries and tourism, have biodiversity value, scientific and educational value, and form natural protection against wave erosion.[542] For Hawaii alone, net benefits of reefs to the economy are estimated at $360 million annually, and the overall asset value is conservatively estimated to be nearly $10 billion.[542] In the Caribbean, coral reefs provide annual net benefits from fisheries, tourism, and shoreline protection services of between $3.1 billion and $4.6 billion. The loss of income by 2015 from degraded reefs is conservatively estimated at several hundred million dollars annually.[532,543]

Coral reef ecosystems are particularly susceptible to the impacts of climate change, as even small increases in water temperature can cause coral bleaching,[544] damaging and killing corals. Ocean acidification due to a rising carbon dioxide concentration poses an additional threat (see *Ecosystems* sector and *Coasts* region). Coral reef ecosystems are also especially vulnerable to invasive species.[545] These impacts, combined with changes in the occurrence and intensity of El Niño events, rising sea level, and increasing storm damage,[246] will have major negative effects on coral reef ecosystems.

Fisheries feed local people and island economies. Almost all communities within the Pacific Islands derive over 25 percent of their animal protein from fish, with some deriving up to 69 percent.[546] For island fisheries sustained by healthy coral reef and marine ecosystems, climate change impacts exacerbate stresses such as overfishing,[246] affecting both fisheries and tourism that depend on abundant and diverse reef fish. The loss of live corals results in local extinctions and a reduced number of reef fish species.[547]

Nearly 70 percent of the world's annual tuna harvest, approximately 3.2 million tons, comes from the Pacific Ocean.[548] Climate change is projected to cause a decline in tuna stocks and an eastward shift in their location, affecting the catch of certain countries.[246]

Coasts

Approximately one-third of all Americans live in counties immediately bordering the nation's ocean coasts.[549,550] In addition to accommodating major cities, the coasts and the exclusive economic zone extending 200 miles offshore provide enjoyment, recreation, seafood, transportation of goods, and energy. Coastal and ocean activities contribute more than $1 trillion to the nation's gross domestic product and the ecosystems hold rich biodiversity and provide invaluable services.[551] However, intense human uses have taken a toll on coastal environments and their resources. Many fish stocks have been severely diminished by over-fishing, large "dead zones" depleted of oxygen have developed as a result of pollution by excess nitrogen runoff, toxic blooms of algae are increasingly frequent, and coral reefs are badly damaged or becoming overgrown with algae. About half of the nation's coastal wetlands have been lost – and most of this loss has occurred during the past 50 years.

Global climate change imposes additional stresses on coastal environments. Rising sea level is already eroding shorelines, drowning wetlands, and threatening the built environment.[43,224] The destructive potential of Atlantic tropical storms and hurricanes has increased since 1970 in association with increasing Atlantic sea surface temperatures, and it is likely that hurricane rainfall and wind speeds will increase in response to global warming.[112] Coastal water temperatures have risen by about 2°F in several regions, and the geographic distributions of marine species have shifted.[37,68,347] Precipitation increases on land have increased river runoff, polluting coastal waters with more nitrogen and phosphorous, sediments, and other contaminants. Furthermore, increasing acidification resulting from the uptake of carbon dioxide by ocean waters threatens corals, shellfish, and other living things that form their shells and skeletons from calcium carbonate[23] (see *Ecosystems* sector). All of these forces converge and interact at the coasts, making these areas particularly sensitive to the impacts of climate change.

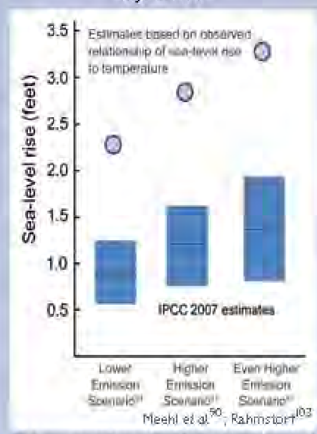
Significant sea-level rise and storm surge will adversely affect coastal cities and ecosystems around the nation; low-lying and subsiding areas are most vulnerable.

The rise in sea level relative to the land surface in any given location is a function of both the amount of global average sea-level rise and the degree to which the land is rising or falling. During the past century in the United States, relative sea level changes ranged from falling several inches to rising as much as 2 feet.[225] High rates of relative sea-level rise, coupled with cutting off the supply of sediments from the Mississippi River and other human alterations, have resulted in the loss of 1,900 square miles of Louisiana's coastal wetlands during the past century, weakening their capacity

Multiple Stresses Confront Coastal Regions

Various forces of climate change at the coasts pose a complex array of management challenges and adaptation requirements. For example, relative sea level is expected to rise at least 2 feet in Chesapeake Bay (located between Maryland and Virginia) where the land is subsiding, threatening portions of cities, inhabited islands, most tidal wetlands, and other low-lying regions. Climate change also will affect the volume of the bay, its salinity distribution and circulation, as will changes in precipitation and freshwater runoff. These changes, in turn, will affect summertime oxygen depletion and efforts to reduce the agricultural nitrogen runoff that causes it. Meanwhile the warming of the bay's waters will make survival there difficult for northern species such as eelgrass and soft clams, while allowing southern species and invaders riding in ships' ballast water to move in and change the mix of species that are caught and must be managed. Additionally, more acidic waters resulting from rising carbon dioxide levels will make it difficult for oysters to build their shells and will complicate the recovery of this key species.[553]

Projected Sea-Level Rise by 2100



Estimates of sea-level rise by the end of the century for three emissions scenarios.[91] Intergovernmental Panel on Climate Change 2007 projections (range shown as bars) exclude changes in ice sheet flow.[90] Light blue circles represent more recent, central estimates derived using the observed relationship of sea-level rise to temperature.[103] Areas where coastal land is sinking, for example by as much as 1.5 feet in this century along portions of the Gulf Coast, would experience that much additional sea-level rise relative to the land.[128]

to absorb the storm surge of hurricanes such as Katrina.[553] Shoreline retreat is occurring along most of the nation's exposed shores.

A "ghost swamp" in south Louisiana shows the effects of saltwater intrusion.

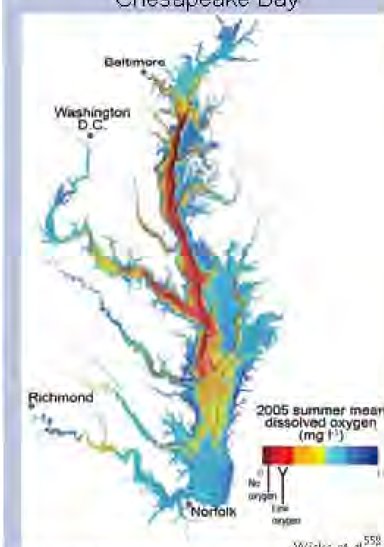
The amount of sea-level rise likely to be experienced during this century depends mainly on the expansion of the ocean volume due to warming and the response of glaciers and polar ice sheets. Complex processes control the discharges from polar ice sheets and some are already producing substantial additions of water to the ocean.[554] Because these processes are not well understood, it is difficult to predict their future contributions to sea-level rise.[90,555]

As discussed in the *Global Climate Change* section, recent estimates of global sea-level rise substantially exceed the IPCC estimates, suggesting sea-level rise between 3 and 4 feet in this century. Even a 2-foot rise in relative sea level over a century would result in the loss of a large portion of the nation's remaining coastal wetlands, as they are not able to build new soil at a fast enough rate.[164] Accelerated sea-level rise would affect sea-grasses, coral reefs, and other important habitats. It would also fragment barrier islands, and place into jeopardy existing homes, businesses, and infrastructure, including roads, ports, and water and sewage systems. Portions of major cities, including Boston and New York, would be subject to inundation by ocean water during storm surges or even during regular high tides.[234]

More spring runoff and warmer coastal waters will increase the seasonal reduction in oxygen resulting from excess nitrogen from agriculture.

Coastal dead zones in places such as the northern Gulf of Mexico[556] and the Chesapeake Bay[557] are likely to increase in size and intensity as warming increases unless efforts to control runoff of agricultural fertilizers are redoubled. Greater spring runoff into East Coast estuaries and the Gulf of Mexico would flush more nitrogen into coastal waters stimulating harmful blooms of algae and the excess production of microscopic plants that settle near the seafloor and deplete oxygen supplies as they decompose. In addition, all else being equal, greater runoff reduces salinity, which when coupled with warmer surface water increases the difference in density between surface and bottom waters, thus preventing the replacement of oxygen in the deeper waters. As dissolved oxygen levels decline below a certain level, living things cannot survive. They leave the area if they can, and die if they cannot.

Dead Zones in the Chesapeake Bay



Climate change is likely to expand and intensify "dead zones," areas where bottom water is depleted of dissolved oxygen because of nitrogen pollution, threatening living things.

150

Coastal waters are very likely to continue to warm by as much 4 to 8°F in this century, both in summer and winter.[234] This will result in a northward shift in the geographic distribution of marine life along the coasts; this is already being observed.[70,347] The shift occurs because some species cannot tolerate the higher temperatures and others are out-competed by species from farther south moving in.[270] Warming also opens the door to invasion by species that humans are intentionally or unintentionally transporting around the world, for example in the ballast water carried by ships. Species that were previously unable to establish populations because of cold winters are likely to find the warmer conditions more welcoming and gain a foothold,[567] particularly as native species are under stress from climate change and other human activities. Non-native clams and small crustaceans have already had major effects on the San Francisco Bay ecosystem and the health of its fishery resources.[559]

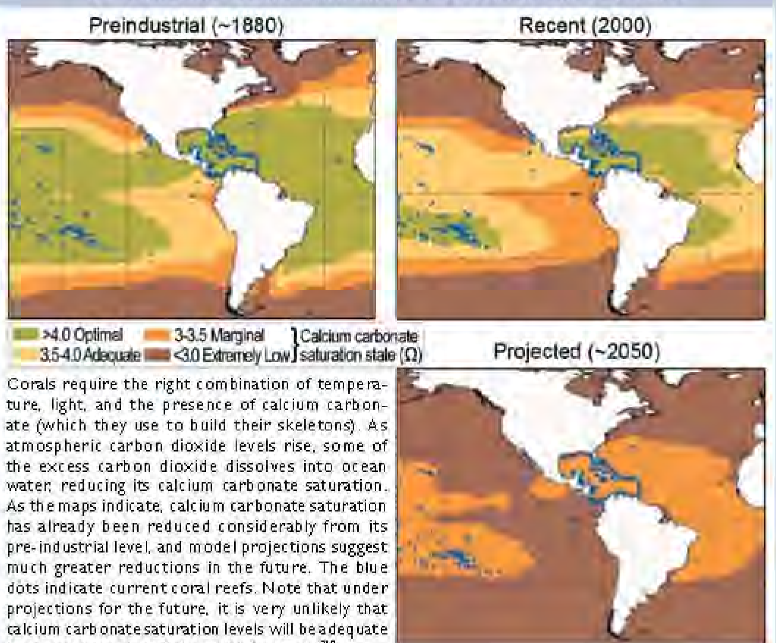
Higher water temperatures and ocean acidification due to increasing atmospheric carbon dioxide will present major additional stresses to coral reefs, resulting in significant die-offs and limited recovery.

In addition to carbon dioxide's heat-trapping effect, the increase in its concentration in the atmosphere is gradually acidifying the ocean. About one-third of the carbon dioxide emitted by human activities has been absorbed by the ocean, resulting in a decrease in the ocean's pH. Since the beginning of the industrial era, ocean pH has declined demonstrably and is projected to decline much more by 2100 if current emissions trends continue. Further declines in pH are very likely to continue to affect the ability of living things to create and maintain shells or skeletons of calcium carbonate. This is because at a lower pH less of the dissolved carbon is available as carbonate ions (see *Global Climate Change*).[70,259]

Ocean acidification will affect living things including important plankton species in the open ocean, mollusks and other shellfish, and corals.[22,23,70,259] The effects on reef-building corals are likely to be particularly severe during this century. Coral calcification rates are likely to decline by more than 30 percent under a doubling of atmospheric carbon dioxide concentrations, with erosion outpacing reef formation at even lower concentrations.[22] In addition, the reduction in pH also affects photosynthesis, growth, and reproduction. The upwelling of deeper ocean water, deficient in carbonate, and thus potentially detrimental to the food chains supporting juvenile salmon has recently been observed along the U.S. West Coast.[259]

Acidification imposes yet another stress on reef-building corals, which are also subject to bleaching – the expulsion of the microscopic algae that live inside the corals

Calcium Carbonate Saturation in Ocean Surface Waters



Corals require the right combination of temperature, light, and the presence of calcium carbonate (which they use to build their skeletons). As atmospheric carbon dioxide levels rise, some of the excess carbon dioxide dissolves into ocean water, reducing its calcium carbonate saturation. As the maps indicate, calcium carbonate saturation has already been reduced considerably from its pre-industrial level, and model projections suggest much greater reductions in the future. The blue dots indicate current coral reefs. Note that under projections for the future, it is very unlikely that calcium carbonate saturation levels will be adequate to support coral reefs in any U.S. waters.[219]

NAST[219]

151

Pacific Coast "Dead Zone"
2006 to 2007

PISCO; NOAA-NWFSC; OSU/COAS[562]

Climate change affects coastal currents that moderate ocean temperatures and the productivity of ecosystems. As such, it is believed to be a factor in the low-oxygen "dead zone" that has appeared along the coast of Washington and Oregon in recent years.[561] In the maps above, blue indicates low-oxygen areas and purple shows areas that are the most severely oxygen depleted.

and are essential to their survival – as a result of heat stress[70] (see *Ecosystems* sector and *Islands* region). As a result of these and other stresses, the corals that form the reefs in the Florida Keys, Puerto Rico, Hawaii, and the Pacific Islands are projected to be lost if carbon dioxide concentrations continue to rise at their current rate.[560]

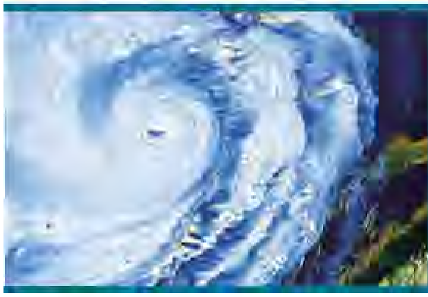
Changing ocean currents will affect coastal ecosystems.

Because it affects the distribution of heat in the atmosphere and the oceans, climate change will affect winds and currents that move along the nation's coasts, such as the California Current that bathes the West Coast from British Columbia to Baja California.[70] In this area, wind-driven upwelling of deeper ocean water along the coast is vital to moderation of temperatures and the high productivity of Pacific Coast ecosystems. Coastal currents are subject to periodic variations caused by the El Niño-Southern Oscillation and the Pacific Decadal Oscillation, which have substantial effects on the success of salmon and other fishery resources. Climate change is expected to affect such coastal currents, and possibly the larger scale natural oscillations as well, though these effects are not yet well understood. The recent emergence of oxygen-depletion events on the continental shelf off Oregon and Washington (a dead zone not directly caused by agricultural runoff and waste discharges such as those in the Gulf of Mexico or Chesapeake Bay) is one example.[561]

Adaptation: Coping with Sea-Level Rise

Adaptation to sea-level rise is already taking place in three main categories: (1) protecting the coastline by building hard structures such as levees and seawalls (although hard structures can, in some cases, actually increase risks and worsen beach erosion and wetland retreat), (2) accommodating rising water by elevating or redesigning structures, enhancing wetlands, or adding sand from elsewhere to beaches (the latter is not a permanent solution, and can encourage development in vulnerable locations), and (3) planned retreat from the coastline as sea level rises.[269]

Several states have laws or regulations that require setbacks for construction based on the planned life of the development and observed erosion rates.[371] North Carolina, Rhode Island, and South Carolina are using such a moving baseline to guide planning. Maine's Coastal Sand Dune Rules prohibit buildings of a certain size that are unlikely to remain stable with a sea-level rise of 2 feet. The Massachusetts Coastal Hazards Commission is preparing a 20-year infrastructure and protection plan to improve hazards management and the Maryland Commission on Climate Change has recently made comprehensive recommendations to reduce the state's vulnerability to sea-level rise and coastal storms by addressing building codes, public infrastructure, zoning, and emergency preparedness. Governments and private interests are beginning to take sea-level rise into account in planning levees and bridges, and in the siting and design of facilities such as sewage treatment plants (see Adaptation box in *Northeast* region).



An Agenda for Climate Impacts Science

Both mitigation and adaptation decisions are becoming increasingly necessary. Advancing our knowledge in the many aspects of science that affect the climate system has already contributed greatly to decision making on climate change issues. Further advances in climate science including better understanding and projections regarding rainfall, storm tracks, storm intensity, heat waves, and sea-level rise will improve decision making capabilities.

The focus below, however, is on advancing our knowledge specifically on climate change impacts and those aspects of climate change responsible for these impacts in order to continue to guide decision making.

Recommendation 1: Expand our understanding of climate change impacts.

There is a clear need to increase understanding of how ecosystems, social and economic systems, human health, and infrastructure will be affected by climate change in the context of other stresses. New understanding will come from a mix of activities including sustained and systematic observations, field and laboratory experiments, model development, and integrated impact assessments. These will incorporate shared learning among researchers, practitioners (such as engineers and water managers), and local stakeholders.

Ecosystems

Ecosystem changes, in response to changes in climate and other environmental conditions, have already been documented. These include changes in the chemistry of the atmosphere and precipitation, vegetation patterns, growing season length, plant productivity, animal species distributions, and the frequency and severity of pest outbreaks and fires. In the marine environment, changes include the health of corals and other living things due to temperature stress and ocean acidification. These observations not only document climate-change impacts, but also provide critical input to understanding how and why these changes occur, and how changes in ecosystems in turn affect climate. In this way, records of observed changes can improve projections of future impacts related to various climate change scenarios.

In addition to observations, large-scale, whole-ecosystem experiments are essential for improving projections of impacts. Ecosystem-level experiments that vary multiple factors, such as temperature, moisture, ground-level ozone, and atmospheric carbon dioxide, would provide process-level understanding of the ways ecosystems could respond to climate change in the context of other environmental stresses. Such experiments are particularly important for ecosystems with the greatest potential to experience massive change due to the crossing of thresholds or tipping points.

Insights regarding ecosystem responses to climate change gained from both observations and experiments are the essential building blocks of ecosystem simulation models. These models, when rigorously developed and tested, provide powerful tools for exploring the ecosystem consequences of alternative future climates. The incorporation of ecosystem models into an integrated assessment framework that includes socioeconomic, atmospheric and ocean chemistry, and atmosphere-ocean general circulation models should be a major goal of impacts research. This knowledge can provide a base for research studies into ways to manage critical ecosystems in an environment that is continually changing.

Economic systems, human health, and the built environment

As natural systems experience variations due to a changing climate, social and economic systems will be affected. Food production, water resources, forests, parks, and other managed systems provide life support for society. Their sustainability will depend on how well they can adapt to a future climate that is different from historical experience.

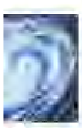
At the same time, climate change is exposing human health and the built environment to increasing risks. Among the likely impacts are an expansion of the ranges of insects and other animals that carry diseases and a greater incidence of health-threatening air pollution events compounded by unusually hot weather associated with climate change. In coastal areas, sea-level rise and storm surge threaten infrastructure including homes, roads, ports, and oil and gas drilling and distribution facilities. In other parts of the country, floods, droughts, and other weather and climate extremes pose increasing threats.

Careful observations along with climate and Earth system models run with a range of emissions scenarios can help society evaluate these risks and plan actions to minimize them. Work in this area would include assessments of the performance of delivery systems, such as those for regional water and electricity supply, so that climate change impacts and costs can be evaluated in terms of changes in risk to system performance. It will be particularly important to understand when the effects on these systems are extremely large and/or rapid, similar to tipping points and thresholds in ecosystems.

In addition, the climate change experienced outside the United States will have implications for our nation. A better understanding of these international linkages, including those related to trade, security, and large-scale movements of people in response to climate change, is desirable.

Recommendation 2: Refine ability to project climate change, including extreme events, at local scales.

One of the main messages to emerge from the past decade of synthesis and assessments is that while climate change is a global issue, it has a great deal of regional variability. There is an indisputable need to improve understanding of climate system effects at these smaller scales, because these are often the scales of decision making in society. Understanding impacts at local scales will also help to target finite resources for adaptation measures. Although much progress has been made in understanding important aspects of this variability, uncertainties remain. Further work is needed on how to quantify cumulative uncertainties across spatial scales and the uncertainties associated with complex, intertwined natural and social systems.



Because region-specific climate changes will occur in the context of other environmental and social changes that are also region-specific, it is important to continue to refine our understanding of regional details, especially those related to precipitation and soil moisture. This would be aided by further testing of models against observations using established metrics designed to evaluate and improve the realism of regional model simulations.

Continued development of improved, higher resolution global climate models, increased computational capacity, extensive climate model experiments, and improved downscaling methods will increase the value of geographically specific climate projections for decision makers in government, business, and the general population.

Extreme weather and climate events are a key component of regional climate. Additional attention needs to be focused on improved observations (made on the relevant time and space scales to capture high-impact extreme events) and associated research and analysis of the potential for future changes in extremes. Impacts analyses indicate that extreme weather and climate events often play a major role in determining climate-change consequences.

Recommendation 3: Expand capacity to provide decision makers and the public with relevant information on climate change and its impacts.

The United States has tremendous potential to create more comprehensive measurement, archive, and data-access systems and to convey needed information that could provide great benefit to society. There are several aspects to fulfilling this goal: defining what is most relevant, gathering the needed information, expanding the capacity to deliver information, and improving the tools for decision makers to use this information to the best advantage. All of these aspects should involve an interactive and iterative process of continual learning between those who provide information and those who use it. Through such a process, monitoring systems, distribution networks, and tools for using information can all be refined to meet user needs.

For example, tools used by researchers that could also be useful to decision makers include those that analyze and display the probability of occurrence of a range of outcomes to help in assessing risks.

Improved climate monitoring can be efficiently achieved by following the Climate Monitoring Principles recommended by the National Academy of Sciences and the Climate Change Science Strategic Plan in addition to integrating current efforts of governments at all levels. Such a strategy complements a long-term commitment to the measurement of the set of essential climate variables identified by both the Climate Change Science Program and the Global Climate Observing System. Attention must be placed on the variety of time and space scales critical for decision making.

Improved impacts monitoring would include information on the physical and economic effects of extreme events (such as floods and droughts), available, for example, from emergency preparedness and resource management authorities. It would also include regular archiving of information about impacts.

Improved access to data and information archives could substantially enhance society's ability to respond to climate change. While many data related to climate impacts are already freely and readily available to a broad range of users, other data, such as damage costs, are not, and efforts should be made to make them available. Easily accessible information should include a set of agreed-upon baseline indicators and measures of environmental conditions that can be used to track the effects of changes in climate. Services that provide reliable, well-documented, and easily used climate information, and make this information available to support users, are important.

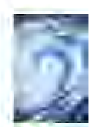
Recommendation 4:
Improve understanding of thresholds likely to lead to abrupt changes in climate or ecosystems.

Paleoclimatic data show that climate can and has changed quite abruptly when certain thresholds are crossed. Similarly, there is evidence that ecological and human systems can undergo abrupt change when tipping points are reached.

Within the climate system there are a number of key risks to society for which understanding is still quite limited. Additional research is needed in some key areas, for example, identifying thresholds that lead to rapid changes in ice sheet dynamics. Sea-level rise is a major concern and improved understanding of the sensitivity of the major ice sheets to sustained warming requires improved observing capability, analysis, and modeling of the ice sheets and their interactions with nearby oceans. Estimates of sea-level rise in previous assessments, such as the recent Intergovernmental Panel on Climate Change 2007 report, did not fully quantify the magnitude and rate of future sea-level rise due to inadequate scientific understanding of potential instabilities of the Greenland and Antarctic ice sheets.

Tipping points in biological systems include the temperature thresholds above which insects survive winter, and can complete two life cycles instead of one in a single growing season, contributing to infestations that kill large numbers of trees. The devastation caused by bark beetles in Canada, and increasingly in the U.S. West, provides an example of how crossing such a threshold can set off massive destruction in an ecosystem with far-reaching consequences.

Similarly, there is increasing concern about the acidification of the world's oceans due to rising atmospheric carbon dioxide levels. There are ocean acidity thresholds beyond which corals and other living things, including some that form the base of important marine food chains, will no longer be able to form the shells and other body structures they need to survive. Improving understanding of such thresholds is an important goal for future research.



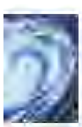
Recommendation 5:
Improve understanding of the most effective ways to reduce the rate and magnitude of climate change, as well as unintended consequences of such activities.

This report underscores the importance of reducing the concentrations of heat-trapping gases in the atmosphere. Impacts of climate change during this century and beyond are projected to be far larger and more rapid in scenarios in which greenhouse gas concentrations continue to grow rapidly compared to scenarios in which concentrations grow more slowly. Additional research will help identify the desired mix of mitigation options necessary to control the rate and magnitude of climate change.

In addition to their intended reduction of atmospheric concentrations of greenhouse gases, mitigation options also have the potential for unintended consequences, which should also be examined in future research. For example, the production, transportation, and use of biofuels could lead to increases in water and fertilizer use as well as in some air pollutants. It could also create competition among land uses for food production, biofuels production, and natural ecosystems that provide many benefits to society. Improved understanding of such unintended consequences, and identification of those options that carry the largest negative impacts, can help decision makers make more informed choices regarding the possible trade-offs inherent in various mitigation strategies.

Recommendation 6:
Enhance understanding of how society can adapt to climate change.

There is currently limited knowledge about the ability of communities, regions, and sectors to adapt to future climate change. It is important to improve understanding of how to enhance society's capacity to adapt to a changing climate in the context of other environmental stresses. Interdisciplinary research on adaptation that takes into account the interconnectedness of the Earth system and the complex nature of the social, political, and economic environment in which adaptation decisions must be made would be central to this effort.



The potential exists to provide insights into the possible effectiveness and limits of adaptation options that might be considered in the future. To realize this potential, new research would be helpful to document past responses to climate variability and other environmental changes, analyze the underlying reasons for them, and explain how individual and institutional decisions were made. However, human-induced climate change is projected to be larger and more rapid than any experienced by modern society so there are limits to what can be learned from the past.

A major difficulty in the analysis of adaptation strategies in this report has been the lack of information about the potential costs of adaptation measures, their effectiveness under various scenarios of climate change, the time horizons required for their implementation, and unintended consequences. These types of information should be systematically gathered and shared with decision makers as they consider a range of adaptation options. It is also clear that there is a substantial gap between the available information about climate change and the development of new guidelines for infrastructure such as housing, transportation, water systems, commercial buildings, and energy systems. There are also social and institutional obstacles to appropriate action, even in the face of adequate knowledge. These obstacles need to be better understood so that they can be reduced or eliminated.

Finally, it is important to carry out regular assessments of adaptation measures that address combined scenarios of future climate change, population growth, and economic development paths. This is an important opportunity for shared learning in which researchers, practitioners, and stakeholders collaborate using observations, models, and dialogue to explore adaptation as part of long-term, sustainable development planning.

Concluding Thoughts

Responding to changing conditions

Human-induced climate change is happening now, and impacts are already apparent. Greater impacts are projected, particularly if heat-trapping gas emissions continue unabated. Previous assessments have established these facts, and this report confirms, solidifies, and extends these conclusions for the United States. It reports the latest understanding of how climate change is already affecting important sectors and regions. In particular, it reports that some climate change impacts appear to be increasing faster than previous assessments had suggested. This report represents a significant update to previous work, as it draws from the U.S. Climate Change Science Program's Synthesis and Assessment Products and other recent studies that examine how climate change and its effects are projected to continue to increase over this century and beyond.

Climate choices

Choices about emissions now and in the coming years will have far-reaching consequences for climate change impacts. A consistent finding of this assessment is that the rate and magnitude of future climate change and resulting impacts depend critically on the level of global atmospheric heat-trapping gas concentrations as well as the types and concentrations of atmospheric particles (aerosols). Lower emissions of heat-trapping gases will delay the appearance of climate change impacts and lessen their magnitude. Unless the rate of emissions is substantially reduced, impacts are expected to become increasingly severe for more people and places.

Similarly, there are choices to be made about adaptation strategies that can help to reduce or avoid some of the undesirable impacts of climate change. There is much to learn about the effectiveness of the various types of adaptation responses and how they will interact with each other and with mitigation actions.

Responses to the climate change challenge will almost certainly evolve over time as society learns by doing. Determining and refining societal responses will be an iterative process involving scientists, policymakers, and public and private decision makers at all levels. Implementing these response strategies will require careful planning and continual feedback on the impacts of mitigation and adaptation policies for government, industry, and society.

The value of assessments

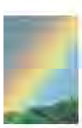
Science has revolutionized our ability to observe and model the Earth's climate and living systems, to understand how they are changing, and to project future changes in ways that were not possible in prior generations. These advances have enabled the assessment of climate change, impacts, vulnerabilities, and response strategies. Assessments serve a very important function in providing the scientific underpinnings of informed policy. They can identify advances in the underlying science, provide critical analysis of issues, and highlight key findings and key unknowns that can guide decision making. Regular assessments also serve as progress reports to evaluate and improve policy making and other types of decision making related to climate change.

Impacts and adaptation research includes complex human dimensions, such as economics, management, governance, behavior, and equity. Comprehensive assessments provide an opportunity to evaluate the social implications of climate change within the context of larger questions of how communities and the nation as a whole create sustainable and environmentally sound development paths.

A vision for future U.S. assessments

Over the past decade, U.S. federal agencies have undertaken two coordinated, national-scale efforts to evaluate the impacts of global climate change on this country. Each effort produced a report to the nation – *Climate Change Impacts on the United States*, published in 2000, and this report, *Global Climate Change Impacts in the United States*, published in 2009. A unique feature of the first report was that in addition to reporting the current state of the science, it created a national discourse on climate change that involved hundreds of scientists and thousands of stakeholders including farmers, ranchers, resource managers, city planners, business people, and local and regional government officials. A notable feature of the second report is the incorporation of information from the 21 topic-specific Synthesis and Assessment Products, many motivated by stakeholder interactions.

A vision for future climate change assessments includes both sustained, extensive stakeholder involvement, and targeted, scientifically rigorous reports that address concerns in a timely fashion. The value of stakeholder involvement includes helping scientists understand what information society wants and needs. In addition, the problem-solving abilities of stakeholders will be essential to designing, initiating, and evaluating mitigation and adaptation strategies and their interactions. The best decisions about these strategies will come when there is widespread understanding of the complex issue of climate change – the science and its many implications for our nation.



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PRIMARY SOURCES OF INFORMATION

CCSP Goal 1: Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change	
CCSP 1.1 Temperature Trends	*Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*
	Thomas R. Karl, NOAA; Susan J. Hassol, STG Inc.; Christopher D. Miller, NOAA; William L. Murray, STG Inc.
CCSP 1.2 Past Climate	*Past Climate Variability and Change in the Arctic and at High Latitudes*
	Richard B. Alley, Pennsylvania State Univ.; Julie Brigham-Grette, Univ. of Massachusetts; Gifford H. Miller, Univ. of Colorado; Leonid Polyak, Ohio State Univ.; James W.C. White, Univ.of Colorado; Joan J. Fitzpatrick, USGS
CCSP 1.3 Reanalysis	*Re-Analysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change*
	Randall M. Dole, Martin P. Hoerling, Siegfried Schubert, NOAA
CCSP Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems	
CCSP 2.1 GHG Emissions	Part A: *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations* Part B: *Global-Change Scenarios: Their Development and Use*
	Leon E. Clarke, James A. Edmonds, Hugh M. Pitcher, Pacific Northwest National Lab.; Henry D. Jacoby, MIT; John M. Reilly, MIT; Richard G. Richels, Electric Power Research Institute; Edward A. Parson, Univ. of Michigan; Virginia R. Burkett, USGS; Karen Fisher-Vanden, Dartmouth College; David W. Keith, Univ. of Calgary; Linda O. Mearns, NCAR; Cynthia E. Rosenzweig, NASA; Mort D. Webster, MIT; John C. Houghton DOE/Office of Biological and Environmental Research
CCSP 2.2 Carbon Cycle	*The First State of the Carbon Cycle Report (SOCCR) North American Carbon Budget and Implications for the Global Carbon Cycle*
	Anthony W. King, ORNL; Lisa Dilling, Univ. of Colorado/NCAR; Gregory P. Zimmerman,ORNL; David Fairman, Consensus Building Institute Inc.; Richard A. Houghton, Woods Hole Research Center; Gregg Marland, ORNL; Adam Z. Rose, Pennsylvania State Univ. and Univ. Southern California; Thomas J. Wilbanks, ORNL
CCSP 2.3 Aerosol Impacts	*Atmospheric Aerosol Properties and Climate Impacts*
	Mian Chin, NASA; Ralph A. Kahn, NASA; Stephen E. Schwartz, DOE/BNL; Lorraine A. Remer, NASA/GSFC; Hogbin Yu, NASA/GSFC/UMBC; David Rind, NASA/GISS; Graham Feingold, NOAA/ESRL; Patricia K. Quinn, NOAA/PMEL; David G. Streets, DOE/ANL; Philip DeCola, NASA HQ; Rangasayi Halthore, NASA HQ/NRL
CCSP 2.4 Ozone Trends	*Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, & Implications for Ultraviolet Radiation Exposure*
	A.R. Ravishankara, NOAA; Michael J. Kurylo, NASA; Christine Ennis, NOAA/ESRL

CCSP Goal 3: *Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future*	
CCSP 3.1 Climate Models	*Climate Models: An Assessment of Strengths and Limitations* David C. Bader and Curt Covey, Lawrence Livermore National Lab.; William J. Gutowski Jr., Iowa State Univ.; Isaac M. Held, NOAA/GFDL; Kenneth E. Kunkel, Illinois State Water Survey; Ronald L. Miller, NASA/GISS; Robin T. Tokmakian, Naval Postgraduate School; Minghua H. Zhang, State Univ. of New York Stony Brook; Anjuli S. Bamzai, U.S. DOE
CCSP 3.2 Climate Projections	*Climate Projections Based on Emissions Scenarios for Long-Lived and Short-Lived Radiatively Active Gases and Aerosols* Hiram Levy II, NOAA/GFDL; Drew Shindell, NASA/GISS; Alice Gilliland, NOAA/ARL; M. Daniel Schwarzkopf, NOAA/GFDL; Larry W. Horowitz, NOAA/GFDL; Anne M. Waple, STG Inc.
CCSP 3.3 Extremes	*Weather and Climate Extremes in a Changing Climate: Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands* Thomas R. Karl, NOAA; Gerald A. Meehl, NCAR; Christopher D. Miller, NOAA; Susan J. Hassol, STG Inc.; Anne M. Waple, STG Inc.; William L. Murray, STG Inc.
CCSP 3.4 Abrupt Climate Change	*Abrupt Climate Change* John P. McGeehin, USGS; John A. Barron, USGS; David M. Anderson, NOAA; David J. Verardo, NSF; Peter U. Clark, Oregon State Univ.; Andrew J. Weaver, Univ. of Victoria; Konrad Steffen, Univ. of Colorado; Edward R. Cook, Columbia Univ.; Thomas L. Delworth, NOAA; Edward Brook, Oregon State Univ.
CCSP Goal 4: *Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes*	
CCSP 4.1 Sea-Level Rise	*Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region* James G. Titus, U.S. EPA; K. Eric Anderson, USGS; Donald R. Cahoon, USGS; Dean B. Gesch, USGS; Stephen K. Gill, NOAA; Benjamin T. Gutierrez, USGS; E. Robert Thieler, USGS; S. Jeffress Williams, USGS
CCSP 4.2 Ecosystem Thresholds	*Thresholds of Climate Change in Ecosystems* Daniel B. Fagre, USGS; Colleen W. Charles, USGS
CCSP 4.3 Impacts	*The Effects of Climate Change on Agriculture, Land Resources, Water Resources and Biodiversity in the United States* Peter Backlund, NCAR; Anthony Janetos, PNNL/Univ. of Maryland; David Schimel, National Ecological Observatory Network; Margaret Walsh, USDA
CCSP 4.4 Ecosystem Adaptation	*Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources* Susan Herrod Julius, U.S. EPA; Jordan M. West, U.S. EPA; Jill S. Baron, USGS and Colorado State Univ.; Linda A. Joyce, USDA Forest Service; Brad Griffith, USGS; Peter Kareiva, The Nature Conservancy; Brian D. Keller, NOAA; Margaret Palmer, Univ. of Maryland; Charles Peterson, Univ. of North Carolina; J. Michael Scott, USGS and Univ. of Idaho
CCSP 4.5 Energy	*Effects of Climate Change on Energy Production and Use in the United States* Thomas J. Wilbanks, ORNL; Vatsal Bhatt, Brookhaven National Lab.; Daniel E. Bilello, National Renewable Energy Lab.; Stanley R. Bull, National Renewable Energy Lab.; James Ekmann, National Energy Technology Lab.; William C. Horak, Brookhaven National Lab.; Y. Joe Huang, Mark D. Levine, Lawrence Berkeley National Lab.; Michael J. Sale, ORNL; David K. Schmalzer, Argonne National Lab.; Michael J. Scott, Pacific Northwest National Lab.

CCSP 4.6 Health	*Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems*
	Janet L. Gamble, U.S. EPA; Kristie L. Ebi, ESS LLC.; Anne E. Grambsch, U.S. EPA; Frances G. Sussman, Environmental Economics Consulting; Thomas J. Wilbanks, ORNL
CCSP 4.7 Transportation	*Impacts of Climate Variability and Change on Transportation Systems and Infrastructure – Gulf Coast Study*
	Michael J. Savonis, Federal Highway Administration; Virginia R. Burkett, USGS; Joanne R. Potter, Cambridge Systematics
CCSP Goal 5: *Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change*	
CCSP 5.1	*Uses and Limitations of Observations, Data, Forecasts, and Other Projections in Decision Support for Selected Sectors and Regions*
	John Haynes, NASA; Fred Vukovich, SAIC; Molly K. Macauley, RFF; Daewon W. Byun, Univ. of Houston; David Renne, NREL; Gregory Glass, Johns Hopkins School of Public Health; Holly Hartmann, Univ. of Arizona
CCSP 5.2 Uncertainty	*Best Practice Approaches for Characterizing, Communicating and Incorporating Scientific Uncertainty in Climate Decision Making*
	M. Granger Morgan, Dept. of Engineering and Public Policy, Carnegie Mellon Univ.; Hadi Dowlatabadi, Inst. for Resources, Environment and Sustainability, Univ. of British Columbia; Max Henrion, Lumina Decision Systems; David Keith, Dept. of Chemical and Petroleum Engineering and Dept. of Economics, Univ. of Calgary; Robert Lempert, The RAND Corp.; Sandra McBride, Duke Univ.; Mitchell Small, Dept. of Engineering and Public Policy, Carnegie Mellon Univ.; Thomas Wilbanks, Environmental Science Division, ORNL
CCSP 5.3 Decision Support	*Decision Support Experiments and Evaluations using Seasonal-to-Interannual Forecasts and Observational Data: A Focus on Water Resources*
	Nancy Beller-Simms, NOAA; Helen Ingram, Univ. of Arizona; David Feldman, Univ. of California; Nathan Mantua, Climate Impacts Group, Univ. of Washington; Katharine L. Jacobs, Arizona Water Institute; Anne M. Waple, STG Inc.
Other Assessments Referenced	
IPCC WG-1	Working Group I - *Climate Change 2007: The Physical Science Basis*
	Susan Solomon, Dahe Qin, Martin Manning, Zhenlin Chen, Melinda Marquis, Kristen B. Averyt, Melina M.B. Tignor, Henry LeRoy Miller, Jr
IPCC WG-2	Working Group II - *Climate Change 2007: Impacts, Adaptation and Vulnerability*
	Martin L. Parry, Osvalda F. Canziani, Jean P. Palutikof, Paul J. van der Linden, Clair E. Hanson
IPCC WG-3	Working Group III - *Climate Change 2007: Mitigation of Climate Change*
	Bert Metz, Ogunlade R. Davidson, Peter R. Bosch, Rutu Dave, Leo A. Meyer
IPCC Emissions Scenarios	*Special Report on Emissions Scenarios*
	Nebojsa Nakicenovic, Robert Swart

IPCC Water	*Climate Change and Water*
	Bryson Bates, Zbigniew W. Kundzewicz, Shaohong Wu, Jean P. Palutikof
NRC	*Potential Impacts of Climate Change on U.S. Transportation*
	Henry G. Schwartz, Jr., Alan C. Clark, G. Edward Dickey, George C. Eads, Robert E. Gallamore, Genevieve Giuliano, William J. Gutowski, Jr., Randell H. Iwasaki, Klaus H. Jacob, Thomas R. Karl, Robert J. Lempert, Luisa M. Paiewonsky, S. George H. Philander, Christopher R. Zeppie
NAST	*Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*
	Jerry M. Melillo, Anthony C. Janetos, Thomas R. Karl, Eric J. Barron, Virginia Rose Burkett, Thomas F. Cecich, Robert W. Corell, Katharine L. Jacobs, Linda A. Joyce, Barbara Miller, M. Granger Morgan, Edward A. Parson, Richard G. Richels, David S. Schimel
ACIA	*Impacts of a Warming Arctic, Arctic Climate Impact Assessment*
	Robert W. Corell, Susan J. Hassol, Pål Prestrud, Patricia A. Anderson, Snorri Baldursson, Elizabeth Bush, Terry V. Callaghan, Paul Grabhorn, Gordon McBean, Michael MacCracken, Lars-Otto Reiersen, Jan Idar Solbakken, Gunter Weller

ACRONYMS AND ABBREVIATIONS

ARS: Agricultural Research Service
CCSP: Climate Change Science Program
CIESIN: Center for International Earth Science Information Network
CIRES: Cooperative Institute for Research in Environmental Sciences
CMIP: Coupled Model Intercomparison Project
DOE: Department of Energy
EIA: Energy Information Administration
IARC: International Arctic Research Center
IPCC: Intergovernmental Panel on Climate Change
NASA: National Aeronautics and Space Administration
NASS: National Agricultural Statistics Service
NAST: National Assessment Synthesis Team
NCDC: National Climatic Data Center
NESDIS: National Environmental Satellite, Data, and Information Service
NOAA: Oceanic and Atmospheric Administration
NRCS: Natural Resources Conservation Service
NSIDC: National Snow and Ice Data Center
NWS: National Weather Service
NWFSC: Northwest Fisheries Science Center
PISCO: Partnership for Interdisciplinary Studies of Coastal Oceans
PLJV: Playa Lakes Joint Venture
SAP: Synthesis and Assessment Product
SRH: Southern Regional Headquarters
USACE: United States Army Corps of Engineers
USBR: States Bureau of Reclamation
USDA: United States Department of Agriculture
U.S. EPA: United States Environmental Protection Agency
USFS: United States Forest Service
USGS: United States Geological Survey

REFERENCES

[1] CCSP, 2009: *Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Decisionmaking.* [Morgan, G., H. Dowlatabadi, M. Henrion, D. Keith, R. Lempert, S. McBrid, M. Small, and T. Wilbanks (eds.)]. Synthesis and Assessment Product 5.2. National Oceanic and Atmospheric Administration, Washington DC.

[2] Historical data: Lüthi, D., M. Le Floch, B. Bereiter, T. Blunier, J.-M. Barnola, U. Siegenthaler, D. Raynaud, J. Jouzel, H. Fischer, K. Kawamura, and T.F. Stocker, 2008: High-resolution carbon dioxide concentration record 650,000-800,000 years before present. *Nature*, **453(7193)**, 379-382.

1959-2008 data: Tans, P., 2008: *Trends in Atmospheric Carbon Dioxide: Mauna Loa.* NOAA Earth System Research Laboratory (ESRL). [Web site] <http://www.esrl.noaa.gov/gmd/ccgg/trends/> Data available at <ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_annmean_mlo.txt>

2100 projected data: International Institute for Applied System Analysis (IIASA) GGI Scenario Database, 2008. <http://www.iiasa.ac.at/Research/GGI/DB/>

[3] Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz, and R. Van Dorland, 2007: Changes in atmospheric constituents and in radiative forcing. In: *Climate Change 2007: The Physical Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 129-234.

[4] Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P.M. Cox, R.E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S Ramachandran, P.L. da Silva Dias, S.C. Wofsy, and X. Zhang, 2007: Couplings between changes in the climate system and biogeochemistry. In: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 499-587.

[5] Ko, M., J.S, Daniel, J.R. Herman, P.A. Newman, and V. Ramaswamy, 2008: The future and recovery. In: *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure.* [Ravishankara, A.R., M.J. Kurylo, and C.A. Ennis (eds.)]. Synthesis and Assessment Product 2.4. NOAA's National Climatic Data Center, Asheville, NC, pp. 133-154.

[6] Ravishankara, A.R., M.J. Kurylo, and A.-M. Schmoltner, 2008: Introduction. In: *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure.* [Ravishankara, A.R., M.J. Kurylo, and C.A. Ennis (eds.)]. Synthesis and Assessment Product 2.4. NOAA's National Climatic Data Center, Asheville, NC, pp. 23-28.

[7] Blasing, T.J., 2008: *Recent Greenhouse Gas Concentrations.* Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory. <http://cdiac.ornl.gov/pns/current_ghg.html>

[8] Fahey, D.W. (lead author), 2007: *Twenty Questions and Answers about the Ozone Layer: 2006 Update.* World Meteorological Organization, Geneva, Switzerland, 50 pp. <http://www.esrl.noaa.gov/csd/assessments/2006/twentyquestions.html>

[9] Thompson, D.W.J. and S. Solomon, 2002: Interpretation of recent Southern Hemisphere climate change. *Science*, **296(5569)**, 895-899.

[10] Kahn, R.A., H. Yu, S.E. Schwartz, M. Chin, G. Feingold, L.A. Remer, D. Rind, R. Halthore, and P. DeCola, 2009: Introduction. In: *Atmospheric Aerosol Properties and Climate Impacts.* [Chin, M., R.A. Kahn, and S.E. Schwartz (eds.)]. Synthesis and Assessment Product 2.3. National Aeronautics and Space Administration, Washington, DC, pp. 9-20.

[11] Solomon, S., G.-K. Plattner, R. Knutti, and P. Friedlingstein, 2009: Irreversible climate change because of carbon dioxide emissions. *Proceedings of the National Academy of Sciences*, **106(6)**, 1704-1709.

[12] Archer, D., 2005: Fate of fossil fuel CO_2 in geologic time. *Journal of Geophysical Research*, **110**, C09S05, doi:10.1029/2004JC002625.

[13] Shindell, D.T., H. Levy II, A. Gilliland, M.D. Schwarzkopf, and L.W. Horowitz, 2008: Climate change from short-lived emissions due to human activities. In: *Climate Projections Based on Emissions Scenarios for Long-Lived and Short-Lived Radiatively Active Gases and Aerosols.* [Levy II, H., D.T. Shindell, A. Gilliland, M.D. Schwarzkopf, and L.W. Horowitz, (eds.)]. Synthesis and Assessment Product 3.2. U.S. Climate Change Science Program, Washington, DC, pp. 27-60.

[14] Santer, B.D., J.E. Penner, and P.W. Thorne, 2006: How well can the observed vertical temperature changes be reconciled with our understanding of the causes of these changes? In: *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences* [Karl, T.R., S.J. Hassol, C.D. Miller, and W.L. Murray (eds.)]. Synthesis and Assessment Product 1.1 U.S. Climate Change Science Program, Washington, DC, pp. 89-118.

[15] Hansen, J., M. Sato, R. Ruedy, L. Nazarenko, A. Lacis, G.A. Schmidt, G. Russell, I. Aleinov, M. Bauer, S. Bauer, N. Bell, B. Cairns, V. Canuto, M. Chandler, Y. Cheng, A. Del Genio, G. Faluveg E. Fleming, A. Friend, T. Hall, C. Jackman, M. Kelley, N. Kiang, D. Koch, J. Lean, J. Lerner, K. Lo, S. Menon, R. Miller, P. Minnis, T. Novakov, V. Oinas, Ja. Perlwitz, Ju. Perlwitz, D. Rind, A. Romanou, D. Shindell, P. Stone, S. Sun, N. Tausnev, D. Thresher, B. Wielicki, T. Wong, M. Yao, and S. Zhang 2005: Efficacy of climate forcings. *Journal of Geophysical Research*, **110**, D18104, doi:10.1029/2005JD005776.

[16] National Research Council, 2005: *Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties.* National Academies Press, Washington DC, 207 pp.

[17] Hansen, J., M. Sato, R. Ruedy, A. Lacis, and V. Oinas, 2000: Global warming in the twenty-first century: an alternative scenario. *Proceedings of the National Academy of Sciences*, **97(18)**, 9875-9880.

[18] Field, C.B., J. Sarmiento, and B. Hales, 2007: The carbon cycle of North America in a global context. In: *The First State of the Carbon Cycle Report (SOCCR): The North American Carbon Budget and Implications for the Global Carbon Cycle* [King, A.W., L. Dilling, G.P. Zimmerman, D.M. Fairman, R.A. Houghton, G. Marland, A.Z. Rose, and T.J.

Wilbanks (eds.)]. Synthesis and Assessment Product 2.2. NOAA's National Climatic Data Center, Asheville, NC, pp. 21-28.

[19] Tarnocai, C., C.-L. Ping, and J. Kimble, 2007: Carbon cycles in the permafrost region of North America. In: *The First State of the Carbon Cycle Report (SOCCR): The North American Carbon Budget and Implications for the Global Carbon Cycle* [King, A.W., L. Dilling, G.P. Zimmerman, D.M. Fairman, R.A. Houghton, G. Marland, A.Z. Rose, and T.J. Wilbanks (eds.)]. Synthesis and Assessment Product 2.2. NOAA's National Climatic Data Center, Asheville, NC, pp. 127-138.

[20] Jansen, E., J. Overpeck, K.R. Briffa, J.-C. Duplessy, F. Joos, V. Masson-Delmotte, D. Olago, B. Otto-Bliesner, W.R. Peltier, S. Rahmstorf, R. Ramesh, D. Raynaud, D. Rind, O. Solomina, R. Villalba and D. Zhang, 2007: Palaeoclimate. In: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 433-497.

[21] Canadell, J.G., C. Le Quéré, M.R. Raupach, C.B. Field, E.T. Buitenhuis, P. Ciais, T.J. Conway, N.P. Gillett, R.A. Houghton, and G. Marland, 2007: Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proceedings of the National Academy of Sciences*, **104(47)**, 18866-18870.

[22] Royal Society, 2005: *Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide*. Policy Document 12/05. Royal Society, London, 60 pp.

[23] Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G.-K. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarmiento, R. Schlitzer, R.D. Slater, I.J. Totterdell, M.-F. Weirig, Y. Yamanaka, and A. Yool, 2005: Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature*, **437(7059)**, 681-686.

[24] Allen, M.R., 2003: Liability for climate change. *Nature*, **421(6926)**, 891-892.

[25] Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, and R. Richels, 2007: *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations*. Sub-report 2.1A of Synthesis and Assessment Product 2.1. U.S. Department of Energy, Office of Biological & Environmental Research, Washington, DC, 154 pp.

[26] The spatial average of annual-average surface air temperatures around the globe is commonly referred to as the global average surface air temperature.

[27] Meier, M.F., M.B. Dyurgerov, U.K. Rick, S. O'Neel, W.T. Pfeffer, R.S. Anderson, S.P. Anderson, and A.F. Glazovsky, 2007: Glaciers dominate eustatic sea-level rise in the 21st century. *Science*, **317(5841)**, 1064-1067.

[28] Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden, and P. Zhai, 2007: Observations: surface and atmospheric climate change. In: *Climate Change 2007: The Physical Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 235-335.

[29] Steffen, K., P.U. Clark, J.G. Cogley, D. Holland, S. Marshall, E. Rignot, and R. Thomas, 2008: Rapid changes in glaciers and ice sheets and their impacts on sea level. In: *Abrupt Climate Change*. Synthesis and Assessment Product 3.4. U.S. Geological Survey, Reston, VA, pp. 60-142.

[30] Lanzante, J.R., T.C. Peterson, F.J. Wentz, and K.Y. Vinnikov, 2006: What do observations indicate about the change of temperatures in the atmosphere and at the surface since the advent of measuring temperatures vertically? In: *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences* [Karl, T.R., S.J. Hassol, C.D. Miller, and W.L. Murray (eds.)]. Synthesis and Assessment Product 1.1 U.S. Climate Change Science Program, Washington, DC, pp. 47-70.

[31] Santer, B.D., P.W. Thorne, L. Haimberger, K.E. Taylor, T.M.L. Wigley, J.R. Lanzante, S. Solomon, M. Free, P.J. Gleckler, P.D. Jones, T.R. Karl, S.A. Klein, C. Mears, D. Nychka, G.A. Schmidt, S.C. Sherwood, and F.J. Wentz, 2008: Consistency of modelled and observed temperature trends in the tropical troposphere. *International Journal of Climatology*, **28(13)**, 1703-1722.

[32] Uncertainties in the data are an order of magnitude smaller than the trend according to Karl, T.R., J.R. Christy, R.A. Clarke, G.V. Gruza, J. Jouzel, M.E. Mann, J. Oerlemans, M.J. Salinger, and S.-W. Wang, 2001: Observed climate variability and change. In: *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 99-181.

Temperature data:

Smith, T.M. and R.W. Reynolds, 2004: Improved extended reconstruction of SST (1854–1997). *Journal of Climate*, **17(12)**, 2466-2477.

Jones, P.D., M. New, D.E. Parker, S. Martin, and I.G. Rigor, 1999: Surface air temperature and its changes over the past 150 years. *Reviews of Geophysics*, **37(2)**, 173-199.

Carbon dioxide data:

Data from 1974 to present: Tans, P., 2008: *Trends in Atmospheric Carbon Dioxide: Mauna Loa*. NOAA Earth System Research Laboratory (ESRL). [Web site] <http://www.esrl.noaa.gov/gmd/ccgg/trends/> Data available at <ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_annmean_mlo.txt>

1958-1974 data are from the Scripps Institution of Oceanography (Keeling) Mauna Loa Observatory record. <http://scrippsco2.ucsd.edu/>

Pre-1958 values are annual points taken from a smooth fit to the Law Dome data: Etheridge, D.M., L.P. Steele, R.L. Langenfelds, R.J. Francey, J.-M. Barnola, and V.I. Morgan, 1996: Natural and anthropogenic changes in atmospheric CO_2 over the last 1000 years from air in Antarctic ice and firn. *Journal of Geophysical Research*, **101(D2)**, 4115-4128.

[33] Easterling, D. and M. Wehner, 2009: Is the climate warming or cooling? *Geophysical Research Letters*, **36**, L08706, doi:10.1029/2009GL037810.

[34] Barnett, T.P., D.W. Pierce, H.G. Hidalgo, C. Bonfils, B.D. Santer, T. Das, G. Bala, A.W. Wood, T. Nozawa, A.A. Mirin, D.R. Cayan, and M.D. Dettinger, 2008: Human-induced changes in the hydrology of the western United States. *Science*, **319(5866)**, 1080-1083.

[35] Willett, K.M., N.P. Gillett, P.D. Jones, and P.W. Thorne, 2007: Attribution of observed surface humidity changes to human influence. *Nature*, **449(7163)**, 710-712.

[36] Santer, B.D., C. Mears, F.J. Wentz, K.E. Taylor, P.J. Gleckler, T.M.L. Wigley, T.P. Barnett, J.S. Boyle, W. Brüggemann, N.P. Gillett, S.A. Klein, G.A. Meehl, T. Nozawa, D.W. Pierce, P.A. Stott, W.M. Washington, and M.F. Wehner, 2007: Identification of human-induced changes in atmospheric moisture content. *Proceedings of the National Academy of Sciences*, **104(39)**, 15248-15253.

[37] Bindoff, N.L., J. Willebrand, V. Artale, A. Cazenave, J. Gregory, S. Gulev, K. Hanawa, C. Le Quéré, S. Levitus, Y. Nojiri, C.K. Shum, L.D. Talley, and A. Unnikrishnan, 2007: Observations: oceanic climate change and sea level. In: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 385-432.

[38] Barnett, T.P., D.W. Pierce, K.M. AchutaRao, P.J. Gleckler, B.D. Santer, J.M. Gregory, and W.M. Washington, 2005: Penetration of human-induced warming into the world's oceans. *Science*, **309(5732)**, 284-287.

[39] Pierce, D.W., T.P. Barnett, K.M. AchutaRao, P.J. Gleckler, J.M. Gregory, and W.M. Washington, 2006: Anthropogenic warming of the oceans: observations and model results. *Journal of Climate*, **19(10)**, 1873-1900.

[40] Lemke, P., J. Ren, R.B. Alley, I. Allison, J. Carrasco, G. Flato, Y. Fujii, G. Kaser, P. Mote, R.H. Thomas, and T. Zhang, 2007: Observations: changes in snow, ice and frozen ground. In: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)], Cambridge University Press, Cambridge, UK, and New York, pp. 337-383.

[41] Luthcke, S.B., H.J. Zwally, W. Abdalati, D.D. Rowlands, R.D. Ray, R.S. Nerem, F.G. Lemoine, J.J. McCarthy, and D.S. Chinn, 2006: Recent Greenland ice mass loss by drainage system from satellite gravity observations. *Science*, **314(5803)**, 1286-1289.

[42] Pfeffer, W.T., J.T. Harper, and S. O'Neel, 2008: Kinematic constraints on glacier contributions to 21st-century sea-level rise. *Science*, **321(5894)**, 1340-1343.

[43] Williams, S.J., B.T. Gutierrez, J.G. Titus, S.K. Gill, D.R. Cahoon, E.R. Thieler, K.E. Anderson, D. FitzGerald, V. Burkett, and J. Samenow, 2009: Sea-level rise and its effects on the coast. In: *Coastal Elevations and Sensitivity to Sea-level Rise: A Focus on the Mid-Atlantic Region* [J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. Synthesis and Assessment Product 4.1. U.S. Environmental Protection Agency, Washington, DC, pp. 11-24.

[44] IPCC (Intergovernmental Panel on Climate Change), 1996: Summary for policy makers. In: *Climate Change 1995: The Science of Climate Change.* Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., L.G. Meiro Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 1-7.

[45] IPCC (Intergovernmental Panel on Climate Change), 2007: Summary for policymakers. In: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 1-18.

[46] Wigley, T.M.L., V. Ramaswamy, J.R. Christy, J.R. Lanzante, C.A. Mears, B.D. Santer, and C.K. Folland, 2006: Executive summary. In: *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences* [Karl, T.R., S.J. Hassol, C.D. Miller, and W.L. Murray (eds.)]. Synthesis and Assessment Product 1.1 U.S. Climate Change Science Program, Washington, DC, pp. 1-15.

[47] National Research Council, 2006: *Surface Temperature Reconstructions for the Last 2,000 Years.* National Academies Press, Washington DC, 196 pp.

[48] Mann, M.E., Z. Zhang, M.K. Hughes, R.S. Bradley, S.K. Miller, S. Rutherford, and F. Ni, 2008: Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia. *Proceedings of the National Academy of Sciences*, **105(36)**, 13252-13257.

[49] Hegerl, G.C., F.W. Zwiers, P. Braconnot, N.P. Gillett, Y. Luo, J.A. Marengo Orsini, N. Nicholls, J.E. Penner, and P.A. Stott, 2007: Understanding and attributing climate change. In: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 663-745.

[50] LeTreut, H., R. Somerville, U. Cubasch, Y. Ding, C. Mauritzen, A. Mokssit, T. Peterson, and M. Prather, 2007: Historical overview of climate changes science. In: *Climate Change 2007: The Physical Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 93-127.

[51] Santer, B.D., T.M.L. Wigley, T.P. Barnett, and E. Anyamba, 1996: Detection of climate change, and attribution of causes. In: *Climate Change 1995: The Science of Climate Change.* Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., L.G. Meiro Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 407-443.

[52] Mitchell, J.F.B., D.J. Karoly, G.C. Hegerl, F.W. Zwiers, M.R. Allen, and J. Marengo, 2001: Detection of climate change and attribution of causes. In: *Climate Change 2001: The Scientific Basis.* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 695-738.

[53] Santer, B.D., M.F. Wehner, T.M.L. Wigley, R. Sausen, G.A. Meehl, K.E. Taylor, C. Ammann, J. Arblaster, W.M. Washington, J.S. Boyle, and W. Brüggemann, 2003: Contributions of anthropogenic and natural forcing to recent tropopause height changes. *Science*, **301(5632)**, 479-483.

[54] Zhang, X., F.W. Zwiers, G.C. Hegerl, F.H. Lambert, N.P. Gillett, S. Solomon, P.A. Stott and T. Nozawa, 2007: Detection of human influence on twentieth-century precipitation trends. *Nature*, **448(7152)**, 461-465.

[55] Burke, E.J., S.J. Brown, and N. Christidis, 2006: Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. *Journal of Hydrometeorology*, **7(5)**, 1113-1125.

[56] Gillett, N.P., F.W. Zwiers, A.J. Weaver, and P.A. Stott, 2003: Detection of human influence on sea level pressure. *Nature*, **422(6929)**, 292-294.

[57] Gedney, N., P.M. Cox, R.A. Betts, O. Boucher, C. Huntingford, and P.A. Stott, 2006: Detection of a direct carbon dioxide effect in continental river runoff records. *Nature*, **439(7078)**, 835-838.

[58] Dole, R. and M. Hoerling, 2008: Introduction. In: *Reanalysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change.* [Dole, R., M. Hoerling, and S. Schubert (eds.)]. Synthesis and Assessment Prod-

uct 1.3. NOAA's National Climatic Data Center, Asheville, NC, pp. 5-10.

[59] The temperature data for the globe is the standard NOAA/NCDC temperature product.

The solar data are a composite of 3 different data sets:

Fröhlich, C. and J. Lean, 2004: Solar radiative output and its variability: evidence and mechanisms. *Astronomy and Astrophysics Review*, **12(4)**, 273-320.

Willson, R.C. and A.V. Mordvinov, 2003: Secular total solar irradiance trend during solar cycles 21023. *Geophysical Research Letters*, **30(5)**, 1199, doi:10.1029/2002GL016038.

Dewitte, S., D. Crommelynck, S. Mekaoui, and A. Jouko, 2004: Measurement and uncertainty of the long-term total solar irradiance trend. *Solar Physics*, **224(1-2)**, 209-216.

[60] Lean, J.L. and D.H. Rind, 2008: How natural and anthropogenic influences alter global and regional surface temperatures: 1889 to 2006. *Geophysical Research Letters*, **35**, L18701, doi:10.1029/2008GL034864.

[61] Min, S.-K., X. Zhang, F.W. Zwiers, and T. Agnew, 2008: Human influence on Arctic sea ice detectable from early 1990s onwards. *Geophysical Research Letters*, **35**, L21701, doi:10.1029/2008GL035725.

[62] Gillett, N.P., D.A. Stone, P.A. Stott, T. Nozawa, A.Y. Karpechko, G.C. Hegerl, M.F. Wehner, and P.D. Jones, 2008: Attribution of polar warming to human influence. *Nature Geoscience*, **1(11)**, 750-754.

[63] Ramaswamy, V., J.W. Hurrell, G.A. Meehl, A. Phillips, B.D. Santer, M.D. Schwarzkopf, D.J. Seidel, S.C. Sherwood, and P.W. Thorne, 2006: Why do temperatures vary vertically (from the surface to the stratosphere) and what do we understand about why they might vary and change over time? In: *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences* [Karl, T.R., S.J. Hassol, C.D. Miller, and W.L. Murray (eds.)]. Synthesis and Assessment Product 1.1. U.S. Climate Change Science Program, Washington, DC, pp. 15-28.

[64] Stott, P.A., 2003: Attribution of regional-scale temperature changes to anthropogenic and natural causes. *Geophysical Research Letters*, **30(14)**, 1724, doi:10.1029/2003GL017324.

[65] Zwiers, F.W. and X. Zhang, 2003: Towards regional-scale climate change detection. *Journal of Climate*, **16(5)**, 793-797.

[66] Santer, B.D., T.M.L. Wigley, P.J. Gleckler, C. Bonfils, M.F. Wehner, K. AchutaRao, T.P. Barnett, J.S. Boyle, W. Brüggemann, M. Fiorino, N.P. Gillett, J.E. Hansen, P.D. Jones, S.A. Klein, G.A. Meehl, S.C.B. Raper, R.W. Reynolds, K.E. Taylor, and W.M. Washington, 2006: Forced and unforced ocean temperature changes in Atlantic and Pacific tropical cyclogenesis regions. *Proceedings of the National Academy of Sciences*, **103(38)**, 13905-13910.

[67] Gillett, N.P., P.A. Stott, and B.D. Santer, 2008: Attribution of cyclogenesis region sea surface temperature change to anthropogenic influence. *Geophysical Research Letters*, **35**, L09707, doi:10.1029/2008GL033670.

[68] Gutowski, W.J., G.C. Hegerl, G.J. Holland, T.R. Knutson, L.O. Mearns, R.J. Stouffer, P.J. Webster, M.F. Wehner, and F.W. Zwiers, 2008: Causes of observed changes in extremes and projections of future changes. In: *Weather and Climate Extremes in a Changing Climate: Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands* [Karl, T.R., G.A. Meehl, C.D. Miller, S.J. Hassol, A.M. Waple, and W.L. Murray (eds.)]. Synthesis and Assessment Product 3.3. U.S. Climate Change Science Program, Washington, DC, pp. 81-116.

[69] Root, T.L., D.P. MacMynowski, M.D. Mastrandrea, and S.H. Schneider, 2005: Human-modified temperatures induce species changes: joint attribution. *Proceedings of the National Academy of Sciences*, **102(21)**, 7465-7469.

[70] Janetos, A., L. Hansen, D. Inouye, B.P. Kelly, L. Meyerson, B. Peterson, and R. Shaw, 2008: Biodiversity. In: *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States* [Backlund, P., A. Janetos, D. Schimel, J. Hatfield, K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, D. Wolfe, M.G. Ryan, S.R. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, W. Schlesinger, D. Lettenmaier, D. Major, L. Poff, S. Running, L. Hansen, D. Inouye, B.P. Kelly, L. Meyerson, B. Peterson, and R. Shaw (eds.)]. Synthesis and Assessment Product 4.3. U.S. Department of Agriculture, Washington, DC, pp. 151-181.

[71] CCSP, 2006: *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences* [Karl, T.R., S.J. Hassol, C.D. Miller, and W.L. Murray (eds.)]. Synthesis and Assessment Product 1.1. U.S. Climate Change Science Program, Washington, DC, 164 pp.

[72] Smith, T.M., R.W. Reynolds, T.C. Peterson, and J. Lawrimore, 2008: Improvements to NOAA's historical merged land–ocean surface temperature analysis (1880–2006). *Journal of Climate*, **21(10)**, 2283-2296.

[73] Haimberger, L., C. Tavolato, and S. Sperka, 2008: Toward elimination of the warm bias in historic radiosonde temperature records – some new results from a comprehensive intercomparison of upper air data. *Journal of Climate*, **21(18)**, 4587-4606.

[74] Sherwood, S.C., C.L. Meyer, R.J. Allen, and H.A. Titchner, 2008: Robust tropospheric warming revealed by iteratively homogenized radiosonde data. *Journal of Climate*, **21(20)**, 5336-5352.

[75] Titchner, H.A., P.W. Thorne, M.P. McCarthy, S.F.B. Tett, L. Haimberger, and D.E. Parker, 2008: Critically reassessing tropospheric temperature trends from radiosondes using realistic validation experiments. *Journal of Climate*, **22(3)**, 465-485.

[76] Delworth, T.L., P.U. Clark, M. Holland, W.E. Johns, T. Kuhlbrodt, J. Lynch-Stieglitz, C. Morrill, R. Seager, A.J. Weaver, and R. Zhang, 2008: The potential for abrupt change in the Atlantic Meridional Overturning Circulation. In: *Abrupt Climate Change*. Synthesis and Assessment Product 3.4. U.S. Geological Survey, Reston, VA, pp. 258-359.

[77] Wentz, F.J., L. Ricciardulli, K. Hilburn, and C. Mears, 2007: How much more rain will global warming bring? *Science*, **317(5835)**, 233-235.

[78] Stott, P.A., D.A. Stone, and M.R. Allen, 2004: Human contribution to the European heatwave of 2003. *Nature*, **432(7017)**, 610-614.

[79] CCSP, 2008: Introduction. In: *Climate Models: An Assessment of Strengths and Limitations* [Bader, D.C., C. Covey, W.J. Gutowski Jr., I.M. Held, K.E. Kunkel, R.L. Miller, R.T. Tokmakian, and M.H. Zhang (authors)]. Synthesis and Assessment Product 3.1 U.S. Department of Energy, Office of Biological and Environmental Research, Washington, DC, pp. 7-12.

[80] Randall, D.A., R.A. Wood, S. Bony, R. Coman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R.J. Stouffer, A. Sumi, and K.E. Taylor, 2007: Climate models and their evaluation. In: *Climate Change 2007: The Physical Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 589-662.

[81] Nakićenović, N. and R. Swart (eds.), 2000: *Special Report on Emissions Scenarios*. A special report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, 599 pp. <http://www.ipcc.ch/ipccreports/sres/emission/index.htm>

[82] Raupach, M.R., G. Marland, P. Ciais, C. Le Quéré, J.G. Canadell, G. Klepper, and C.B. Field, 2007: Global and regional drivers of accelerating CO_2 emissions. *Proceedings of the National Academy of Sciences*, **104(24)**, 10288-10293.

[83] O'Neill, B.C. and M. Oppenheimer, 2004: Climate change impacts are sensitive to the concentration stabilization path. *Proceedings of the National Academy of Sciences*, **101(47)**, 16411-16416.

[84] Schneider, S.H. and M.D. Mastrandrea, 2005: Probabilistic assessment of "dangerous" climate change and emissions pathways. *Proceedings of the National Academy of Sciences*, **102(44)**, 15728-15735.

[85] Lenton, T.M., H. Held, E. Kriegler, J.W. Hall, W. Lucht, S. Rahmstorf, and H.J. Schellnhuber, 2008: Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences*, **105(6)**, 1786-1793.

[86] Hansen, J., M. Sato, R. Ruedy, P. Kharecha, A. Lacis, R. Miller, L. Nazarenko, K. Lo, G.A. Schmidt, G. Russell, I. Aleinov, S. Bauer, E. Baum, B. Cairns, V. Canuto, M. Chandler, Y. Cheng, A. Cohen, A. Del Genio, G. Faluvegi, E. Fleming, A. Friend, T. Hall, C. Jackman, J. Jonas, M. Kelley, N.Y. Kiang, D. Koch, G. Labow, J. Lerner, S. Menon, T. Novakov, V. Oinas, Ja. Perlwitz, Ju. Perlwitz, D. Rind, A. Romanou, R. Schmunk, D. Shindell, P. Stone, S. Sun, D. Streets, N. Tausnev, D. Thresher, N. Unger, M. Yao, and S. Zhang, 2007: Dangerous human-made interference with climate: a GISS modelE study. *Atmospheric Chemistry and Physics*, **7(9)**, 2287-2312.

[87] Ramanathan, V. and Y. Feng, 2008: On avoiding dangerous anthropogenic interference with the climate system: formidable challenges ahead. *Proceedings of the National Academy of Sciences*, **105(38)**, 14245-14250.

[88] Meinshausen, M., 2006: What does a 2°C target mean for greenhouse gas concentrations? - A brief analysis based on multi-gas emission pathways and several climate sensitivity uncertainty estimates. In: *Avoiding Dangerous Climate Change* [Schellnhuber, J.S., W. Cramer, N. Nakićenović, T.M.L. Wigley, and G. Yohe (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 265-280.

[89] Meinshausen, M., B. Hare, T.M.L. Wigley, D. van Vuuren, M.G.J. den Elzen, and R. Swart, 2006: Multi-gas emission pathways to meet climate targets. *Climatic Change*, **75(1)**, 151-194.

[90] Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver, and Z.-C. Zhao, 2007: Global climate projections. In: *Climate Change 2007: The Physical Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 747-845.

[91] Refer to the description of the emissions scenarios in the *Global Climate Change* section on pages 22-25. "Lower emissions scenario" refers to IPCC SRES B1, "higher emissions scenario" refers to A2 and "even higher emissions scenario" refers to A1FI.

[92] IPCC Emissions Scenarios (Even Higher, Higher Emission Scenario, Lower Emission Scenario): Nakićenović, N. and R. Swart (eds.), 2000: Appendix VII: Data tables. In: *Special Report on Emissions Scenarios*. A special report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York. <http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission/> Emission trajectories are spline fits as per Raupach, M.R., G. Marland, P. Ciais, C. Le Quéré, J.G. Canadell, G. Klepper, and C.B. Field, 2007: Global and regional drivers of accelerating CO_2 emissions. *Proceedings of the National Academy of Sciences*, **104(24)**, 10288-10293.

Stabilization scenario (450 ppm): CCSP 2.1a Scenario Information 070707 data file. From: Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, and R. Richels, 2007: *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations*. Sub-report 2.1A of Synthesis and Assessment Product 2.1. U.S. Department of Energy, Office of Biological & Environmental Research, Washington, DC. The emissions and concentrations shown were from MINICAM 1 and 2. See CCSP 2.1A Executive summary for more information. Spread sheet available at <http://www.climatescience.gov/Library/sap/sap2-1/finalreport/default.htm>

Observations of CO_2 emissions (Fossil Fuel CO_2 Emissions graphic) are updates to: Marland, G., B. Andres, T. Boden, 2008: *Global CO_2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2005*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN. <http://cdiac.ornl.gov/ftp/ndp030/global.1751_2005.ems>

Observations of CO_2 concentrations (Atmospheric CO_2 Concentrations graphic): Tans, P., 2008: *Trends in Atmospheric Carbon Dioxide: Mauna Loa*. NOAA Earth System Research Laboratory (ESRL). [Web site] <http://www.esrl.noaa.gov/gmd/ccgg/trends/> Data available at <ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_annmean_mlo.txt>

[93] CMIP3-A: This analysis uses 15 models simulations from the WCRP CMIP3 that were available at resolutions finer than 4 degrees (CCSM3.0, CSIRO, UKMO-HadCM3, IPSL, ECHAM5/MPI, CGCM3.1(T47), GFDL2.0, UKMO-HadGEM1, MIROC3.2(medres), MRI-CGCM2.3.2a, CNRM, GFDL2.1, INM-CM3, ECHO-G, PCM). See Wehner, M., 2005: Changes in daily precipitation and surface air temperature extremes in the IPCC AR4 models. *US CLIVAR Variations*, **3(3)**, 5-9.

Hatching indicates at least two out of three models agree on the sign of the projected change in precipitation.

We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset, <http://www-pcmdi.llnl.gov/projects/cmip/index.php>. Support of this dataset is provided by the Office of Science, U.S. Department of Energy. For an overview and documentation of the CMIP3 modelling activity, see Meehl, G.A., C. Covey, T. Delworth, M. Latif, B. McAvaney, J.F.B. Mitchell, R.J. Stouffer, and K.E. Taylor, 2007: The WCRP CMIP3 multi-model dataset: a new era in climate change research. *Bulletin of the American Meteorological Society*, **88(9)**, 1383-1394.

[94] Hare, B. and M. Meinshausen, 2006: How much warming are we committed to and how much can be avoided? *Climatic Change*, **75(1)**, 111-149.

[95] den Elzen, M.G.J. and M. Meinshausen, 2006: Multi-gas emission pathways for meeting the EU 2°C climate target. In: *Avoiding Dangerous Climate Change* [Schellnhuber, J.S., W. Cramer, N. Nakićenović, T.M.L. Wigley and G. Yohe (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 299-310.

[96] Seidel, D.J., Q. Fu, W.J. Randel, and T.J. Reichler, 2008: Widening of the tropical belt in a changing climate. *Nature Geoscience*, **1(1)**, 21-24.

[97] Cook, E.R., P.J. Bartlein, N. Diffenbaugh, R. Seager, B.N. Shuman, R.S. Webb, J.W. Williams, and C. Woodhouse, 2008: Hydrological variability and change. In: *Abrupt Climate Change*. Synthesis and Assessment Product 3.4. U.S. Geological Survey, Reston, VA, pp. 143-257.

[98] Emanuel, K., 2005: Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, **436(7051)**, 686-688.

[99] Vecchi, G.A., K.L. Swanson, and B.J. Soden, 2008: Whither hurricane activity? *Science*, **322(5902)**, 687-689.

[100] Emanuel, K., R. Sundararajan, and J. Williams, 2008: Hurricanes and global warming: Results from downscaling IPCC AR4 simulations. *Bulletin of the American Meteorological Society*, **89(3)**, 347-367.

[101] Vecchi, G.A. and B.J. Soden, 2007: Effect of remote sea surface temperature change on tropical cyclone potential intensity. *Nature*, **450(7172)**, 1077-1070.

[102] Alley, R.B., P.U. Clark, P. Huybrechts, and I. Joughin, 2005: Ice-sheet and sea-level changes ice-sheet and sea-level changes. *Science*, **310(5747)**, 456-460.

[103] Rahmstorf, S., 2007: A semi-empirical approach to projecting future sea-level rise. *Science*, **315(5810)**, 368-370.

[104] Mitrovica, J.X., N. Gomez, and P.U. Clark, 2009: The sea-level fingerprint of West Antarctic collapse. *Science*, **323(5915)**, 753.

[105] Clark, P.U., A.J. Weaver, E. Brook, E.R. Cook, T.L. Delworth, and K. Steffen, 2008: Introduction: Abrupt changes in the Earth's climate system. In: *Abrupt Climate Change*. Synthesis and Assessment Product 3.4. U.S. Geological Survey, Reston, VA, pp. 19-59.

[106] Brook, E., D. Archer, E. Dlugokencky, S. Frolking, and D. Lawrence, 2008: Potential for abrupt changes in atmospheric methane. In: *Abrupt Climate Change*. Synthesis and Assessment Product 3.4. U.S. Geological Survey, Reston, VA, pp. 360-452.

[107] Temperatures for the contiguous U.S. are based on data from the U.S. Historical Climatology Network Version 2 (Menne *et al.* 2008). Temperatures for Alaska, Hawaii, and Puerto Rico are based on data from the Cooperative Observers Network adjusted to remove non-climatic influences such as changes in instruments and observer practices and changes in the station environment (Menne and Williams, 2008).

U.S. time series on page 27 is calculated with data for the contiguous US, Alaska, and Hawaii. US map on page 28 lower left includes observed temperature change in Puerto Rico. Winter temperature trend map in the agriculture section, page 76, is for the contiguous US only.

References for this endnote:

Menne, M.J., C.N. Williams, and R.S. Vose, 2009: The United States Historical Climatology Network Monthly Temperature Data - Version 2. *Bulletin of the American Meteorological Society*, Early online release, 25 February 2009, doi:10.1175/2008BAMS2613.1

Menne, M.J. and C.N. Williams Jr., 2008: Homogenization of temperature series via pairwise comparisons. *Journal of Climate*, **22(7)**, 1700-1717.

[108] Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr, and P. Whetton, 2007: Regional climate projections. In: *Climate Change 2007: The Physical Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 847-940.

[109] CMIP3-C: Analysis for the contiguous U.S. was based on methods described in: Hayhoe, K., D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, S.C. Moser, S.H. Schneider, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan, and J.H. Verville, 2004: Emission pathways, climate change, and impacts on California. *Proceedings of the National Academy of Sciences*, **101(34)**, 12422-12427; and Hayhoe, K., C. Wake, B. Anderson, X.-Z. Liang, E. Maurer, J. Zhu, J. Bradbury, A. DeGaetano, A.M. Stoner, and D. Wuebbles, 2008: Regional climate change projections for the Northeast USA. *Mitigation and Adaptation Strategies for Global Change*, **13(5-6)**, 425-436. This analysis uses 16 models simulations from the WCRP CMIP3. Where models had multiple runs, only the first run available from each model was used. See <http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html> for more information.

The Alaskan projections are based on 14 models that best captured the present climate of Alaska; see Walsh, J.E., W.L. Chaman, V. Romanovsky, J.H. Christensen, and M. Stendel, 2008: Global climate model performance over Alaska and Greenland. *Journal of Climate*, **21(23)**, 6156-6174.

Caribbean and Pacific islands analyses use 15 models simulations from the WCRP CMIP3 that were available at resolutions finer than 4 degrees (CCSM3.0, CSIRO, UKMO-HadCM3, IPSL, ECHAM5/MPI, CGCM3.1(T47), GFDL2.0, UKMO-HadGEMI, MIROC3.2(medres), MRI-CGCM2.3.2a, CNRM, GFDL2.1, INM-CM3, ECHO-G, PCM). See Wehner, M., 2005: Changes in daily precipitation and surface air temperature extremes in the IPCC AR4 models. *US CLIVAR Variations*, **3(3)**, 5-9.

We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset, <http://www-pcmdi.llnl.gov/projects/cmip/index.php>. Support of this dataset is provided by the Office of Science, U.S. Department of Energy. For an overview and documentation of the CMIP3 modelling activity, see Meehl, G.A., C. Covey, T. Delworth, M. Latif, B. McAvaney, J.F.B. Mitchell, R.J. Stouffer, and K.E. Taylor, 2007: The WCRP CMIP3 multi-model dataset: a new era in climate change research. *Bulletin of the American Meteorological Society*, **88(9)**, 1383-1394.

[110] Detailed local-scale projections about temperature and precipitation changes displayed in this report were generated using well-documented "statistical downscaling" techniques [Wood *et al.*, 2002] for the contiguous U.S. and Alaska. These techniques use statistical relationships between surface observations and climate simulations of the past to develop modifications for the global model results. These modifications are then applied to the climate projections for the future scenarios. The approach is also used to drive daily simulations by a well-established hydrological modeling framework for the contiguous U.S. [Liang *et al.*, 1994]. This method, which modifies global climate model simulations to better account for landscape variations and other features affecting climate at the regional to local scale, has been previously applied to generate high-resolution regional climate projections for the Northeast, Midwest, Northwest, and Southwest [Wood *et al.*, 2004; Hayhoe *et al.*, 2004; Hayhoe *et al.*, 2008; Cayan *et al.*, 2008; Cherkauer *et al.*, 2009]. Comparison of these methods with dynamically downscaled projections generated using regional climate model simulations provide strong justification for the use of such techniques [Wood *et al.*, 2004; Hayhoe *et al.*, 2008].

References for this endnote:

Cayan, D., E. Maurer, M. Dettinger, M. Tyree, and K. Hayhoe, 2008: Climate change scenarios for the California region. *Climatic Change*, **87(Supplement 1)**, S21-S42.

Cherkauer, K. and T. Sinha, 2009: Hydrologic impacts of projected future climate change in the Lake Michigan region. *Journal of Great Lakes Research*, in press.

Hayhoe, K., D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, S.C. Moser, S.H. Schneider, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan, and J.H. Verville, 2004: Emission pathways, climate change, and impacts on Cali-

fornia. *Proceedings of the National Academy of Sciences*, **101(34)**, 12422-12427.

Hayhoe, K., C. Wake, B. Anderson, X.-Z. Liang, E. Maurer, J. Zhu, J. Bradbury, A. DeGaetano, A.M. Stoner, and D. Wuebbles, 2008: Regional climate change projections for the Northeast USA. *Mitigation and Adaptation Strategies for Global Change*, **13(5-6)**, 425-436.

Liang, X., D. Lettenmaier, E. Wood, and S. Burges, 1994: A simple hydrologically-based model of land surface water and energy fluxes for general circulation models. *Journal of Geophysical Research*, **99(D7)**, 14415-14428.

Maurer, E.P., A.W. Wood, J.C. Adam, D.P. Lettenmaier, and B. Nijssen, 2002: A long-term hydrologically-based data set of land surface fluxes and states for the conterminous United States. *Journal of Climate*, **15(22)**, 3237-3251.

Wood, A.W., L.R. Leung, V. Sridhar, and D.P. Lettenmaier, 2004: Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs. *Climatic Change*, **62(1-3)**, 189-216.

Wood, A.W., E.P. Maurer, A. Kumar, and D.P. Lettenmaier, 2002: Long range experimental hydrologic forecasting for the eastern U.S. *Journal of Geophysical Research*, **107(D20)**, 4429, doi:10.1029/2001JD000659.

[111] NOAA's National Climatic Data Center, 2008: *The USHCN Version 2 Serial Monthly Dataset*. [Web site] <http://www.ncdc.noaa.gov/oa/climate/research/ushcn/>

[112] Kunkel, K.E., P.D. Bromirski, H.E. Brooks, T. Cavazos, A.V. Douglas, D.R. Easterling, K.A. Emanuel, P.Ya. Groisman, G.J. Holland, T.R. Knutson, J.P. Kossin, P.D. Komar, D.H. Levinson, and R.L. Smith, 2008: Observed changes in weather and climate extremes. In: *Weather and Climate Extremes in a Changing Climate: Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands* [Karl, T.R., G.A. Meehl, C.D. Miller, S.J. Hassol, A.M. Waple, and W.L. Murray (eds.)]. Synthesis and Assessment Product 3.3. U.S. Climate Change Science Program, Washington, DC, pp. 35-80.

[113] Groisman, P.Ya., R.W. Knight, T.R. Karl, D.R. Easterling, B. Sun, and J.H. Lawrimore, 2004: Contemporary changes of the hydrological cycle over the contiguous United States, trends derived from *in situ* observations. *Journal of Hydrometeorology*, **5(1)**, 64-85. The climate regions are different than those used in this article but the methodology is identical.

[114] Karl, T.R., G.A. Meehl, T.C. Peterson, K.E. Kunkel, W.J. Gutowski Jr., and D.R. Easterling, 2008: Executive summary. In: *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands* [Karl, T.R., G.A. Meehl, C.D. Miller, S.J. Hassol, A.M. Waple, and W.L. Murray (eds.)]. Synthesis and Assessment Product 3.3. U.S. Climate Change Science Program, Washington, DC, pp. 1-9.

[115] Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H.-P. Huang, N. Harnik, A. Leetmaa, N.-C. Lau, C. Li, J. Velez, and N. Naik, 2007: Model projections of an imminent transition to a more arid climate in southwestern North America. *Science*, **316(5828)**, 1181-1184.

[116] USGS, 2005: *Changes in Streamflow Timing in the Western United States in Recent Decades*. USGS fact sheet 2005-3018. U.S. Geological Survey, National Streamflow Information Program, La Jolla, CA, 4 pp. <http://pubs.usgs.gov/fs/2005/3018/>

[117] CMIP3-B: Analysis for the contiguous U.S. was based on methods described in: Hayhoe, K., D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, S.C. Moser, S.H. Schneider, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan, and J.H. Verville, 2004: Emission pathways, climate change, and impacts on California. *Proceedings of the National Academy of Sciences*, **101(34)**, 12422-12427; and Hayhoe, K., C. Wake, B. Anderson, X.-Z. Liang, E. Maurer, J. Zhu, J. Bradbury, A. DeGaetano, A.M. Stoner, and D. Wuebbles, 2008: Regional climate change projections for the Northeast USA. *Mitigation and Adaptation Strategies for Global Change*, **13(5-6)**, 425-436. This analysis uses 16 models simulations from the WCRP CMIP3. Where models had multiple runs, only the first run available from each model was used. See <http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html> for more information.

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[118] Swanson, K.L., 2008: Nonlocality of Atlantic tropical cyclone intensities. *Geochemistry, Geophysics, Geosystems*, **9**, Q04V01, doi:10.1029/2007GC001844.

[119] Knutson, T.R., J.J. Sirutis, S.T. Garner, G.A. Vecchi, and I. Held, 2008: Simulated reduction in Atlantic hurricane frequency under twenty-first-century warming conditions. *Nature Geoscience*, **1(6)**, 359-364.

[120] Emanuel, K., 2007: Environmental factors affecting tropical cyclone power dissipation. *Journal of Climate*, **20(22)**, 5497-5509.

[121] Number of strongest hurricanes, number of landfalling strongest hurricanes, and number of landfalling hurricanes are based on data obtained from NOAA's Oceanographic and Meteorological Laboratory: <http://www.aoml.noaa.gov/hrd/hurdat/ushurrlist18512005-gt.txt> with updates. The total number of named storms are adjusted to account for missing tropical storms and hurricanes in the pre-satellite era using the method of Vecchi and Knutson (2008). Basin and landfalling totals are displayed in 5-year increments (pentads) from 1881 through 2010. The final 5-year period was standardized to a comparable 5-year period assuming the level of activity from 2006 to 2008 persists through 2010.

Vecchi, G.A. and T.R. Knutson, 2008: On estimates of historical North Atlantic tropical cyclone activity. *Journal of Climate*, **21(14)**, 3580-3600.

[122] Elsner, J.B., J.P. Kossin, and T.H. Jagger, 2008: The increasing intensity of the strongest tropical cyclones. *Nature*, **455(7209)**, 92-95.

[123] Bell, G.D. and M. Chelliah, 2006: Leading tropical modes associated with interannual and multidecadal fluctuations in North Atlantic hurricane activity. *Journal of Climate*, **19(4)**, 590-612.

[124] Levinson, D.H. and J. Lawrimore (eds.), 2008: State of the climate in 2007. *Bulletin of the American Meteorological Society*, **89(7, Supplement)**, S1-S179.

[125] Kossin, J.P., K.R. Knapp, D.J. Vimont, R.J. Murnane, and B.A. Harper, 2007: A globally consistent reanalysis of hurricane variability and trends. *Geophysical Research Letters*, **34**, L04815, doi:10.1029/2006GL028836.

[126] Rahmstorf, S., A. Cazenave, J.A. Church, J.E. Hansen, R.F. Keeling, D.E. Parker, and R.C.J. Somerville, 2007: Recent climate observations compared to projections. *Science*, **316(5825)**, 709.

[127] Zervas, C., 2001: *Sea Level Variations of the United States 1955-1999*. NOAA technical report NOS CO-OPS 36. National Oceanic and Atmospheric Administration, Silver Spring, MD, 66 pp.

<http://tidesandcurrents.noaa.gov/publications/techrpt36doc.pdf> Trends were calculated for locations that had at least 10 months of data per year and at least 41 years of data during the 51-year period.

[128] Sea-level rise numbers are calculated based on an extrapolation of NOAA tide gauge stations with records exceeding 50 years, as reported in Zervas, C., 2001: *Sea Level Variations of the United States 1985-1999*. NOAA technical report NOS CO-OPS 36. National Oceanic and Atmospheric Administration, Silver Spring, MD, 66 pp. <http://tidesandcurrents.noaa.gov/publications/techrpt36doc.pdf>

[129] Kunkel, K.E., N.E. Westcott, and D.A.R. Kristovich, 2002: Assessment of potential effects of climate changes on heavy lake-effect snowstorms near Lake Erie. *Journal of Great Lakes Research*, **28(4)**, 521-536.

[130] Burnett, A.W., M.E. Kirby, H.T. Mullins, and W.P. Patterson, 2003: Increasing Great Lake-effect snowfall during the twentieth century: a regional response to global warming? *Journal of Climate*, **16(21)**, 3535-3542.

[131] Trapp, R.J., N.S. Diffenbaugh, H.E. Brooks, M.E. Baldwin, E.D. Robinson, and J.S. Pal, 2007: Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing. *Proceedings of the National Academy of Sciences*, **104(50)**, 19719-19723.

[132] ACIA, 2005: *Arctic Climate Impact Assessment*. Cambridge University Press, Cambridge, UK, and New York, 1042 pp. <http://www.acia.uaf.edu/pages/scientific.html>

[133] Stroeve, J., M.M. Holland, W. Meier, T. Scambos, and M. Serreze, 2007: Arctic sea ice decline: faster than forecast. *Geophysical Research Letters*, **34**, L09501, doi:10.1029/2007GL029703.

[134] L'Heureux, M.L., A. Kumar, G.D. Bell, M.S. Halpert, and R.W. Higgins, 2008: Role of the Pacific-North American (PNA) pattern in the 2007 Arctic sea ice decline. *Geophysical Research Letters*, **35**, L20701, doi:10.1029/2008GL035205.

[135] Johannessen, O.M., 2008: Decreasing Arctic sea ice mirrors increasing CO_2 on decadal time scale. *Atmospheric and Oceanic Science Letters*, **1(1)**, 51-56.

[136] National Snow and Ice Data Center, 2008: *Arctic Sea Ice Down to Second-Lowest Extent; Likely Record-Low Volume*. Press release October 2, 2008. <http://nsidc.org/news/press/20081002_seaice_pressrelease.html>

[137] Polyak, L., J. Andrews, J. Brigham-Grette, D. Darby, A. Dyke, S. Funder, M. Holland, A. Jennings, J. Savelle, M. Serreze, and E. Wolff, 2009: History of sea ice in the Arctic. In: *Past Climate Variability and Change in the Arctic and at High Latitude*. Synthesis and Assessment Product 1.2. U.S. Geological Survey, Reston, VA, pp. 358-420.

[138] Images from *Sea Ice Yearly Minimum 1979-2007*. [Web site] NASA/Goddard Space Flight Center Scientific Visualization Studio. Thanks to Rob Gerston (GSFC) for providing the data. <http://svs.gsfc.nasa.gov/goto?3464>

[139] Fetterer, F., K. Knowles, W. Meier, and M. Savoie, 2002: updated 2008: *Sea Ice Index*. [Web site] National Snow and Ice Data Center, Boulder, CO. <http://nsidc.org/data/seaice_index/>

[140] Pacala, S., R. Birdsey, S. Bridgham, R.T. Conant, K. Davis, B. Hales, R. Houghton, J.C. Jenkins, M. Johnston, G. Marland, and K. Paustian, 2007: The North American carbon budget past and present. In: *The First State of the Carbon Cycle Report (SOCCR): The North American Carbon Budget and Implications for the Global Carbon Cycle* [King, A.W., L. Dilling, G.P. Zimmerman, D.F. Fairman, R.A. Houghton, G. Marland, A.Z. Rose, and T.J. Wilbanks (eds.)]. Synthesis and Assessment Product 2.2. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, pp. 29-36.

[141] Marland, G., R.J. Andres, T.J. Blasing, T.A. Boden, C.T. Broniak, J.S. Gregg, L.M. Losey, and K. Treanton, 2007: Energy, industry, and waste management activities: an introduction to CO_2 emissions from fossil fuels. In: *The First State of the Carbon Cycle Report (SOCCR): The North American Carbon Budget and Implications for the Global Carbon Cycle* [King, A.W., L. Dilling, G.P. Zimmerman, D.M. Fairman, R.A. Houghton, G. Marland, A.Z. Rose, and T.J. Wilbanks (eds.)]. Synthesis and Assessment Product 2.2. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, pp. 57-64.

[142] Bates, B.C., Z.W. Kundzewicz, S. Wu, and J.P. Palutikof (eds.), 2008: *Climate Change and Water*. Technical paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva, Switzerland, 210 pp.

[143] Feng, S. and Q. Hu, 2007: Changes in winter snowfall/precipitation ratio in the contiguous United States. *Journal of Geophysical Research*, **112**, D15109, doi:10.1029/2007JD008397.

[144] Guttman, N.B. and R.G. Quayle, 1996: A historical perspective of U.S. climate divisions. *Bulletin of the American Meteorological Society*, **77(2)**, 293-303. Operational practices described in this paper continue.

[145] Groisman, P.Ya., R.W. Knight, D.R. Easterling, T.R. Karl, G.C. Hegerl, and V.N. Razuvaev, 2005: Trends in intense precipitation in the climate record. *Journal of Climate*, **18(9)**, 1326-1350.

[146] Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jimenez, K.A. Miller, T. Oki, Z. Sen, and I.A. Shiklomanov, 2007: Freshwater resources and their management. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 173-210.

[147] Groisman, P.Ya. and R.W. Knight, 2008: Prolonged dry episodes over the conterminous United States: new tendencies emerging during the last 40 years. *Journal of Climate*, **21(9)**, 1850-1862.

[148] Tebaldi, C., K. Hayhoe, J.M. Arblaster, and G.A. Meehl, 2006: Going to the extremes: an intercomparison of model-simulated historical and future changes in extreme events. *Climatic Change*, **79(3-4)**, 185-211.

[149] Lettenmaier, D., D. Major, L. Poff, and S. Running, 2008: Water resources. In: *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States* [Backlund, P., A. Janetos, D. Schimel, J. Hatfield, K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, D. Wolfe, M.G. Ryan, S.R. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, W. Schlesinger, D. Lettenmaier, D. Major, L. Poff, S. Running, L. Hansen, D. Inouye, B.P. Kelly, L. Meyerson, B. Peterson, and R. Shaw (eds.)]. Synthesis and Assessment Product 4.3. U.S. Department of Agriculture, Washington, DC, pp. 121-150.

[150] Hayhoe, K., C.P. Wake, T.G. Huntington, L. Luo, M.D. Schwartz, J. Sheffield, E. Wood, B. Anderson, J. Bradbury, A. DeGaetano, T.J. Troy, and D. Wolfe, 2007: Past and future changes in climate and hydrological indicators in the U.S. Northeast. *Climate Dynamics*, **28(4)**, 381-407.

[151] Milly, P.C.D., J. Betancourt, M. Falkenmark, R.M. Hirsch, Z.W. Kundzewicz, D.P. Lettenmaier, and R.J. Stouffer, 2008: Stationarity is dead: Whither water management? *Science*, **319(5863)**, 573-574.

[152] Christensen, N.S., A.W. Wood, N. Voisin, D.P. Lettenmaier, and R.N. Palmer, 2004: The effects of climate change on the hydrology

and water resources of the Colorado River basin. *Climatic Change*, **62(1-3)**, 337-363.

[153] Mote, P., A. Hamlet, and E. Salathé, 2008: Has spring snowpack declined in the Washington Cascades? *Hydrology and Earth System Sciences*, **12(1)**, 193-206.

[154] Knowles, N., M.D. Dettinger, and D.R. Cayan, 2006: Trends in snowfall versus rainfall in the western United States. *Journal of Climate*, **19(18)**, 4545-4559.

[155] Huntington T.G., G.A. Hodgkins, B.D. Keim, and R.W. Dudley, 2004: Changes in the proportion of precipitation occurring as snow in New England (1949 to 2000). *Journal of Climate*, **17(13)**, 2626-2636.

[156] Burakowski, E.A., C.P. Wake, B. Braswell, and D.P. Brown, 2008: Trends in wintertime climate in the northeastern United States: 1965–2005. *Journal of Geophysical Research*, **113**, D20114, doi:10.1029/2008JD009870/

[157] Stewart, I.T., D.R. Cayan, and M.D. Dettinger, 2004: Changes in snowmelt runoff timing in western North America under a 'business as usual' climate change scenario. *Climatic Change*, **62(1-3)**, 217-232.

[158] Stewart, I.T., D.R. Cayan, and M.D. Dettinger, 2005: Changes toward earlier streamflow timing across western North America. *Journal of Climate*, **18(8)**, 1136-1155.

[159] Rauscher, S.A., J.S. Pal, N.S. Diffenbaugh, and M.M. Benedetti, 2008: Future changes in snowmelt-driven runoff timing over the western United States. *Geophysical Research Letters*, **35**, L16703, doi:10.1029/2008GL034424.

[160] Pierce, D.W., T.P. Barnett, H.G. Hidalgo, T. Das, C. Bonfils, B.D. Santer, G. Bala, M.D. Dettinger, D.R. Cayan, A. Mirin, A.W. Wood, and T. Nozawa, 2008: Attribution of declining western U.S. snowpack to human effects. *Journal of Climate*, **21(23)**, 6425-6444.

[161] Bonfils, C., B.D. Santer, D.W. Pierce, H.G. Hidalgo, G. Bala, T. Das, T.P. Barnett, D.R. Cayan, C. Doutriaux, A.W. Wood, A. Mirin, and T. Nozawa, 2008: Detection and attribution of temperature changes in the mountainous western United States. *Journal of Climate*, **21(23)**, 6404-6424.

[162] U.S. Environmental Protection Agency, 2008: *National Water Program Strategy: Response to Climate Change*. U.S. Environmental Protection Agency, Washington, DC, 97 pp. <http://www.epa.gov/water/climatechange/>

[163] Ebi, K.L., J. Balbus, P.L. Kinney, E. Lipp, D. Mills, M.S. O'Neill, and M. Wilson, 2008: Effects of global change on human health. In: *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems* [Gamble, J.L. (ed.), K.L. Ebi, F.G. Sussman, and T.J. Wilbanks (authors)]. Synthesis and Assessment Product 4.6. U.S. Environmental Protection Agency, Washington, DC, pp. 39-87.

[164] Field, C.B., L.D. Mortsch, M. Brklacich, D.L. Forbes, P. Kovacs, J.A. Patz, S.W. Running, and M.J. Scott, 2007: North America. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 617-652.

[165] Winter, J., J.W. Harvey, O.L. Franke, and W.M. Alley, 1998: *Ground Water and Surface Water: A Single Resource*. USGS circular 1139. U.S. Geological Survey, Denver, CO, 79 pp. <http://pubs.usgs.gov/circ/circ1139/>

[166] Austin, J.A. and S.M. Colman, 2007: Lake Superior summer water temperatures are increasing more rapidly than regional air temperatures: a positive ice-albedo feedback. *Geophysical Research Letters*, **34**, L06604, doi:10.1029/2006GL029021.

[167] U.S. General Accounting Office, 2003: *Freshwater Supply: States' Views of How Federal Agencies Could Help Them Meet the Challenges of Expected Shortages*. GAO-03-514. General Accounting Office, Washington, DC, 110 pp. <http://www.gao.gov/new.items/d03514.pdf>

[168] U.S. Environmental Protection Agency, 2002: *The Clean Water and Drinking Water Infrastructure Gap Analysis*. EPA-816-R-02-020. U.S. Environmental Protection Agency, Washington, DC, 50 pp. <http://www.epa.gov/safewater/gapreport.pdf>

[169] National Research Council, 2004: *Confronting the Nation's Water Problems: The Role of Research*. National Academies Press, Washington, DC, 310 pp.

[170] Yohe, G.W., R.D. Lasco, Q.K. Ahmad, N.W. Arnell, S.J. Cohen, C. Hope, A.C. Janetos, and R.T. Perez, 2007: Perspectives on climate change and sustainability. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 811-841.

[171] U.S. Bureau of Reclamation, 2005: *Water 2025: Preventing Crises and Conflict in the West*. U.S. Bureau of Reclamation, Washington, DC, 32 pp. Updated from USBR <http://www.usbr.gov/uc/crsp/GetSiteInfo>

[172] Wilbanks, T.J., P. Romero Lankao, M. Bao, F. Berkhout, S. Cairncross, J.-P. Ceron, M. Kapshe, R. Muir-Wood, and R. Zapata-Marti, 2007: Industry, settlement and society. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 357-390.

[173] Adger, W.N., S. Agrawala, M.M.Q. Mirza, C. Conde, K. O'Brien, J. Pulhin, R. Pulwarty, B. Smit, and K. Takahashi, 2007: Assessment of adaptation practices, options, constraints and capacity. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 717-743.

[174] Hartmann, H.C., 2008: Decision support for water resources management. In: *Uses and Limitations of Observations, Data, Forecasts and Other Projections in Decision Support for Selected Sectors and Regions*. Synthesis and Assessment Product 5.1. U.S. Climate Change Science Program, Washington, DC, pp. 45-55.

[175] Ruhl, J.B., 2005: Water wars, eastern style: divvying up the Apalachicola-Chattahoochee-Flint River Basin. *Journal of Contemporary Water Research & Education*, **131**, 47-54.

[176] Leitman, S., 2008: Lessons learned from transboundary management efforts in the Apalachicola-Chattahoochee-Flint Basin, USA. In: *Transboundary Water Resources: A Foundation for Regional Stability in Central Asia* [Moerlins, J.E., M.K. Khankhasayev, S.F. Leitman, and E.J. Makhmudov (eds.)]. Springer, Dordrecht and London, pp. 195-208.

[177] Gobalet, K., P. Schulz, T. Wake, and N. Siefkin, 2004: Archaeological perspectives on Native American fisheries of California, with emphasis on steelhead and salmon. *Transactions of the American Fisheries Society*, **133(4)**, 801-833.

[178] Hammersmark, C., W. Fleenor, and S. Schladow, 2005: Simulation of flood impact and habitat extent for a tidal freshwater marsh restoration. *Ecological Engineering*, **25(2)**, 137-152.

[179] Kondolf, G., P. Angermeier, K. Cummins, T. Dunne, M. Healey, W. Kimmerer, P. Moyle, D. Murphy, D. Patten, S. Railsback, D. Reed, R. Spies, and R. Twiss, 2008: Projecting cumulative benefits of multiple river restoration projects: An example from the Sacramento-San Joaquin River system in California. *Environmental Management*, **42(6)**, 933-945.

[180] McKee, L., N. Ganju, and D. Schoellhamer, 2006: Estimates of suspended sediment entering San Francisco Bay from the Sacramento and San Joaquin Delta, San Francisco Bay, California. *Journal of Hydrology*, **323(1-4)**, 335-352.

[181] Trenham, P., H. Shaffer, and P. Moyle, 1998: Biochemical identification and assessment of population subdivision in morphologically similar native and invading smelt species (*Hypomesus*) in the Sacramento San Joaquin estuary, California. *Transactions of the American Fisheries Society*, **127(3)**, 417-424.

[182] Vengosh, A., J. Gill, M. Davisson, and G. Hudson, 2002: A multi-isotope (B, Sr, O, H, and C) and age dating (^{3}H-^{3}He and ^{14}C) study of groundwater from Salinas Valley, California: hydrochemistry, dynamics, and contamination processes. *Water Resources Research*, **38(1)**, 1008, doi:10.1029/2001WR000517.

[183] Haggerty, G.M., D. Tave, R. Schmidt-Petersen, and J. Stomp, 2008: Raising endangered fish in New Mexico. *Southwest Hydrology*, **7(4)**, 20-21.

[184] National Research Council, 2004: *Endangered and Threatened Fishes in the Klamath River Basin: Causes of Decline and Strategies for Recovery*. National Academies Press, Washington, DC, 398 pp.

[185] National Research Council, 2008: *Hydrology, Ecology, and Fishes of the Klamath River Basin*. National Academies Press, Washington, DC, 272 pp.

[186] National Research Council, 2007: *Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability*. National Academies Press, Washington, DC, 218 pp.

[187] U.S. Bureau of Reclamation, 2007: *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead: Final Environmental Impact Statement*. [U.S. Bureau of Reclamation, Boulder City, NV], 4 volumes. <http://www.usbr.gov/lc/region/programs/strategies/FEIS/index.html>

[188] University of Arizona, Undated: *Native American Water Rights in Arizona*. [Web site] <http://www.library.arizona.edu/about/libraries/govdocs/waterdoc.html>

[189] Cook, E.R., C.A. Woodhouse, C.M. Eakin, D.M. Meko, and D.W. Stahle, 2004: Long-term aridity changes in the western United States. *Science*, **306(5698)**, 1015-1018.

[190] Ingram, H., D. Feldman, N. Mantua, K.L. Jacobs, D. Fort, N. Beller-Simms, and A.M. Waple, 2008: The changing context. In: *Decision-Support Experiments and Evaluations Using Seasonal-to-Interannual Forecasts and Observational Data: A Focus on Water Resources* [Beller-Simms, N., H. Ingram, D. Feldman, N. Mantua, K.L. Jacobs, and A.M. Waple (eds.)]. Synthesis and Assessment Product 5.3. NOAA's National Climatic Data Center, Asheville, NC, pp. 7-28.

[191] Bull, S.R., D.E. Bilello, J. Ekmann, M.J. Sale, and D.K. Schmalzer, 2007: Effects of climate change on energy production and distribution in the United States. In: *Effects of Climate Change on Energy Production and Use in the United States* [Wilbanks, T.J., V. Bhatt, D.E. Bilello, S.R. Bull, J. Ekmann, W.C. Horak, Y.J. Huang, M.D. Levine, M.J. Sale, D.K. Schmalzer, and M.J. Scott (eds.)]. Synthesis and Assessment Product 4.5. U.S. Climate Change Science Program, Washington, DC, pp. 45-80.

[192] Hyman, R.C., J.R. Potter, M.J. Savonis, V.R. Burkett, and J.E. Tump, 2008: Why study climate change impacts on transportation? In: *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I* [Savonis, M.J., V.R. Burkett, and J.R. Potter (eds.)]. Synthesis and Assessment Product 4.7. U.S. Department of Transportation, Washington, DC, pp. 1-1 to 1F-2 [48 pp.]

[193] Hatfield, J., K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, and D. Wolfe, 2008: Agriculture. In: *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States* [Backlund, P., A. Janetos, D. Schimel, J. Hatfield, K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, D. Wolfe, M.G. Ryan, S.R. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, W. Schlesinger, D. Lettenmaier, D. Major, L. Poff, S. Running, L. Hansen, D. Inouye, B.P. Kelly, L. Meyerson, B. Peterson, and R. Shaw (eds.)]. Synthesis and Assessment Product 4.3. U.S. Department of Agriculture, Washington, DC, pp. 21-74.

[194] Feldman, D.L., K.L. Jacobs, G. Garfin, A. Georgakakos, B. Morehouse, P. Restrepo, R. Webb, B. Yarnal, D. Basketfield, H.C. Hartmann, J. Kochendorfer, C. Rosenzweig, M. Sale, B. Udall, and C. Woodhouse, 2008: Making decision-support information useful, useable, and responsive to decision-maker needs. In: *Decision-Support Experiments and Evaluations Using Seasonal-to-Interannual Forecasts and Observational Data: A Focus on Water Resources* [Beller-Simms, N., H. Ingram, D. Feldman, N. Mantua, K.L. Jacobs, and A.M. Waple (eds.)]. Synthesis and Assessment Product 5.3. NOAA's National Climatic Data Center, Asheville, NC, pp. 101-140.

[195] McCabe, G.J. and D.M. Wolock, 2007: Warming may create substantial water supply shortages in the Colorado River basin. *Geophysical Research Letters*, **34**, L22708, doi:10.1029/2007GL031764.

[196] Brekke, L., B. Harding, T. Piechota, B. Udall, C. Woodhouse, and D. Yates (eds.), 2007: Appendix U: Climate Technical Work Group Report: Review of science and methods for incorporating climate change information into Bureau of Reclamation's Colorado River Basin planning studies. In: *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead: Final Environmental Impact Statement*. U.S. Bureau of Reclamation, Boulder City, NV, 110 pp. <http://www.usbr.gov/lc/region/programs/strategies/FEIS/index.html>

[197] U.S. Department of Energy, 2006: *Energy Demands on Water Resources. Report to Congress on the Interdependency of Energy and Water*. Sandia National Laboratories, Albuquerque, NM, 80 pp. <http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf>

[198] California Energy Commission, 2005: *California's Water – Energy Relationship*. CEC-700-2005-011-SF. California Energy Commission, [Sacramento], 174 pp. <http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF>

[199] California Energy Commission, 2006: *Refining Estimates of Water-related Energy Use in California*. CEC-500-2006-118. California Energy Commission, [Sacramento]. <http://www.energy.ca.gov/2006publications/CEC-500-2006-118/CEC-500-2006-118.PDF>

[200] U.S. Energy Information Administration, 2008: *Energy in Brief: What are Greenhouse Gases and How Much are Emitted by the United States?* [Web site] Energy Information Administration, Washington, DC. <http://tonto.eia.doe.gov/energy_in_brief/greenhouse_gas.cfm>

[201] Wilbanks, T.J., *et al.*, 2007: Executive summary. In: *Effects of Climate Change on Energy Production and Use in the United States* [Wilbanks, T.J., V. Bhatt, D.E. Bilello, S.R. Bull, J. Ekmann, W.C. Horak, Y.J. Huang, M.D. Levine, M.J. Sale, D.K. Schmalzer,

and M.J. Scott (eds.)]. Synthesis and Assessment Product 4.5. U.S. Climate Change Science Program, Washington, DC, pp. x-xii.

[202] From *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*, U.S. EPA. Allocations from "Electricity & Heat" and "Industry" to end uses are WRI estimates based on energy use data from the International Energy Agency (IEA, 2005). All data is for 2003. All calculations are based on CO_2 equivalents, using 100-year global warming potentials from the IPCC (1996).

[203] U.S. Energy Information Administration, 2008: *Annual Energy Review 2007*. U.S. Department of Energy, Washington, DC, 400 pp. <http://www.eia.doe.gov/emeu/aer/pdf/aer.pdf>

[204] Bhatt, V., J. Eckmann, W.C. Horak, and T.J. Wilbanks, 2007: Possible indirect effects on energy production and distribution in the United States. In: *Effects of Climate Change on Energy Production and Use in the United States* [Wilbanks, T.J., V. Bhatt, D.E. Bilello, S.R. Bull, J. Ekmann, W.C. Horak, Y.J. Huang, M.D. Levine, M.J. Sale, D.K. Schmalzer, and M.J. Scott (eds.)]. Synthesis and Assessment Product 4.5. U.S. Climate Change Science Program, Washington, DC, pp. 81-97.

[205] Scott, M.J. and Y.J. Huang, 2007: Effects of climate change on energy use in the United States. In: *Effects of Climate Change on Energy Production and Use in the United States* [Wilbanks, T.J., V. Bhatt, D.E. Bilello, S.R. Bull, J. Ekmann, W.C. Horak, Y.J. Huang, M.D. Levine, M.J. Sale, D.K. Schmalzer, and M.J. Scott (eds.)]. Synthesis and Assessment Product 4.5. U.S. Climate Change Science Program, Washington, DC, pp. 8-44.

[206] U.S. Department of Energy, 2008: *Buildings Energy Data Book*. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, [Washington, DC]. <http://buildingsdatabook.eere.energy.gov/>

[207] U.S. Census Bureau, 2002: *Population of States and Counties of the United States: 1790-2000*. U.S. Census Bureau, Washington, DC, 226 pp. <http://www.census.gov/population/www/censusdata/hiscendata.html> See <http://www.census.gov/popest/counties/> for 2008 estimates.

[208] Feldman, D.L., K.L. Jacobs, G. Garfin, A. Georgakakos, B. Morehouse, R. Webb, B. Yarnal, J. Kochendorfer, C. Rosenzweig, M. Sale, B. Udall, and C. Woodhouse, 2008: Decision-support experiments within the water resource management sector. In: *Decision-Support Experiments and Evaluations Using Seasonal-to-Interannual Forecasts and Observational Data: A Focus on Water Resources* [Beller-Simms, N., H. Ingram, D. Feldman, N. Mantua, K.L. Jacobs, and A.M. Waple (eds.)]. Synthesis and Assessment Product 5.3. NOAA's National Climatic Data Center, Asheville, NC, pp. 65-100.

[209] Hightower, M. and S.A. Pierce, 2008: The energy challenge. *Nature*, **452(7185)**, 285-286.

[210] Wilbanks, T.J., *et al.*, 2007: Conclusions and research priorities. In: *Effects of Climate Change on Energy Production and Use in the United States* [Wilbanks, T.J., V. Bhatt, D.E. Bilello, S.R. Bull, J. Ekmann, W.C. Horak, Y.J. Huang, M.D. Levine, M.J. Sale, D.K. Schmalzer, and M.J. Scott (eds.)]. Synthesis and Assessment Product 4.5. U.S. Climate Change Science Program, Washington, DC, pp. 98-108.

[211] Maulbetsch, J.S. and M.N. DiFilippo, 2006: *Cost and Value of Water Use at Combined Cycle Power Plants*. CEC-500-2006-034. California Energy Commission, PIER Energy-Related Environmental Research. <http://www.energy.ca.gov/2006publications/CEC-500-2006-034/CEC-500-2006-034.PDF>

[212] U.S. Energy Information Administration, 2002: *National Trends in Coal Transportation*. [Web site] Energy Information Administration, Washington, DC. <http://www.eia.doe.gov/cneaf/coal/ctrdb/natltrends.html>

[213] NOAA's National Climatic Data Center, 2008: *Climate of 2008: Midwestern U.S. Flood Overview*. [Web site] <http://www.ncdc.noaa.gov/oa/climate/research/2008/flood08.html>

[214] CBO Testimony, 2005: *Macroeconomic and Budgetary Effects of Hurricanes Katrina and Rita*. Statement of Douglas Holtz-Easkin, Director, before the Committee on the Budget, U.S. House of Representatives. Congressional Budget Office, Washington, DC, 21 pp. <http://www.cbo.gov/doc.cfm?index=6684>

[215] Potter, J.R., V.R. Burkett, and M.J. Savonis, 2008: Executive summary. In: *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I* [Savonis, M. J., V.R. Burkett, and J.R. Potter (eds.)]. Synthesis and Assessment Product 4.7. U.S. Department of Transportation, Washington, DC, pp. ES-1 to ES-10.

[216] U.S. Energy Information Administration, U.S. Department of Energy [data]; assembled by Evan Mills, Lawrence Berkeley National Laboratory. Data available at <http://www.eia.doe.gov/cneaf/electricity/page/disturb_events.html>

[217] Kafalenos, R.S., K.J. Leonard, D.M. Beagan, V.R. Burkett, B.D. Keim, A. Meyers, D.T. Hunt, R.C. Hyman, M.K. Maynard, B. Fritsche, R.H. Henk, E.J. Seymour, L.E. Olson, J.R. Potter, and M.J. Savonis, 2008: What are the implications of climate change and variability for Gulf coast transportation? In: *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I* [Savonis, M.J., V.R. Burkett, and J.R. Potter (eds.)]. Synthesis and Assessment Product 4.7. U.S. Department of Transportation, Washington, DC, pp. 4-1 to 4F-27 [104 pp.]

[218] U.S. Energy Information Administration, 2008: *Monthly Energy Review*. U.S. Department of Energy, Energy Information Administration, Washington, DC. <http://www.eia.doe.gov/emeu/mer/contents.html>

[219] National Assessment Synthesis Team (NAST), 2001: *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*. Cambridge University Press, Cambridge, UK, and New York, 612 pp. <http://www.usgcrp.gov/usgcrp/Library/nationalassessment/>

[220] ACIA, 2004: *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*. Cambridge University Press, Cambridge, UK, and New York, 139 pp. <http://www.acia.uaf.edu>

[221] U.S. Environmental Protection Agency, 2008: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006*. USEPA 430-R-08-005. U.S. Environmental Protection Agency, Washington, DC, 473 pp. <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>

[222] National Research Council, 2008: *Potential Impacts of Climate Change on U.S. Transportation*. Transportation Research Board special report 290. Transportation Research Board, Washington, DC, 280 pp. <http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf>

[223] Schimel, D., A. Janetos, P. Backlund, J. Hatfield, M.G. Ryan, S.R. Archer, and D. Lettenmaier, 2008: Synthesis. In: *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States* [Backlund, P., A. Janetos, D. Schimel, J. Hatfield, K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, D. Wolfe, M.G. Ryan, S.R. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, W. Schlesinger, D. Lettenmaier, D. Major, L. Poff, S. Running, L. Hansen, D. Inouye, B.P. Kelly, L. Meyerson, B. Peterson, and R. Shaw (eds.)]. Synthesis and Assessment Product 4.3. U.S. Department of Agriculture, Washington, DC, pp. 183-193.

[224] Burkett, V.R., R.C. Hyman, R. Hagelman, S.B. Hartley, M. Sheppard, T.W. Doyle, D.M. Beagan, A. Meyers, D.T. Hunt, M.K. Maynard, R.H. Henk, E.J. Seymour, L.E. Olson, J.R. Potter, and

N.N. Srinivasan, 2008: Why study the Gulf Coast? In: *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I* [Savonis, M.J., V.R. Burkett, and J.R. Potter (eds.)]. Synthesis and Assessment Product 4.7. U.S. Department of Transportation, Washington, DC, pp. 2-1 to 2F-26. [66 pp.]

[225] Peterson, T.C., M. McGuirk, T.G. Houston, A.H. Horvitz, and M.F. Wehner, 2008: *Climate Variability and Change with Implications for Transportation*. National Research Council, Washington, DC, 90 pp. <http://onlinepubs.trb.org/onlinepubs/sr/sr290Many.pdf>

[226] Hay, J.E., R. Warrick, C. Cheatham, T. Manarangi-Trott, J. Konno, and P. Hartley, 2005: *Climate Proofing: A Risk-based Approach to Adaptation*. Asian Development Bank, Manila, The Philippines, 191 pp. <http://www.adb.org/Documents/Reports/Climate-Proofing/default.asp>

[227] OSHA, 2008: Heat stress. In: *OSHA Technical Manual, Section III: Chapter 4*. Occupational Safety & Health Administration, Washington, DC. <http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_4.html>

[228] Landsea, C.W., 1993: A climatology of intense (or major) Atlantic hurricanes. *Monthly Weather Review*, **121(6)**, 1710-1713.

[229] NOAA's National Climatic Data Center, 2008: *Billion Dollar U.S. Weather Disasters* [Web site]. <http://www.ncdc.noaa.gov/oa/reports/billionz.html>

[230] Larsen, P.H., S. Goldsmith, O. Smith, M.L. Wilson, K. Strzepek, P. Chinowsky, and B. Saylor, 2008: Estimating future costs for Alaska public infrastructure at risk from climate change. *Global Environmental Change*, **18(3)**, 442-457.

[231] U.S. Environmental Protection Agency, 2008: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006*. USEPA 430-R-08-005. U.S. Environmental Protection Agency, Washington, DC, 473 pp. <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>

[232] National Agricultural Statistics Service, 2002: *2002 Census of Agriculture*. USDA National Agricultural Statistics Service, Washington, DC. <http://www.agcensus.usda.gov/Publications/2002/index.asp>

[233] Wolfe, W., L. Ziska, C. Petzoldt, A. Seaman, L. Chase, and K. Hayhoe, 2007: Projected change in climate thresholds in the northeastern U.S.: implications for crops, pests, livestock, and farmers. *Mitigation and Adaptation Strategies for Global Change*, **13(5-6)**, 555-575.

[234] Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles, 2007: *Confronting Climate Change in the U.S. Northeast: Science, Impacts and Solutions*. Synthesis report of the Northeast Climate Impacts Assessment. Union of Concerned Scientists, Cambridge, MA, 146 pp.

[235] Gu, L., P.J. Hanson, W.M. Post, D.P. Kaiser, B. Yang, R. Nemani, S.G. Pallardy, and T. Meyers, 2008: The 2007 eastern U.S. spring freeze: increased cold damage in a warming world? *BioScience*, **58(3)**, 253-262.

[236] Inouye, D.W., 2008: Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. *Ecology*, **89(2)**, 353-362.

[237] Either hydrogen dioxide or oxygenated hydrocarbons.

[238] Peet, M.M. and D.W. Wolf, 2000: Crop ecosystem responses to climate change: vegetable crops. In: *Climate Change and Global Crop Productivity* [Reddy, K.R. and H.F. Hodges (eds.)]. CABI Publishing, New York, and Wallingford, UK, 472 pp.

[239] Bridges, D.C. (ed.), 1992: *Crop Losses Due to Weeds in the United States*. Weed Science Society of America, Champaign, IL, 403 pp.

[240] Joyce, L.A., G.M. Blate, J.S. Littell, S.G. McNulty, C.I. Millar, S.C. Moser, R.P. Neilson, K. O'Halloran, and D.L. Peterson, 2008: National forests. In: *Preliminary Review of Adaptation Options for Climate-sensitive Ecosystems and Resources*. [Julius, S.H., J.M. West (eds.), J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (authors)]. Synthesis and Assessment Product 4.4. U.S. Environmental Protection Agency, Washington, DC, pp. 3-1 to 3-127.

[241] Kiely, T., D. Donaldson, and A. Grube, 2004: *Pesticides Industry Sales and Usage: 2000 and 2001 Market Estimates*. U.S. Environmental Protection Agency, Washington, DC, 33 pp. <http://www.epa.gov/oppbead1/pestsales/>

[242] Natural Resources Conservation Service, 1997: *1997 Five-Year Natural Resources Inventory*. USDA Natural Resources Conservation Service, Washington, DC. <http://www.nrcs.usda.gov/technical/NRI/1997/index.html>

[243] Ryan, M.G., S.R. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, and W. Schlesinger, 2008: Land resources. In: *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States* [Backlund, P., A. Janetos, D. Schimel, J. Hatfield, K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, D. Wolfe, M.G. Ryan, S.R. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, W. Schlesinger, D. Lettenmaier, D. Major, L. Poff, S. Running, L. Hansen, D. Inouye, B.P. Kelly, L. Meyerson, B. Peterson, and R. Shaw (eds.)]. Synthesis and Assessment Product 4.3. U.S. Department of Agriculture, Washington, DC, pp. 75-120.

[244] Parmesan, C., 1996: Climate and species range. *Nature*, **382(6594)**, 765-766.

[245] Hinzman, L.D., N.D. Bettez, W.R. Bolton, F.S. Chapin, M.B. Dyurgerov, C.L. Fastie, B. Griffith, R.D. Hollister, A. Hope, H.P. Huntington, A.M. Jensen, G.J. Jia, T. Jorgenson, D.L. Kane, D.R. Klein, G. Kofinas, A.H. Lynch, A.H. Lloyd, A.D. McGuire, F.E. Nelson, M. Nolan, W.C. Oechel, T.E. Osterkamp, C.H. Racine, V.E. Romanovsky, R.S. Stone, D.A. Stow, M. Sturm, C.E. Tweedie, G.L. Vourlitis, M.D. Walker, D.A. Walker, P.J. Webber, J.M. Welker, K.S. Winker, and K. Yoshikawa, 2005: Evidence and implications of recent climate change in northern Alaska and other Arctic regions. *Climatic Change*, **72(3)**, 251-298.

[246] Mimura, N., L. Nurse, R.F. McLean, J. Agard, L. Briguglio, P. Lefale, R. Payet, and G. Sem, 2007: Small islands. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 687-716.

[247] Millennium Ecosystem Assessment, 2005: *Ecosystems and Human Well-being: Biodiversity Synthesis*. World Resources Institute, Washington, DC, 86 pp. <http://www.millenniumassessment.org>

[248] Fischlin, A., G.F. Midgley, J.T. Price, R. Leemans, B. Gopal, C. Turley, M.D.A. Rounsevell, O.P. Dube, J. Tarazona, and A.A. Velichko, 2007: Ecosystems, their properties, goods, and services. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 211-272.

[249] National Interagency Fire Center, [2008]: *Total Wildland Fires and Acres (1960-2007)*. National Interagency Coordination Center, Boise, ID. Data at <http://www.nifc.gov/fire_info/fire_stats.htm>

[250] CCSP, 2009: Case studies. In: *Thresholds of Climate Change in Ecosystems* [Fagre, D.B., C.W. Charles, C.D. Allen, C. Birkeland, F.S. Chapin III, P.M. Groffman, G.R. Guntenspergen, A.K. Knapp,

A.D. McGuire, P.J. Mulholland, D.P.C. Peters, D.D. Roby, and G. Sugihara] Synthesis and Assessment Product 4.2. U.S. Geological Survey, Reston, VA, pp. 32-73.

[251] Pounds, J.A., M.R. Bustamante, L.A. Coloma, J.A. Consuegra, M.P. L. Fogden, P.N. Foster, E. La Marca, K.L. Masters, A. Merino-Viteri, R. Puschendorf, S.R. Ron, G.A. Sánchez-Azofeifa, C.J. Still, and B.E. Young, 2006: Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature*, **439(7073)**, 161-167.

[252] Peterson, T.C., D.M. Anderson, S.J. Cohen, M. Cortez-Vázquez, R.J. Murnane, C. Parmesan, D. Phillips, R.S. Pulwarty, and J.M.R. Stone, 2008: Why weather and climate extremes matter. In: *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands* [Karl, T.R., G.A. Meehl, C.D. Miller, S.J. Hassol, A.M. Waple, and W.L. Murray (eds.)]. Synthesis and Assessment Product 3.3. U.S. Climate Change Science Program, Washington, DC, pp. 11-34.

[253] Backlund, P., D. Schimel, A. Janetos, J. Hatfield, M.G. Ryan, S.R. Archer, and D. Lettenmaier, 2008: Introduction. In: *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States* [Backlund, P., A. Janetos, D. Schimel, J. Hatfield, K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, D. Wolfe, M.G. Ryan, S.R. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, W. Schlesinger, D. Lettenmaier, D. Major, L. Poff, S. Running, L. Hansen, D. Inouye, B.P. Kelly, L. Meyerson, B. Peterson, and R. Shaw (eds.)]. Synthesis and Assessment Product 4.3. U.S. Department of Agriculture, Washington, DC, pp. 11-20.

[254] Burkett, V.R., D.A. Wilcox, R. Stottlemeyer, W. Barrow, D. Fagre, J. Baron, J. Price, J.L. Nielsen, C.D. Allen, D.L. Peterson, G. Ruggerone, and T. Doyle, 2005: Nonlinear dynamics in ecosystem response to climatic change: case studies and policy implications. *Ecological Complexity*, **2(4)**, 357-394.

[255] Anderson, K.E., D.R. Cahoon, S.K. Gill, B.T. Gutierrez, E.R. Thieler, J.G. Titus, and S.J. Williams, 2009: Executive summary. In: *Coastal Elevations and Sensitivity to Sea-level Rise: A Focus on the Mid-Atlantic Region* [J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. Synthesis and Assessment Product 4.1. U.S. Environmental Protection Agency, Washington, DC, pp. 1-8.

[256] Park, R.A., M.S. Trehan, P.W. Mausel, and R.C. Howe, 1989: *The Effects of Sea Level Rise on U.S. Coastal Wetlands*. U.S. Environmental Protection Agency, Washington, DC, 55 pp.

[257] Gutierrez, B.T., S.J. Williams, and E.R. Thieler, 2009: Ocean coasts. In: *Coastal Elevations and Sensitivity to Sea-level Rise: A Focus on the Mid-Atlantic Region* [J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. Synthesis and Assessment Product 4.1. U.S. Environmental Protection Agency, Washington, DC, pp. 43-56.

[258] *Monaco Declaration*, 2009: Developed at the *Second International Symposium on the Ocean in a High-CO_2 World*, Monaco, 6-9 October 2008. <http://ioc3.unesco.org/oanet/Symposium2008/MonacoDeclaration.pdf>

[259] Feely, R.A., C.L. Sabine, J.M. Hernandez-Ayon, D. Ianson, and B. Hales, 2008: Evidence for upwelling of corrosive "acidified" water onto the continental shelf. *Science*, **320(5882)**, 1490-1492.

[260] Beckage, B., B. Osborne, D.G. Gavin, C. Pucko, T. Siccama, and T. Perkins, 2008: A rapid upward shift of a forest ecotone during 40 years of warming in the Green Mountains of Vermont. *Proceedings of the National Academy of Sciences*, **105(11)**, 4197-4202.

[261] Beever, E.A., P.F. Brussard, and J. Berger, 2003: Patterns of apparent extirpation among isolated populations of pikas (*Ochotona princeps*) in the Great Basin. *Journal of Mammology*, **84(1)**, 37-54.

[262] Krajick, K., 2004: All downhill from here? *Science*, **303(5664)**, 1600-1602.

[263] Battin, J., M.W. Wiley, M.H. Ruckelshaus, R.N. Palmer, E. Korb, K.K. Bartz, and H. Imaki, 2007: Projected impacts of climate change on salmon habitat restoration. *Proceedings of the National Academy of Sciences*, **104(16)**, 6720-6725.

[264] Williams, J.E., A.L. Haak, N.G. Gillespie, H.M. Neville, and W.T. Colyer, 2007: *Healing Troubled Waters: Preparing Trout and Salmon Habitat for a Changing Climate*. Trout Unlimited, Arlington, VA, 12 pp. <http://www.tu.org/climatechange>

[265] Daily, G.C., T. Soderqvist, S. Aniyar, K. Arrow, P. Dasgupta, P.R. Ehrlich, C. Folke, A. Jansson, B.O. Jansson, N. Kautsky, S. Levin, J. Lubchenco, K.G. Maler, D. Simpson, D. Starrett, D. Tilman, and B. Walker, 2000: Ecology - The value of nature and the nature of value. *Science*, **289(5478)**, 395-396.

[266] Hamilton, J.M. and R.S.J. Tol, 2004: The impact of climate change on tourism and recreation. In: *Human-Induced Climate Change - An Interdisciplinary Assessment* [Schlesinger, M., H.S. Kheshgi, J. Smith, F.C. de la Chesnaye, J.M. Reilly, T. Wilson, and C. Kolstad (eds.)]. Cambridge University Press, Cambridge (UK), pp. 147-155.

[267] Cordell, H.K., B. McDonald, R.J. Teasley, J.C. Bergstrom, J. Martin, J. Bason, and V.R. Leeworthy, 1999: Outdoor recreation participation trends. In: *Outdoor Recreation in American Life: A National Assessment of Demand and Supply Trends* [Cordell, H.K. and S.M. McKinney (eds.)]. Sagamore Publishing, Champaign, IL, pp. 219-321.

[268] Wall, G., 1998: Implications of global climate change for tourism and recreation in wetland areas. *Climatic Change*, **40(2)**, 371-389.

[269] Titus, J.G. and M. Craghan, 2009: Shore protection and retreat. In: *Coastal Elevations and Sensitivity to Sea-level Rise: A Focus on the Mid-Atlantic Region* [J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. Synthesis and Assessment Product 4.1. U.S. Environmental Protection Agency, Washington, DC, pp. 87-104.

[270] Peterson, C.H., R.T. Barber, K.L. Cottingham, H.K. Lotze, C.A. Simenstad, R.R. Christian, M.F. Piehler, and J. Wilson, 2008: National estuaries. In: *Preliminary Review of Adaptation Options for Climate-sensitive Ecosystems and Resources*. [Julius, S.H., J.M. West (eds.), J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (authors)]. Synthesis and Assessment Product 4.4. U.S. Environmental Protection Agency, Washington, DC, pp. 7-1 to 7-108.

[271] Titus, J.G. and J.E. Neumann, 2009: Implications for decisions. In: *Coastal Elevations and Sensitivity to Sea-level Rise: A Focus on the Mid-Atlantic Region* [J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. Synthesis and Assessment Product 4.1. U.S. Environmental Protection Agency, Washington, DC, pp. 141-156.

[272] Confalonieri, U., B. Menne, R. Akhtar, K.L. Ebi, M. Hauengue, R.S. Kovats, B. Revich, and A. Woodward, 2007: Human health. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 391-431.

[273] Borden, K.A. and S.L. Cutter, 2008: Spatial patterns of natural hazards mortality in the United States. *International Journal of Health Geographics*, **7:64**, doi:10.1186/1476-072X-7-64.

[274] Gamble, J.L., K.L. Ebi, A. Grambsch, F.G. Sussman, T.J. Wilbanks, C.E. Reid, K. Hayhoe, J.V. Thomas, and C.P. Weaver, 2008: Introduction. In: *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems* [Gamble, J.L. (ed.), K.L. Ebi, F.G. Sussman, and T.J. Wilbanks (authors)]. Synthesis and Assessment Product 4.6. U.S. Environmental Protection Agency, Washington, DC, pp. 13-37.

[275] Brikowski, T.H., Y. Lotan, and M.S. Pearle, 2008: Climate-related increase in the prevalence of urolithiasis in the United States. *Proceedings of the National Academy of Sciences*, **105(28)**, 9841-9846.

[276] Semenza, J.C., 1999: Acute renal failure during heat waves. *American Journal of Preventive Medicine*, **17(1)**, 97.

[277] Luber, G.E. and L.M Conklin, 2006: Heat-related deaths: United States, 1999–2003. *Morbidity and Mortality Weekly Report*, **55(29)**, 796-798.

[278] Zanobetti, A. and J. Schwartz, 2008: Temperature and mortality in nine US cities. *Epidemiology*, **19(4)**, 563-570.

[279] Davis, R.E., P.C. Knappenberger, P.J. Michaels, and W.M. Novicoff, 2003: Changing heat-related mortality in the United States. *Environmental Health Perspectives*, **111(14)**, 1712-1718.

[280] U.S. Energy Information Administration, 2005: Table HC10.6: Air conditioning characteristics by U.S. census region, 2005. In: *2005 Residential Energy Consumption Survey*. Data available at <http://www.eia.doe.gov/emeu/recs/recs2005/hc2005_tables/detailed_tables2005.html>

[281] U.S. Energy Information Administration, 2005: Table 2: Type of air-conditioning equipment by census region and survey year. In: *2005 Residential Energy Consumption Survey*. Data available at <http://www.eia.doe.gov/emeu/consumptionbriefs/recs/actrends/recs_ac_trends_table2.html>

[282] Sheridan, S.C., A.J. Kalkstein, and L.S. Kalkstein, 2008: Trends in heat-related mortality in the United States, 1975–2004. *Natural Hazards*, Online First™, doi:10.1007/s11069-008-9327-2.

[283] Hayhoe, K., K. Cherkauer, N. Schlegal, J. VanDorn, S. Vavrus, and D. Wuebbles, 2009: Regional climate change projections for Chicago and the Great Lakes. *Journal of Great Lakes Research*, in press.

[284] Hayhoe, K., D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, S.C. Moser, S.H. Schneider, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan, and J.H. Verville, 2004: Emissions pathways, climate change, and impacts on California. *Proceedings of the National Academy of Sciences*, **101(34)**, 12422-12427.

[285] Vavrus, S. and J. van Dorn, 2008: Projected future temrperature and precipitation extremes in Chicago. *Journal of Great Lakes Research*, in press.

[286] Lemmen, D.S. and F.J. Warren (eds.), 2004: *Climate Change Impacts and Adaptation: A Canadian Perspective*. Climate Change Impacts and Adaptation Program, Natural Resources Canada, Ottawa, ON, 174 pp. <http://adaptation.nrcan.gc.ca/perspective/pdf/report_e.pdf>

[287] Ebi, K.L., J. Smith, I. Burton, and J. Scheraga, 2006: Some lessons learned from public health on the process of adaptation. *Mitigation and Adaptation Strategies for Global Change*, **11(3)**, 607-620.

[288] Ebi, K.L., T.J. Teisberg, L.S. Kalkstein, L. Robinson, and R.F. Weiher, 2004: Heat watch/warning systems save lives: estimated costs and benefits for Philadelphia 1995-98. *Bulletin of the American Meteorological Society*, **85(8)**, 1067-1073.

[289] Medina-Ramon, M. and J. Schwartz, 2007: Temperature, temperature extremes, and mortality: a study of acclimatisation and effect modification in 50 U.S. cities. *Occupational and Environmental Medicine*, **64(12)**, 827-833.

[290] U.S. Environmental Protection Agency, 2008: *National Air Quality: Status and Trends through 2007*. U.S. EPA Air Quality Assessment Division, Research Triangle Park, NC, 48 pp. <http://www.epa.gov/airtrends/2008/index.html>

[291] Tao, Z., A. Williams, H.-C. Huang, M. Caughey, and X.-Z. Liang, 2007: Sensitivity of U.S. surface ozone to future emissions and climate changes. *Geophysical Research Letters*, **34**, L08811, doi:10.1029/2007GL029455.

[292] California Air Resources Board, 2007: *Recent Research Findings: Health Effects of Particulate Matter and Ozone Air Pollution*. [Online fact sheet] California Air Resources Board, [Sacramento], 7 pp. <http://www.arb.ca.gov/research/health/fs/pm_ozone-fs.pdf>

[293] California Climate Action Team, 2006: *Climate Action Team Report to Governor Schwarzenegger and the Legislature*. California Environmental Protection Agency, Sacramento, 107 pp. <http://www.climatechange.ca.gov/climate_action_team/reports/index.html>

[294] Westerling A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam, 2006: Warming and earlier spring increase western U.S. forest wildfire activity. *Science*, **313(5789)**, 940-943.

[295] Rhode Island Public Transit Authority, Undated: *Air Quality Alert Days Program*. [Web site] <http://www.ripta.com/content259.html>

[296] Friedman, M.S., K.E. Powell, L. Hutwagner, L.M. Graham, and W.G. Teague, 2001: Impact of changes in transportation and commuting behaviors during the 1996 Summer Olympic Games in Atlanta on air quality and childhood asthma. *Journal of the American Medical Association*, **285(7)**, 897-905.

[297] Wuebbles, D.J., H. Lei, and J.-T. Lin, 2007: Intercontinental transport of aerosols and photochemical oxidants from Asia and its consequences. *Environmental Pollution*, **150**, 65-84.

[298] Bell, M.L., R. Goldberg, C. Hogrefe, P. Kinney, K. Knowlton, B. Lynn, J. Rosenthal, C. Rosenzweig, and J.A. Patz, 2007: Climate change, ambient ozone, and health in 50 U.S. cities. *Climatic Change*, **82(1-2)**, 61-76.

[299] U.S. Environmental Protection Agency, 2008: *National Pollutant Discharge Elimination System (NPDES) Combined Sewer Overflows Demographics*. [Web site] <http://cfpub.epa.gov/npdes/cso/demo.cfm?program_id=5>

[300] Tibbetts, J., 2005: Combined sewer systems: down, dirty, and out of date. *Environmental Health Perspectives*, **113(7)**, A464-A467.

[301] U.S. Environmental Protection Agency, 2008: *Clean Watersheds Needs Survey 2004: Report to Congress*. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/cwns/2004rtc/cwns2004rtc.pdf>

[302] Patz, J.A., S.J. Vavrus, C.K. Uejio, and S.L. McClellan, 2008: Climate change and waterborne disease risk in the Great Lakes region of the U.S. *American Journal of Preventive Medicine*, **35(5)**, 451-458.

[303] Centers for Disease Control and Prevention, 2009: *West Nile Virus: Statistics, Surveillance, and Control*. [Web site] <http://www.cdc.gov/ncidod/dvbid/westnile/surv&control.htm>

[304] Kilpatrick, A.M., M.A. Meola, R.M. Moudy, and L.D. Kramer, 2008: Temperature, viral genetics, and the transmission of West Nile virus by *Culex pipiens* mosquitoes. *PLoS Pathogens*, **4(6)**, e1000092. doi:10.1371/journal.ppat.1000092

[305] Sussman, F.G., M.L. Cropper, H. Galbraith, D. Godschalk, J. Loomis, G. Luber, M. McGeehin, J.E. Neumann, W.D. Shaw, A. Vedlitz, and S. Zahran, 2008: Effects of global change on human welfare. In: *Analyses of the Effects of Global Change on Human*

Health and Welfare and Human Systems [Gamble, J.L. (ed.), K.L. Ebi, F.G. Sussman, and T.J. Wilbanks (authors)]. Synthesis and Assessment Product 4.6. U.S. Environmental Protection Agency, Washington, DC, pp. 111-168.

[306] Smith, J.B. and D. Tirpak (eds.), 1989: *The Potential Effects of Global Climate Change on the United States* U.S. Environmental Protection Agency, Washington, DC, 413 pp.

[307] Ziska, L.H. and F.A. Caulfield, 2000: Rising CO_2 and pollen production of common ragweed (*Ambrosia artemisiifolia L.*), a known allergy-inducing species: implications for public health. *Australian Journal of Plant Physiology*, **27(10)**, 893-898.

[308] Mohan J.E., L.H. Ziska, W.H. Schlesinger, R.B. Thomas, R.C. Sicher, K. George, and J.S. Clark, 2006: Biomass and toxicity responses of poison ivy (*Toxicodendron radicans*) to elevated atmospheric CO_2. *Proceedings of the National Academy of Sciences*, **103(24)**, 9086-9089.

[309] Hunt, R., D.W. Hand, M.A. Hannah, and A.M. Neal, 1991: Response to CO_2 enrichment in 27 herbaceous species. *Functional Ecology*, **5(3)**, 410-421.

[310] Ziska, L.H., 2003: Evaluation of the growth response of six invasive species to past, present and future atmospheric carbon dioxide. *Journal of Experimental Botany*, **54(381)**, 395-404.

[311] CDC, 2007: *2007 National Diabetes Fact Sheet.* Centers for Disease Control and Prevention, Atlanta, GA, 14 pp. <http://www.cdc.gov/diabetes/pubs/factsheet07.htm>

[312] Patz, J.A., H.K. Gibbs, J.A. Foley, J.V. Rogers, and K.R. Smith, 2007: Climate change and global health: quantifying a growing ethical crisis. *EcoHealth*, **4(4)**, 397-405.

[313] Wilbanks, T.J., P. Kirshen, D. Quattrochi, P. Romero-Lankao, C. Rosenzweig, M. Ruth, W. Solecki, J. Tarr, P. Larsen, and B. Stone, 2008: Effects of global change on human settlements. In: *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems* [Gamble, J.L. (ed.), K.L. Ebi, F.G. Sussman, and T.J. Wilbanks (authors)]. Synthesis and Assessment Product 4.6. U.S. Environmental Protection Agency, Washington, DC, pp. 89-109.

[314] U.S. Census Bureau, 2005: *Domestic Net Migration in the United States: 2000 to 2004: Population Estimates and Projections.* <http://www.census.gov/prod/2006pubs/p25-1135.pdf>

[315] U.S. General Accounting Office, 2003: *Alaska Native Villages: Most Are Affected by Flooding and Erosion, but Few Qualify for Federal Assistance.* GAO-04-142. U.S. General Accounting Office, Washington, DC, 82 pp. <http://purl.access.gpo.gov/GPO/LPS42077>

[316] Gamble, J.L., K.L. Ebi, F.G. Sussman, T.J. Wilbanks, C. Reid, J.V. Thomas, and C.P. Weaver, 2008: Common themes and research recommendations. In: *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems* [Gamble, J.L. (ed.), K.L. Ebi, F.G. Sussman, and T.J. Wilbanks (authors)]. Synthesis and Assessment Product 4.6. U.S. Environmental Protection Agency, Washington, DC, pp. 169-176.

[317] United States Conference of Mayors, 2005: *U.S. Conference of Mayors Climate Protection Agreement,* as endorsed by the 73rd Annual U.S. Conference of Mayors meeting, Chicago, 2005. <http://usmayors.org/climateprotection/agreement.htm>

[318] Semenza, J.C., J.E. McCullough, W.D. Flanders, M.A. McGeehin, and J.R. Lumpkin, 1999: Excess hospital admissions during the July 1995 heat wave in Chicago. *American Journal of Preventive Medicine*, **16(4)**, 269-277.

[319] Borden, K.A., M.C. Schmidtlein, C.T. Emrich, W.W. Piegorsch, and S.L. Cutter, 2007: Vulnerability of U.S. cities to environmental hazards. *Journal of Homeland Security and Emergency Management*, **4(2)**, article 5. <http://www.bepress.com/jhsem/vol4/iss2/5>

[320] van Kamp, I., K. Leidelmeijer, G. Marsman, and A. de Hollander, 2003: Urban environmental quality and human well-being: towards a conceptual framework and demarcation of concepts; a literature study. *Landscape and Urban Planning*, **65(1-2)**, 5-18.

[321] Grimmond, S., 2007: Urbanization and global environmental change: local effects of urban warming. *Geographical Journal*, **173(1)**, 83-88.

[322] Anderson, C.A., 2001: Heat and violence. *Current Directions in Psychological Science*, **10(1)**, 33-38.

[323] Anderson, C.A., B.J. Bushman, and R.W. Groom, 1997: Hot years and serious and deadly assault: empirical test of the heat hypothesis. *Journal of Personality and Social Psychology*, **73(6)**, 1213-1223.

[324] Milly, P.C.D., R.T. Wetherald, K.A. Dunne, and T.L. Delworth, 2002: Increasing risk of great floods in a changing climate. *Nature*, **415(6871)**, 514-517.

[325] Miller, N.L., K. Hayhoe, J. Jin, and M. Auffhammer, 2008: Climate, extreme heat, and electricity demand in California. *Journal of Applied Meteorology and Climatology*, **47(6)**, 1834-1844.

[326] Wang, J.X.L. and J.K. Angell, 1999: *Air Stagnation Climatology for the United States (1948-1998).* NOAA/Air Resources Laboratory atlas no.1. NOAA Air Resources Laboratory, Silver Spring, MD, 74 pp.

[327] Riebsame, W.E., S.A. Changnon Jr., and T.R. Karl, 1991: *Drought and Natural Resources Management in the United States: Impacts and Implications of the 1987–89 Drought.* Westview Press, Boulder, CO, 174 pp.

[328] NOAA's National Climatic Data Center, 2009: *NCDC Climate Monitoring: U.S. Records* [Web site] <http://www.ncdc.noaa.gov/oa/climate/research/records/>

[329] NOAA's National Climatic Data Center, 2009: *U.S. Percent Area Wet or Dry.* [Web site] <http://www.ncdc.noaa.gov/img/climate/research/2008/ann/Reg110_wet-dry_bar01001208-mod_pg.gif>

[330] Leung L.R. and W.I. Gustafson Jr., 2005: Potential regional climate change and implications to U.S. air quality. *Geophysical Research Letters*, **32**, L16711, doi:10.1029/2005GL022911.

[331] Several U.S. Department of Energy reports document the increase in electricity demand to provide air-conditioning in hotter summers in many regions of the country: Chapter 2: Carbon dioxide emissions. In: *Emissions of Greenhouse Gases in the United States 2002.* Report released 2004. <http://www.eia.doe.gov/oiaf/1605/archive/gg03rpt/index.html>; *South Atlantic Household Electricity Report.* Release date: 2006. <http://www.eia.doe.gov/emeu/reps/enduse/er01_so-atl.html>; *South Central Appliance Report 2001.* Updated 2005. <http://www.eia.doe.gov/emeu/reps/appli/w_s_c.html>

[332] CCSP, 2007: *Effects of Climate Change on Energy Production and Use in the United States.* [Wilbanks, T.J., V. Bhatt, D.E. Bilello, S.R. Bull, J. Ekmann, W.C. Horak, Y.J. Huang, M.D. Levine, M.J. Sale, D.K. Schmalzer, and M.J. Scott (eds.)]. Synthesis and Assessment Product 4.5. U.S. Department of Energy, Office of Biological & Environmental Research, Washington, DC, 160 pp. See chapters 2 and 3.

[333] Daily data were used for both air stagnation and heat waves:

1. Heat waves:

 • The GHCN-Daily dataset from NCDC was used <http://www.ncdc.noaa.gov/oa/climate/ghcn-daily/>

 • Data from 979 U.S. stations having long periods of record and high quality.

 • At each station, a day was considered hot if the maximum temperature for that day was at or above the 90% of daily maximum temperatures at that station.

2. Air stagnation:

 • For each day in summer and at each air-stagnation grid point,

it was determined if that location had stagnant air.

- The stagnation index was formulated by Wang, J.X.L. and J.K. Angell, 1999: *Air Stagnation Climatology for the United States (1948-1998)*. NOAA/Air Resources Laboratory atlas no.1 NOAA Air Resources Laboratory, Silver Spring, MD, 74 pp. <http://www.arl.noaa.gov/documents/reports/atlas.pdf>

- Operational implementation of this index is described at <http://www.ncdc.noaa.gov/oa/climate/research/stagnation/index.php>

Note: Although Wang and Angell used a criteria of four day stagnation periods, single stagnation days were used for this analysis.

3. For each location in the air stagnation grid, the nearest station (of the aforementioned 979 U.S. stations) was used to determine the coincidence of summer days having stagnant air and excessive heat as a percentage of the number of days having excessive heat.

[334] Solecki, W.D. and C. Rosenzweig, 2006: Climate change and the city: observations from metropolitan New York. In: *Cities and Environmental Change* [Bai, X. (ed.)]. Yale University Press, New York.

[335] Rosenzweig, C. and W. Solecki (eds.), 2001: *Climate Change and a Global City: The Potential Consequences of Climate Variability and Change – Metro East Coast*. Columbia Earth Institute, New York. <http://metroeast_climate.ciesin.columbia.edu/>

[336] Kirshen, P., M. Ruth, W. Anderson, T.R. Lakshmanan, S. Chapra, W. Chudyk, L. Edgers, D. Gute, M. Sanayei, and R. Vogel, 2004: *Climate's Long-term Impacts on Metro Boston (CLIMB) Final Report*. Civil and Environmental Engineering Department, Tufts University, 165 pp. <http://www.clf.org/uploadedFiles/CLIMB_Final_Report.pdf>

[337] Grimm, N.B., S.H. Faeth, N.E. Golubiewski, C.L. Redman, J. Wu, X. Bai, and J.M. Briggs, 2008: Global change and the ecology of cities. *Science*, **319(5864)**, 756-760.

[338] Kuo, F.E. and W.C. Sullivan, 2001: Environment and crime in the inner city: Does vegetation reduce crime? *Environment and Behavior*, **33(3)**, 343-367.

[339] Julius, S.H., J.M. West, G. Blate, J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M. Palmer, C. Peterson, and J.M. Scott, 2008: Executive summary. In: *Preliminary Review of Adaptation Options for Climate-sensitive Ecosystems and Resources* [Julius, S.H. and J.M. West (eds.), J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (authors)]. Synthesis and Assessment Product 4.4. U.S. Environmental Protection Agency, Washington, DC, pp. 1-1 to 1-6.

[340] Baker, L.A., A.J. Brazel, N. Selover, C. Martin, N. McIntyre, F.R. Steiner, A. Nelson, and L. Musacchio, 2002: Urbanization and warming of Phoenix (Arizona, USA): impacts, feedbacks, and mitigation. *Urban Ecosystems*, **6(3)**, 183-203.

[341] LoVecchio, F., J.S. Stapczynski, J. Hill, A.F. Haffer, J.A. Skindlov, D. Engelthaler, C. Mrela, G.E. Luber, M. Straetemans, and Z. Duprey, 2005: Heat-related mortality – Arizona, 1993-2002, and United States, 1979-2002. *Morbidity and Mortality Weekly Report*, **54(25)**, 628-630.

[342] Scott, D., J. Dawson, and B. Jones, 2008: Climate change vulnerability of the US Northeast winter recreation–tourism sector. *Mitigation and Adaptation Strategies for Global Change*, **13(5-6)**, 577-596.

[343] Bin, O., C. Dumas, B. Poulter, and J. Whitehead, 2007: *Measuring the Impacts of Climate Change on North Carolina Coastal Resources*. National Commission on Energy Policy, Washington, DC, 91 pp. <http://econ.appstate.edu/climate/>

[344] Mills, E., 2005: Insurance in a climate of change. *Science*, **309(5737)**, 1040-1044.

[345] Adapted from U.S. Government Accountability Office, 2007: *Climate Change: Financial Risks to Federal and Private Insurers in Coming Decades are Potentially Significant*. U.S. Government Accountability Office, Washington, DC, 68 pp. <http://purl.access.gpo.gov/GPO/LPS89701> Data shown are not adjusted for inflation.

[346] Pielke Jr., R.A., J. Gratz, C.W. Landsea, D. Collins, M. Saunders, and R. Musulin, 2008: Normalized hurricane damages in the United States: 1900-2005. *Natural Hazards Review*, **9(1)**, 29-42.

[347] Rosenzweig, C., G. Casassa, D.J. Karoly, A. Imeson, C. Liu, A. Menzel, S. Rawlins, T.L. Root, B. Seguin, and P. Tryjanowski, 2007: Assessment of observed changes and responses in natural and managed systems. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 79-131.

[348] Pielke Jr., R.A., 2005: Response to: "Attribution of Disaster Losses" by E. Mills. *Science*, **310(5754)**, 1615.

[349] Mills, E., 2009: A global review of insurance industry responses to climate change. *The Geneva Papers on Risk and Insurance–Issues and Practice*, in press.

[350] Meehl, G.A. and C. Tebaldi, 2004: More intense, more frequent, and longer lasting heat waves in the 21st century. *Science*, **305(5686)**, 994-997.

[351] Mills, E., 2006: Synergisms between climate change mitigation and adaptation: an insurance perspective. *Mitigation and Adaptation Strategies for Global Change*, **12(5)**, 809-842.

[352] U.S. Government Accountability Office, 2007 [data]; assembled by Evan Mills, Lawrence Berkeley National Laboratory.

[353] Reeve, N. and R. Toumi, 1999: Lightning activity as an indicator of climate change. *Quarterly Journal of the Royal Meteorological Society*, **125(555)**, 893-903.

[354] Price, C. and D. Rind, 1994: Possible implications of global climate change on global lightning distributions and frequencies. *Journal of Geophysical Research*, **99(D5)**, 10823-10831.

[355] Ross, C., E. Mills, and S. Hecht, 2007: Limiting liability in the greenhouse: insurance risk-management in the context of global climate change. *Stanford Environmental Law Journal and Stanford Journal of International Law, Symposium on Climate Change Risk*, **26A/43A**, 251-334.

[356] Nutter, F.W., 1996: Insurance and the natural sciences: partners in the public interest. *Research Review: Journal of the Society of Insurance Research*, **Fall**, 15-19.

[357] Federal Emergency Management Agency, 2008: *Emergency Management Institute*. [Web site] <http://training.fema.gov/EMIWeb/CRS/>

[358] Bernstein, L., J. Roy, K.C. Delhotal, J. Harnisch, R. Matsuhashi, L. Price, K. Tanaka, E. Worrell, F. Yamba, and Z. Fengqi, 2007: Industry. In: *Climate Change 2007: Mitigation of Climate Change*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Metz, B., O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 447-496.

[359] Hayhoe, K., C.P. Wake, B. Anderson, X.-Z. Liang, E. Maurer, J. Zhu, J. Bradbury, A. DeGaetano, A. Hertel, and D. Wuebbles, 2008: Regional climate change projections for the northeast U.S. *Mitigation and Adaptation Strategies for Global Change*, **13(5-6)**, 425-436.

[360] New York City Department of Health and Mental Hygiene, 2006: Deaths associated with heat waves in 2006. In: *NYC Vital Signs: Investigation Report, Special Report*. Department of Health and Mental Hygiene, New York, 4 pp. <http://www.nyc.gov/html/doh/downloads/pdf/survey/survey-2006heatdeaths.pdf>

[361] Kunkel, K.E., H.-C. Huang, X.-Z. Liang, J.-T. Lin, D. Wuebbles, Z. Tao, A. Williams, M. Caughey, J. Zhu, and K. Hayhoe, 2008: Sensitivity of future ozone concentrations in the northeast U.S. to regional climate change. *Mitigation and Adaptation Strategies for Global Change*, **13(5-6)**, 597-606.

[362] Hauagge, R. and J.N. Cummins, 1991: Phenotypic variation of length of bud dormancy in apple cultivars and related malus species. *Journal of the American Society for Horticultural Science*, **116(1)**, 100-106.

[363] DeMoranville, C., 2007: Personal communication from May 29, 2008. Experts at the University of Massachusetts Cranberry Station estimate cranberry chilling requirements to be around 1,200-1,400 hours, but they advise growers to seek 1,500 hours to avoid crop failure. There are 4-5 commonly grown cultivars but no low-chill varieties. Dr. Carolyn DeMoranville is the director of the UMass Cranberry Station, a research and extension center of UMass-Amherst.

[364] Iverson, L., A. Prasad, and S. Matthews, 2008: Potential changes in suitable habitat for 134 tree species in the northeastern United States. *Mitigation and Adaptation Strategies for Global Change*, **13(5-6)**, 487-516.

[365] U.S. Department of Agriculture (USDA) National Agriculture Statistics Service (NASS), 2002: *Statistics by State*. [Web site] <http://www.nass.usda.gov/Statistics_by_State/>

[366] St. Pierre, N.R., B. Cobanov, and G. Schnitkey, 2003: Economic losses from heat stress by U.S. livestock industries. *Journal of Dairy Science*, **86(E Sup)**, E52- E77.

[367] Gornitz, V., S. Couch, and E.K. Hartig, 2001: Impacts of sea level rise in the New York City metropolitan area. *Global and Planetary Change*, **32(1)**, 61-88.

[368] AIR Worldwide Corporation, 2008: *The Coastline at Risk: 2008 Update to the Estimated Insured Value of U.S. Coastal Properties*. AIR Worldwide Corporation, Boston, MA, 3 pp. <http://www.air-worldwide.com/download.aspx?c=388&id=15836>

[369] Kirshen, P., C. Watson, E. Douglas, A. Gontz, J. Lee, and Y. Tian, 2008: Coastal flooding in the northeastern United States due to climate change. *Mitigation and Adaptation Strategies for Global Change*, **13(5-6)**, 437-451.

[370] Bowman, M., D. Hill, F. Buonaiuto, B. Colle, R. Flood, R. Wilson, R. Hunter, and J. Wang, 2008: Threats and responses associated with rapid climate change in metropolitan New York. In: *Sudden and Disruptive Climate Change: Exploring the Real Risks and How We Can Avoid Them*. [MacCracken, M.C., F. Moore, and J.C. Topping Jr. (eds.)]. Earthscan, London and Sterling, VA, pp. 119-142.

[371] Titus, J.G., 2009: Ongoing adaptation. In: *Coastal Elevations and Sensitivity to Sea-level Rise: A Focus on the Mid-Atlantic Region* [J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. Synthesis and Assessment Product 4.1. U.S. Environmental Protection Agency, Washington, DC, pp. 157-162.

[372] International Snowmobile Manufacturers Association, 2006: *International Snowmobile Industry Facts and Figures*. [Web site] <http://www.snowmobile.org/pr_snowfacts.asp>

[373] Northeast Climate Impact Assessment (NECIA), 2006: *Climate Change in the U.S. Northeast: A Report of the Northeast Climate Impacts Assessment*. Union of Concerned Scientists, Cambridge, MA, 35 pp.

[374] Atlantic States Marine Fisheries Commission, 2005: *American Lobster*. [Web site] <http://www.asmfc.org/americanLobster.htm>

[375] Fogarty, M.J., 1995: Populations, fisheries, and management. In: *The Biology of the American Lobster* Homarus americanus. [Factor, J.R. (ed.)]. Academic Press, San Diego, CA, pp. 111-137.

[376] Glenn, R.P. and T.L. Pugh, 2006: Epizootic shell disease in American lobster (*Homarus americanus*) in Massachusetts coastal waters: interactions of temperature, maturity, and intermolt duration. *Journal of Crustacean Biology*, **26(4)**, 639-645.

[377] Fogarty, M., L. Incze, K. Hayhoe, D. Mountain, and J. Manning, 2008: Potential climate change impacts on Atlantic cod (*Gadus morhua*) off the northeastern United States. *Mitigation and Adaptation Strategies for Global Change*, **13(5-6)**, 453-466.

[378] Dutil, J.-D. and K. Brander, 2003: Comparing productivity of North Atlantic cod (*Gadus morhua*) stocks and limits to growth production. *Fisheries Oceanography*, **12(4-5)**, 502-512.

[379] Drinkwater, K.F., 2005: The response of Atlantic cod (*Gadus morhua*) to future climate change. *ICES Journal of Marine Science*, **62(7)**, 1327-1337.

[380] Karl, T.R. and R.W. Knight, 1998: Secular trends of precipitation amount, frequency, and intensity in the United States. *Bulletin of the American Metrological Society*, **79(2)**, 231-241.

[381] Keim, B.D., 1997: Preliminary analysis of the temporal patterns of heavy rainfall across the southeastern United States. *Professional Geographer*, **49(1)**, 94-104.

[382] Observed changes in precipitation for the Southeast were calculated from the US Historical Climatology Network Version 2. See Menne, M.J., C.N. Williams, and R.S. Vose, 2009: The United States Historical Climatology Network Monthly Temperature Data - Version 2. *Bulletin of the American Meteorological Society*, Early online release, 25 February 2009, doi:10.1175/2008BAMS2613.1

[383] Temperature:

Menne, M.J., C.N. Williams, and R.S. Vose, 2009: The United States Historical Climatology Network Monthly Temperature Data - Version 2. *Bulletin of the American Meteorological Society*, Early online release, 25 February 2009, doi:10.1175/2008BAMS2613.1

Precipitation:

NOAA's National Climatic Data Center, 2008: *The USHCN Version 2 Serial Monthly Dataset*. [Web site] <http://www.ncdc.noaa.gov/oa/climate/research/ushcn/>

[384] Hoyos, C.D., P.A. Agudelo, P.J. Webster, and J.A. Curry, 2006: Deconvolution of the factors contributing to the increase in global hurricane intensity. *Science*, **312(577)**, 94-97.

[385] Mann, M.E. and K.A. Emanuel, 2006: Atlantic hurricane trends linked to climate change. *EOS Transactions of the American Geophysical Union*, **87(24)**, 233, 244.

[386] Trenberth, K.E. and D.J. Shea, 2006: Atlantic hurricanes and natural variability in 2005. *Geophysical Research Letters*, **33**, L12704, doi:10.1029/2006GL026894.

[387] Webster, P.J., G.J. Holland, J.A. Curry, and H.-R. Chang, 2005: Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science*, **309(5742)**, 1844-1846.

[388] Komar, P.D. and J.C. Allan, 2007: Higher waves along U.S. East Coast linked to hurricanes. *EOS Transactions of the American Geophysical Union*, **88(30)**, 301.

[389] Change calculated from daily minimum temperatures from NCDC's Global Historical Climatology Network - Daily data set. <http://www.ncdc.noaa.gov/oa/climate/ghcn-daily/>

[390] Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden, and C.D. Woodroffe, 2007: Coastal systems and low-lying areas. In: *Climate Change 2007: Impacts, Adaptations and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, pp. 316-356.

[391] Boyles, S., 2008: *Heat Stress and Beef Cattle*. Ohio State University Extension Service. <http://beef.osu.edu/library/heat.html>

[392] Convention on Biological Diversity, 2006: *Guidance for Promoting Synergy Among Activities Addressing Biological Diversity, Desertification, Land Degradation and Climate Change*. CBD technical series 25. Secretariat of the Convention on Biological Diversity, Montreal, Canada, 43 pp. <http://www.biodiv.org/doc/publications/cbd-ts-25.pdf>

[393] Burkett, V., 2008: The northern Gulf of Mexico coast: human development patterns, declining ecosystems, and escalating vulnerability to storms and sea level rise. In: *Sudden and Disruptive Climate Change: Exploring the Real Risks and How We Can Avoid Them*. [MacCracken, M.C., F. Moore, and J.C. Topping (eds.)]. Earthscan Publications, London [UK], and Sterling, VA, pp. 101-118.

[394] Twilley, R.R., E. Barron, H.L. Gholz, M.A. Harwell, R.L. Miller, D.J. Reed, J.B. Rose, E. Siemann, R.G. Welzel, and R.J. Zimmerman, 2001: *Confronting Climate Change in the Gulf Coast Region: Prospects for Sustaining Our Ecological Heritage*. Union of Concerned Scientists, Cambridge, MA, and Ecological Society of America, Washington, DC, 82 pp.

[395] USGS, photos and images:
Photos on the left:
Tihansky, A.B., 2005: Before-and-after aerial photographs show coastal impacts of Hurricane Katrina. *Sound Waves*, September. <http://soundwaves.usgs.gov/2005/09/fieldwork2.html>
Images on the right:
Adapted from Fauver, L., 2007: Predicting flooding and coastal hazards: USGS hydrologists and geologists team up at the National Hurricane Conference to highlight data collection. *Sounds Waves*, June. <http://soundwaves.usgs.gov/2007/06/meetings.html>

[396] Barras, J.A., 2006: *Land Area Change in Coastal Louisiana After the 2005 Hurricanes: A Series of Three Maps*. U.S. Geological Survey open-file report 2006-1274. <http://pubs.usgs.gov/of/2006/1274>

[397] Main Development Region of the Atlantic Ocean is defined in: Bell, G.D., E. Blake, C.W. Landsea, S.B. Goldenberg, R. Pasch, and T. Kimberlain, 2008: Tropical cyclones: Atlantic basin. In: Chapter 4: The Tropics, of *State of the Climate in 2007* [Levinson, D.H. and J.H. Lawrimore (eds.)]. *Bulletin of the American Meteorological Society*, **89(Supplement)**, S68-S71.

[398] Williams, K.L., K.C. Ewel, R.P. Stumpf, F.E. Putz, and T.W. Workman, 1999: Sea-level rise and coastal forest retreat on the west coast of Florida. *Ecology*, **80(6)**, 2045-2063.

[399] McNulty, S.G., J.M. Vose, and W.T. Swank, 1996: Potential climate change affects on loblolly pine productivity and hydrology across the southern United States. *Ambio*, **25(7)**, 449-453.

[400] Zimmerman, R.J., T.J. Minello, and L.P. Rozas, 2002: Salt marsh linkages to productivity of penaeid shrimps and blue crabs in the northern Gulf of Mexico. In: *Concepts and Controversies in Tidal Marsh Ecology* [Weinstein, M.P. and D.A. Kreeger (eds.)]. Kluwer, Dordrecht and Boston, pp. 293-314.

[401] U.S. Army Corps of Engineers, 2009: *Risk Reduction Plan: Levees/Floodwalls/Armoring*. [Web site] U.S. Army Corps of Engineers New Orleans District. <http://www.mvn.usace.army.mil/hps2/hps_levees_flood_armor.asp>

[402] Kling, G.W., K. Hayhoe, L.B. Johnson, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, and D.R. Zak, 2003: *Confronting Climate Change in the Great Lakes Region: Impacts on Our Communities and Ecosystems*. Union of Concerned Scientists, Cambridge, MA, and Ecological Society of America, Washington, DC, 92 pp. <http://www.ucsusa.org/greatlakes/>

[403] Hayhoe, K., D. Wuebbles, and the Climate Science Team, 2008: *Climate Change and Chicago: Projections and Potential Impacts*. City of Chicago, [175 pp.] <http://www.chicagoclimateaction.org/>

[404] Wuebbles, D.J. and K. Hayhoe, 2004: Climate change projections for the United States Midwest. *Mitigation and Adaptation Strategies for Global Change*, **9(4)**, 335-363.

[405] Ebi, K.L. and G.A. Meehl, 2007: The heat is on: climate change and heat waves in the Midwest. In: *Regional Impacts of Climate Change: Four Case Studies in the United States*. Pew Center on Global Climate Change, Arlington, VA, pp. 8-21. <http://www.pewclimate.org/regional_impacts>

[406] Kalkstein, L.S., J.S. Green, D.M. Mills, A.D. Perrin, J.P. Samenow, and J.-C. Cohen, 2008: Analog European heat waves for U.S. cities to analyze impacts on heat-related mortality. *Bulletin of the American Meteorological Society*, **89(1)**, 75-85.

[407] Hayhoe, K., S. Sheridan, J.S. Greene and L. Kalkstein, 2009: Climate change, heat waves, and mortality projections for Chicago. *Journal of Great Lakes Research*, in press.

[408] Lin, J.-T., K.O. Patten, X.-Z. Liang, and D.J. Wuebbles, 2008: Climate change effects on ozone air quality in the United States and China with constant precursor emissions. *Journal of Applied Meteorology and Climatology*, **47(7)**, 1888-1909.

[409] Holloway, T., S.N. Spak, D. Barker, M. Bretl, K. Hayhoe, J. Van Dorn, and D. Wuebbles, 2008: Change in ozone air pollution over Chicago associated with global climate change. *Journal of Geophysical Research*, **113**, D22306, doi:10.1029/2007JD009775.

[410] Hedegaard, G.B., J. Brandt, J.H. Christensen, L.M. Frohn, C. Geels, K.M. Hansen, and M. Stendel, 2008: Impacts of climate change on air pollution levels in the Northern Hemisphere with special focus on Europe and the Arctic. *Atmospheric Chemistry and Physics*, **8(12)**, 3337-3367.

[411] Several different city of Chicago analyses have substantiated the finding of up to 77 degree difference – for example, see City of Chicago, Department of Environment, Undated: *City Hall Rooftop Garden*. [Web site] <http://egov.cityofchicago.org/city/webportal/portalDeptCategoryAction.do?deptCategoryOID=-536889314&contentType=COC_EDITORIAL&topChannelName=Dept&entityName=Environment&deptMainCategoryOID=-536887205>

[412] Angel, J. and K. Kunkel, 2009: The response of Great Lakes water levels to future climate scenarios with an emphasis of Lake Michigan. *Journal of Great Lakes Research*, in press.

[413] Annin, P., 2006: *The Great Lakes Water Wars*. Island Press, Washington, DC, 303 pp.

[414] Assel, R.A., 2003: *An Electronic Atlas of Great Lakes Ice Cover, Winters: 1973-2002*. NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 2 CD-ROM set or DVD. <http://www.glerl.noaa.gov/data/ice/atlas>

[415] Changnon, S.A. (ed.), 1996: *The Great Flood of 1993: Causes, Impacts and Responses*. Westview Press, Boulder, CO, 321 pp.

[416] Changnon, S.A. and K.E. Kunkel, 2006: *Severe Storms in the Midwest*. Illinois State Water Survey, Champaign, IL, 74 pp. <http://www.sws.uiuc.edu/pubdoc/IEM/ISWSIEM2006-06.pdf>

[417] Kunkel, K.E., K. Andsager, G. Conner, W.L. Decker, H.J. Hilaker Jr., P.N. Knox, F.V. Nurnberger, J.C. Rogers, K. Scheeringa, W.M. Wendland, J. Zandlo, and J.R. Angel, 1998: An expanded digital daily database for climatic resources applications in the midwestern United States. *Bulletin of the American Meteorological Society*, **79(7)**, 1357-1366.

[418] Agricultural Research Service, 1990: *USDA Plant Hardiness Zone Map*. Agricultural Research Service, Washington, DC, 1 map.
Arbor Day Foundation, 2006: *Hardiness Zones*. [Web site] The Arbor Day Foundation, Nebraska City, NE. <http://www.arborday.org/media/zones.cfm>

[419] Woodhouse, C.A. and J.T. Overpeck, 1998: 2000 years of drought variability in the central United States. *Bulletin of the American Meteorological Society*, **79(12)**, 2693-2714.

[420] DeGaetano, A.T. and R.J. Allen, 2002: Trends in twentieth-century temperature extremes across the United States. *Journal of Climate*, **15(22)**, 3188-3205.

[421] Garbrecht, J., M. Van Liew, and G.O. Brown, 2004: Trends in precipitation, streamflow, and evapotranspiration in the Great Plains of the United States. *Journal of Hydrologic Engineering*, **9(5)**, 360-367.

[422] McGuire, V., 2007: *Water-level Changes in the High Plains Aquifer, Predevelopment to 2005 and 2003 to 2005*. U.S. Geological Survey scientific investigations report 2006–5324. U.S. Geological Survey, Reston, VA, 7 pp. <http://pubs.usgs.gov/sir/2006/5324/>

[423] Dennehy, K. 2000: *High Plains Regional Ground-Water Study*. U.S. Geological Survey fact sheet FS-091-00, 6 pp. <http://pubs.er.usgs.gov/usgspubs/fs/fs09100>

[424] Gurdak, J.J., R.T. Hanson, P.B. McMahon, B.W. Bruce, J.E. McCray, G.D. Thyne, and R.C. Reedy, 2007: Climate variability controls on unsaturated water and chemical movement, High Plains aquifer, USA. *Vadose Zone Journal*, **6(3)**, 533-547.

[425] Green, T.R., M. Taniguchi, and H. Kooi, 2007: Potential impacts of climate change and human activity on subsurface water resources. *Vadose Zone Journal*, **6(3)**, 531-532.

[426] Data from the PRISM Group, Oregon State University <http://www.prismclimate.org>; Map created by National Climatic Data Center, March 2009.

[427] Mahmood, R., S.A. Foster, T. Keeling, K.G. Hubbard, C. Carlson, and R. Leeper, 2006: Impacts of irrigation on 20th century temperature in the northern Great Plains. *Global and Planetary Change*, **54(1-2)**, 1-18.

[428] Moore, N. and S. Rojstaczer, 2002: Irrigation's influence on precipitation: Texas High Plains, USA. *Geophysical Research Letters*, **29(16)**, 1755, doi:10.1029/2002GL014940.

[429] Schubert, S.D., M.J. Suarez, P.J. Pegion, R.D. Koster, and J.T. Bacmeister, 2004: On the cause of the 1930s Dust Bowl. *Science*, **303(5665)**, 1855-1859.

[430] Motha, R.P. and W. Baier, 2005: Impacts of present and future climate change and climate variability on agriculture in the temperate regions: North America. *Climatic Change*, **70(1-2)**, 137-164.

[431] Izaurralde, R.C., N.J. Rosenberg, R.A. Brown, and A.M. Thomson, 2003: Integrated assessment of Hadley Center (HadCM2) climate-change impacts on agricultural productivity and irrigation water supply in the conterminous United States: Part II. Regional agricultural production in 2030 and 2095. *Agricultural and Forest Meteorology*, **117(1-2)**, 97-122.

[432] Ziska, L. and K. George, 2004: Rising carbon dioxide and invasive, noxious plants: potential threats and consequences. *World Resource Review*, **16**, 427-447.

[433] Parton, W., M. Gutmann, and D. Ojima, 2007: Long-term trends in population, farm income, and crop production in the Great Plains. *Bioscience*, **57(9)**, 737-747.

[434] Reilly, J., F. Tubiello, B. McCarl, D. Abler, R. Darwin, K. Fuglie, S. Hollinger, C. Izaurralde, S. Jagtap, J. Jones, L. Mearns, D. Ojima, E. Paul, K. Paustian, S. Riha, N. Rosenberg, and C. Rosenzweig, 2003: U.S. agriculture and climate change: new results. *Climatic Change*, **57(1-2)**, 43-69.

[435] Allen, V.G., C.P. Brown, R. Kellison, E. Segarra, T. Wheeler, P.A. Dotray, J.C. Conkwright, C.J. Green, and V. Acosta-Martinez, 2005: Integrating cotton and beef production to reduce water withdrawal from the Ogallala aquifer in the southern high plains. *Agronomy Journal*, **97(2)**, 556-567.

[436] Hanson, J.D., M.A. Liebig, S.D. Merrill, D.L. Tanaka, J.M. Krupinsky, and D.E. Stott, 2007: Dynamic cropping systems: increasing adaptability amid an uncertain future. *Agronomy Journal*, **99(4)**, 939-943.

[437] Cameron, G.N. and D. Scheel, 2001: Getting warmer: effect of global climate change on distribution of rodents in Texas. *Journal of Mammalogy*, **82(3)**, 652-680.

[438] Levia, D.F. and E.E. Frost, 2004: Assessment of climatic suitability for the expansion of *Solenopsis invicta* Buren in Oklahoma using three general circulation models. *Theoretical and Applied Climatology*, **79(1-2)**, 23-30.

[439] Peterson, A.T., 2003: Projected climate change effects on Rocky Mountain and Great Plains birds: generalities of biodiversity consequences. *Global Change Biology*, **9(5)**, 647-655.

[440] Niemuth, N.D. and J.W. Solberg, 2003: Response of waterbirds to number of wetlands in the prairie pothole region of North Dakota, USA. *Waterbirds*, **26(2)**, 233-238.

[441] Conway, W.C., L.M. Smith, and J.D. Ray, 2005: Shorebird breeding biology in wetlands of the Playa Lakes, Texas, USA. *Waterbirds*, **28(2)**, 129-138.

[442] Scanlon, B., R. Reedy, and J. Tachovsky, 2007: Semiarid unsaturated zone chloride profiles: archives of past land use change impacts on water resources in the southern High Plains, United States. *Water Resources Research*, **43**, W06423, doi:10.1029/2006WR005769.

[443] Haukos, D.A. and L.M. Smith, 2003: Past and future impacts of wetland regulations on playa ecology in the southern Great Plains. *Wetlands*, **23(3)**, 577-589.

[444] Matthews, J., 2008: *Anthropogenic Climate Change in the Playa Lakes Joint Venture Region: Understanding Impacts, Discerning Trends, and Developing Responses*. Playa Lakes Joint Venture, Lafayette, CO, 40 pp. <http://www.pljv.org/cms/climate-change>

[445] Playa Lakes Joint Venture, Undated: *Playas and the Ogallala Aquifer – What's the Connection?* Playa Lakes Joint Venture, Lafayette, CO, 2 pp. <http://www.pljv.org/assets/Media/Recharge.pdf>

[446] U.S. Census Bureau, 2007: *Census Bureau Announces Most Populous Cities*. Press release June 28, 2007. <http://www.census.gov/Press-Release/www/releases/archives/population/010315.html>

[447] Ebi, K.L., D.M. Mills, J.B. Smith, and A. Grambsch, 2006: Climate change and human health impacts in the United States: an update on the results of the US national assessment. *Environmental Health Perspectives*, **114(9)**, 1318-1324.

[448] Nielsen, D.C., P.W. Unger, and P.R. Miller, 2005: Efficient water use in dryland cropping systems in the Great Plains. *Agronomy Journal*, **97(2)**, 364-372.

[449] NOAA's National Climatic Data Center, 2008: Southwest region Palmer Hydrological Drought index (PHDI). In: *Climate of 2008 – October: Southwest Region Moisture Status*. [Web site] NOAA National Climatic Data Center, Asheville, NC. <http://www.ncdc.noaa.gov/img/climate/research/prelim/drought/Reg107Dv00_palm06_pg.gif>

[450] Guhathakurta, S. and P. Gober, 2007: The impact of the Phoenix urban heat island on residential water use. *Journal of the American Planning Association*, **73(3)**, 317-329.

[451] Gleick, P.H., 1988: Regional hydrologic consequences of increases in atmospheric CO_2 and other trace gases. *Climatic Change*, **10(2)**, 137-160.

[452] Woodhouse, C.A., S.T. Gray, and D.M. Meko, 2006: Updated streamflow reconstructions for the upper Colorado River basin. *Water Resources Research*, **42**, W05415, doi:10.1029/2005WR004455.

[453] Meko, D.M., C.A. Woodhouse, C.A. Basisan, T. Knight, J.J. Lukas, M.K. Hughes, and M.W. Salzer, 2007: Medieval drought in the upper Colorado River basin. *Geophysical Research Letters*, **34**, L10705, doi:10.1029/2007GL029988.

[454] Stine, S., 1994: Extreme and persistent drought in California and Patagonia during mediaeval time. *Nature*, **369(6481)**, 546-549.

[455] Breshears, D.D., N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Hastens, M.L. Floyd, J. Belnap, J.J.

Anderson, O.B. Myers, and C.W. Meyer, 2005: Regional vegetation die-off in response to global-change drought. *Proceedings of the National Academy of Sciences*, **102(42)**, 15144-15148.

[456] Archer, C.L. and K. Caldiera, 2008: Historical trends in the jet streams. *Geophysical Research Letters*, **35**, L08803, doi:10.1029/2008GL033614.

[457] McAfee, S.A. and J.L. Russell, 2008: Northern annular mode impact on spring climate in the western United States. *Geophysical Research Letters*, **35**, L17701, doi:10.1029/2008GL034828.

[458] Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam, 2006: Warming and earlier spring increase western U.S. forest wildfire activity. *Science*, **313(5789)**, 940-943.

[459] Lenihan, J.M., D. Bachelet, R.P. Neilson, and R. Drapek, 2008: Response of vegetation distribution, ecosystem productivity, and fire to climate change scenarios for California. *Climatic Change*, **87(Supplement 1)**, S215-S230.

[460] Westerling, A.L. and B.P. Bryant, 2008: Climate change and wildfire in California. *Climatic Change*, **87(Supplement 1)**, S231-S249.

[461] Fried, J.S., J.K. Gilless, W.J. Riley, T.J. Moody, C.S. de Blas, K. Hayhoe, M. Moritz, S. Stephens and M. Torn, 2008: Predicting the effect of climate change on wildfire behavior and initial attack success. *Climatic Change*, **87(Supplement 1)**, S251-S264.

[462] Moritz, M.A. and S.L. Stephens, 2008: Fire and sustainability: considerations for California's altered future climate. *Climatic Change*, **87(Supplement 1)**, S265-S271.

[463] Rehfeldt, G.E., N.L. Crookston, M.V. Warwell, and J.S. Evans, 2006: Empirical analyses of plant-climate relationships for the western United States. *International Journal of Plant Sciences*, **167(6)**, 1123-1150.

[464] Weiss, J. and J.T. Overpeck, 2005: Is the Sonoran Desert losing its cool? *Global Change Biology*, **11(12)**, 2065-2077.

[465] Dole, K.P., M.E. Loik, and L.C. Sloan, 2003: The relative importance of climate change and the physiological effects CO_2 on freezing tolerance for the future distribution of *Yucca brevifolia*. *Global and Planetary Change*, **36(1-2)**, 137-146.

[466] Loarie, S.R., B.E. Carter, K. Hayhoe, S. McMahon, R. Moe, C.A. Knight, and D.D. Ackerley, 2008: Climate change and the future of California's endemic flora. *PLoS ONE*, **3(6)**, e2502, doi:10.1371/journal.pone.0002502.

[467] Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. daFonseca, and J. Kent, 2000: Biodiversity hotspots for conservation priorities. *Nature*, **403(6772)**, 853-858.

[468] Mittermeier R.A., P. Robles Gil, M. Hoffman, J. Pilgrim, T. Brooks, C. Goettsch Mittermeier, J. Lamoreux, and G.A.B. da Fonseca, 2005: *Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*. Conservation International, Washington DC, 392 pp.

[469] Farjon, A. and C.N. Page (eds.), 1999: *Conifers: Status Survey and Conservation Action Plan*. IUCN/SSC Conifer Special Group. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland, and Cambridge, UK, 121 pp.

[470] Nixon, K.C., 1993: The genus *Quercus* in Mexico. In: *Biological Diversity of Mexico: Origins and Distribution* [Ramamoorthy, T.P., R. Bye, A. Lot, and J. Fa (eds.)]. Oxford University Press, New York, 812 pp.

[471] Brower, L.P., G. Castilleja, A. Peralta, J. López-Garcia, L. Bojórquez-Tapia, S. Diaz, D. Melgarejo, and M. Missrie, 2002: Quantitative changes in forest quality in a principal overwintering area of the monarch butterfly in Mexico, 1971–1999. *Conservation Biology*, **16(2)**, 346-359.

[472] Goodrich, G. and A. Ellis, 2008: Climatic controls and hydrologic impacts of a recent extreme seasonal precipitation reversal in Arizona. *Journal of Applied Meteorology and Climatology*, **47(2)**, 498-508.

[473] Allan, R.P. and B.J. Soden, 2008: Atmospheric warming and the amplifications of precipitation extremes. *Science*, **321(5895)**, 1481-1484.

[474] Bales, R.C., N.P. Molotch, T.H. Painter, M.D. Dettinger, R. Rice, and J. Dozier, 2006: Mountain hydrology of the western United States. *Water Resources Research*, **42**, W08432, doi:10.1029/2005WR004387.

[475] Delta Risk Management Strategy, 2008: Section 2: Sacramento/San Joaquin Delta and Suisun Marsh. In: *Phase I Report: Risk Analysis*. California Department of Water Resources, [13 pp.] <http://www.drms.water.ca.gov>

[476] Delta Risk Management Strategy, 2008: Summary report. In: *Phase I Report: Risk Analsysis*. California Department of Water Resources, [42 pp.]. <http://www.drms.water.ca.gov>

[477] Zimmerman, G., C. O'Brady, and B. Hurlbutt, 2006: Climate change: modeling a warmer Rockies and assessing the implications. In: *The 2006 State of the Rockies Report Card*. Colorado College, Colorado Springs, pp. 89-102. <http://www.coloradocollege.edu/stateoftherockies/06ReportCard.html>

[478] Lazar, B. and M. Williams, 2008: Climate change in western ski areas: potential changes in the timing of wet avalanches and snow quality for the Aspen ski areas in the years 2030 and 2100. *Cold Regions Science and Technology*, **51(2-3)**, 219-228.

[479] Kleeman, M.J., 2008: A preliminary assessment of the sensitivity of air quality in California to global change. *Climatic Change*, **87(Supplement 1)**, S273-S292.

[480] Vicuna, S., R. Leonardson, M.W. Hanemann, L.L. Dale, and J.A. Dracup, 2008: Climate change impacts on high elevation hydropower generation in California's Sierra Nevada: a case study in the upper American River. *Climatic Change*, **87(Supplement 1)**, S123-S137.

[481] Medellín-Azuara, J., J.J. Harou, M.A. Olivares, K. Madani, J.R. Lund, R.E. Howitt, S.K. Tanaka, M.W. Jenkins, and T. Zhu, 2008: Adaptability and adaptations of California's water supply system to dry climate warming. *Climatic Change*, **87(Supplement 1)**, S75-S90.

[482] Baldocchi, D. and S. Wong, 2008: Accumulated winter chill is decreasing in the fruit growing regions of California. *Climatic Change*, **87(Supplement 1)**, S153-S166.

[483] Lobell, D., C. Field, K. Nicholas Cahill, and C. Bonfils, 2006: Impacts of future climate change on California perennial crop yields: model projections with climate and crop uncertainties. *Agricultural and Forest Meteorology*, **141(2-4)**, 208-218.

[484] Purkey, D.R., B. Joyce, S. Vicuna, M.W. Hanemann, L.L. Dale, D. Yates, and J.A. Dracup, 2008: Robust analysis of future climate change impacts on water for agriculture and other sectors: a case study in the Sacramento Valley. *Climatic Change*, **87(Supplement 1)**, S109-S122.

[485] Mote, P.W., 2003: Trends in temperature and precipitation in the Pacific Northwest during the twentieth century. *Northwest Science*, **77(4)**, 271-282.

[486] Mote, P., E. Salathé, V. Dulière, and E. Jump, 2008: *Scenarios of Future Climate for the Pacific Northwest*. Climate Impacts Group, University of Washington, Seattle, 12 pp. <http://cses.washington.edu/db/pubs/abstract628.shtml>

[487] Hamlet, A.F., P.W. Mote, M. Clark, and D.P. Lettenmaier, 2005: Effects of temperature and precipitation variability on snowpack trends in the western United States. *Journal of Climate*, **18(21)**, 4545-4561.

[488] Mote, P.W., 2006: Climate-driven variability and trends in mountain snowpack in western North America. *Journal of Climate*, **19(23)**, 6209-6220.

Letter 4

From: Nina Donofrio
Sent: Tuesday, June 23, 2009 8:29 AM
To: Janet Spilman
Subject: Comments on CTP EIR from web site...

Hi Janet: FYI -
A visitor to your website sent you the following message:

Visitor Name: Grace C Schulman for the EarthKeeping Ministry Respond By: Electronic Mail Email Address: [redacted] Site URL: http://www.sctainfo.org/feedback.asp
Feedback Category: Other
Feedback Subject: Comments on the CTP & DEIR Feedback Description: Sonoma County, all nine cities in the county, and the SCTA have shown tremendous leadership and commitment by adopting the goals of GHG emission reduction to 25% below 1990 levels by 2015. The Climate Action Plan published by the Climate Protection Campaign (CPC) acknowledges that the transportation sector accounts for almost 60% of the GHG emissions in Sonoma County. It is therefore important that this sector should task itself to make most of the GHG reductions in order to meet the overall goal for the county. However, in the DEIR, insufficient emphasis was made on these important locally established goals which are consistent with the mandates of AB32 and SB375. 4-1

We strongly support recommendations made by the CPC in its Climate Action Plan which include: 4-2
- Fully build out transit including the SMART train and plans for walking and bicycling networks in the urban area.
- Replace fuel used in public transit and municipal fleets with locally-produced biofuels.
- Strengthen city-centered, transit-oriented development.

Given the long timeframe of the CTP, which addresses transportation plans into the future through 2035, we urge the SCTA to examine the draft 2009 CPT closely, and seek to implement only projects that are consistent with this overriding important goal of GHG emission reduction. 4-3

Grace C. Schulman
EarthKeeping Ministry
Christ Church United Methodist
[redacted]

[redacted]
Email: gcschulman@yahoo.com

Letter 4, Grace Schulman, EarthKeeping Ministry

Response 4-1: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 4-2: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 4-3: The commenter's statements are not related to the adequacy of the Draft EIR and no further response is required.

Letter 5

SONOMA COUNTY Asthma Coalition

AMERICAN LUNG ASSOCIATION. IN CALIFORNIA

115 Talbot Avenue
Santa Rosa, CA 95404
707-527-5864
707-542-6111 fax

Call 1.800.LUNG.USA (800.586.4872) to reach your nearest American Lung Association or to speak with a health professional at our free HelpLine.

www.californialung.org

RECEIVED JUN 23 2009 SONOMA COUNTY TRANSPORTATION AUTHORITY

June 15, 2009

Sonoma County Transportation Authority
490 Mendocino Avenue, Suite 206
Santa Rosa, CA 95404

Re: DEIR Comprehensive Transportation Plan

Dear Sonoma County Transportation Authority:

Thank you very much for the opportunity to comment on the draft EIR for the Sonoma County Transportation Authority's (SCTA) Comprehensive Transportation Plan. The American Lung Association in California (ALAC) and the Sonoma County Asthma Coalition applaud the SCTA's work to develop a comprehensive transportation plan that will advance critical smart growth and transportation planning to reduce air pollution and greenhouse gas emissions, and promote healthier communities. 5-1

We recognize the hard work put in by staff on this plan and the daunting nature of crafting a plan that will dramatically reduce vehicle miles traveled. However, it is critical that this plan include specific strategies and timelines for how those goals will be met. Unfortunately, this plan fails to meet its own objectives, which are to reduce greenhouse gases 25 percent below 1990 levels by 2015 and 40 percent reductions by 2035. 5-2

The threats to public health caused by air pollution and global warming are serious. According to the California Air Resources Board, 2,400 premature deaths annually in the Bay Area are caused by air pollution (see attached). The CTP and DEIR documents are very important because transportation accounts for approximately 60% of Sonoma County's greenhouse gas (GHG) emissions and significant air pollution. Although Sonoma County meets federal air quality standards, emissions generated here are transported to other areas and contribute to poor air quality in other regions. 5-3

The Sonoma County Asthma Coalition has worked for the last seven years to reduce the incidence of asthma and to promote a reduction in the triggers that cause and exacerbate asthma, including air pollution both indoors and out. Both ALAC and the Sonoma County Asthma Coalition call on the Sonoma County Transportation Authority to propose an alternative alignment of projects in order that the plan aligns with the county's GHG reduction goal. 5-4

We recommend eliminating some roadway projects, and funding more alternative modes of transportation to reduce dependency on the automobile. 5-5

1

We would also like to see a more detailed analysis of the public health impacts of this plan included in the Cumulative Impacts and Air Quality section, in particular health and public safety impacts from roadway expansion projects such as Highway 101 and other projects, as well as impacts on "sensitive receptors" in order to underline the importance of considering those most vulnerable to air pollution. The California Air Resources Board (CARB), in their "Air Quality Land Use Handbook," provides the following definition:

"Sensitive individuals refer to those segments of the population most susceptible to poor air quality (i.e. children, the elderly, and those with pre-existing serious health problems affected by air quality). Land uses where sensitive individuals are most likely to spend time include schools and schoolyards, parks and playgrounds, daycare centers, nursing homes, hospitals, and residential communities (sensitive sites or sensitive land uses)".[1]

5-5

The risks of the increased impacts of expansion of roadway projects on the health of vulnerable populations, and the environmental impacts of increased emissions must be of fundamental importance as the county designs its transportation plan for our future. The DEIR should expand the air quality and cumulative impacts sections to include residential communities located near freeways, as well as schools, schoolyards, parks and playgrounds, daycare centers, nursing homes, and hospitals. Research conducted among school children in Sonoma County estimated prevalence rates of probable asthma at 18% (California Health Interview Survey, 2005). Asthma strikes hardest among minority and low-income populations, which are also more likely to live near freeways and busy roadways. There is extensive research indicating increased asthma and cancer risks for those who live less than 1,000 feet from a freeway.

5-6

Finally, the achievement of greenhouse gas reductions in this report relies on the assumption that emissions from vehicles will improve over time. However, the assumption that air quality will automatically improve is inconsistent with state data that projects a significant increase in air pollution from higher temperatures associated with global warming.

"Climate change has the potential to significantly impact the health of Californians. Research suggests that the most serious effects in average climate, but rather to increased frequency of extreme conditions, principal more frequent, longer and more intense heat waves. Heat wave conditions are also associated with weather patterns conducive to increased air pollution formation and wildfire outbreaks, both of which pose risks to public health. In addition, climate change also has the potential to influence asthma symptoms...."

(2009 Climate Action Team Biennial Report to the Governor and Legislature)

5-7

We submit that the serious societal, climate and health impacts of expanding freeways and roadways in a time of rapid climate change must be reconsidered in order to understand the potential risks to human and environmental health of the projects in this plan. We hope you will provide this analysis and include further alternatives such as fewer roadways and increased bicycle and pedestrian facilities, and public transit, and other alternative transportation options to reduce those impacts.

5-8

Thank you so much for your attention to these concerns.

Jenny Bard	Shan Magnuson
Regional Air Quality Director American Lung Association in CA	Associate Director Sonoma County Asthma Coalition

2

Health Impacts of Air Pollution Exposure in California

The California Air Resources Board published new findings in 2008 and 2009 on the public health impacts of air pollution in California. The data highlights the serious health

> **Ozone** – ozone exposure can cause reduced lung function, increase the incidence of respiratory symptoms, coughing, chest tightness, and shortness of breath, exacerbate asthma symptoms, and even increase the probability of premature death.
>
> **Particulate Matter** - exposure to particulate matter has been associated with cardio-respiratory diseases, hospital admissions, emergency room visits, asthma attacks, and the vast majority of premature death associated with exposure to air pollution.

impacts of exposure to unhealthy levels of ozone and particulate matter. Research supported by CARB into public health impacts of global warming is ongoing, with new studies related to global warming, ozone and particulate matter expected to be released soon.

Current Health Impacts of Air Pollution in California

According to CARB's 2009 estimates, the annual health impacts of exposure to unhealthy levels of ozone and particulate matter in California can be valued at $170 and include:

- 19,000 premature deaths
- 9,400 hospital admissions for respiratory and cardiovascular disease
- 280,000 asthma and other lower respiratory symptoms
- 22,000 cases of acute bronchitis
- 1 million school absences due to respiratory conditions
- 1.9 million work days lost due to respiratory conditions

Diesel engine emissions are responsible for a majority of California's estimated cancer risk attributable to air pollution. In 2008, CARB estimated Diesel Particulate Matter annually contributes to:

- 3,500 Premature deaths
- 250 cases of lung cancer
- Decreased lung function in children
- Chronic bronchitis
- Increased respiratory and cardiovascular hospitalizations
- Aggravated asthma

3

- Increased respiratory symptoms
- Lost workdays

Local Health Impacts of Air Pollution in California

Annual Premature Deaths by Air Basin [figures based on 2008 mortality data]

Exposure to PM2.5 levels above 5 µg/m3*		Exposure to primary Diesel PM	
Air Basin	**Premature Deaths (Mean)**	**Air Basin**	**Premature Deaths (Mean)**
Great Basin Valleys	3	Great Basin Valleys	<1
Lake County	1	Lake County	8
Lake Tahoe	1	Lake Tahoe	<1
Mojave Desert	200	Mojave Desert	65
Mountain Counties	110	Mountain Counties	26
North Central Coast	90	North Central Coast	20
North Coast	68	North Coast	12
Northeast Plateau	8	Northeast Plateau	<1
Sacramento Valley	1,200	Sacramento Valley	180
Salton Sea	190	Salton Sea	35
San Diego County	1200	San Diego County	280
San Francisco Bay	2,600	San Francisco Bay	540
San Joaquin Valley	2,400	San Joaquin Valley	250
South Central Coast	440	South Central Coast	68
South Coast	9,700	South Coast	2,000
Statewide Total (2004-2006 emissions data)	**18,000**	**Statewide Total (2005 emissions data)**	**3,500**

*California Air Resources Board scientific reviewers estimate that exposure to ambient PM2.5 concentrations above 5 ug/m3 can be associated with premature death

Ongoing Research into Global Warming's Effects on Air Pollution

Recent state-sponsored research indicates that global warming could overwhelm current emission controls and require greater reductions to protect air quality. Potential impacts of global warming on California's air quality may include:

- **By 2050:** California could experience up to an additional 30 days per year when ozone exceeds 1-hour state standards, with a lengthened ozone season expanding out from mid-summer (Mahmud, Kleeman, 2008)

- **By 2100**: Los Angeles and the San Joaquin Valley could experience a 75%-85% increase in the number of days conducive to ozone formation (CA Climate Change Center, 2006)

Soon-to-be released state studies of global warming impacts on California will provide updated projections of challenges the state will face in meeting air quality standards in the face of rising temperatures. Previews of some of the research presented to CARB earlier this month indicate increases in ozone and particulate matter may occur, and significantly improved emission control measures may need to be adopted to confront the negative air quality and public health consequences of global warming throughout the state.

4

Letter 5, Jenny Bard, American Lung Association; Shan Magnuson, Sonoma County Asthma Coalition

Response 5-1: Comment noted. Since no comments regarding the adequacy of the analysis in the Draft EIR were provided, no further response is required.

Response 5-2: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 5-3: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts), Response to Comment 2-7 and the air quality analysis in the Draft EIR, Section 4.2 (Air Quality) that shows improved air quality conditions under the 2009 CTP.

Response 5-4: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 5-5: The commenter is referred to Master Response 3.4.6 (Adequacy of Alternatives Analysis) and Response to Comment 2-7 and 2-13.

Additionally, the CTP is a policy document and the Draft EIR is a program EIR, therefore the goals, objectives and policy recommendations of the CTP and mitigation measures recommend in the Draft EIR are programmatic. Although a program EIR had been prepared for the CTP, every new project in within the CTP is subject to a project-specific environmental review as required by CEQA. As such, as the project specific environmental review occurs, impacts associated with development of those projects and their potential impacts on sensitive individuals will be analyzed in subsequent project-specific environmental documents.

Response 5-6: The commenter is referred to Response to Comment 2-7 and 2-13.

Response 5-7: The commenter is referred to Response to Comment 2-12 and 3-13.

Response 5-8: The commenters concerns regarding the environmental effects of the proposed 2009 CTP are responded to in Response to Comments 5-1 through 5-7.

Letter 6

PMC

MEETING MINUTES

Meeting Date:	May 13, 2009 3:00 pm to 4:30 pm	**Author:**	Danielle Griffith
Meeting Topic:	2009 CTP EIR	**Attendees:**	Robert B. Tanner Ann Hancock – Climate Protection Campaign Grace Schulman Alan Strachan Alejandro Peres
		Staff present:	Janet Spilman, SCTA Seana Gause, SCTA Chris Barney, SCTA Patrick Angell, PMC Danielle Griffith, PMC
Project Number:	28-0114	**Cc:**	Doug Kim

This memo summarizes the CTP EIR's Public Meeting for comment on the DEIR.

1. **SPEAKER?** Why isn't CO2 examined in the EIR? Under the Energy summary there is increased consumption but doesn't convert into CO2 equivalent. **6-1**
   a. Is there a bottom line comparison of CTP implementation and 1990, existing v. 1990 conditions? Comes within AB 32 window, where we will hit the cap, CO2 transportation related? **6-2**
   b. Is there a problem with AB 32 1990 and gap we are going to hit? **6-3**
   c. If the EIR shows we are not hitting it, does it jeopardize the AB 32? **6-4**
   d. Does the EIR show the AB 32 cap? Makes no contribution with requirements towards the cap. **6-5**
2. **Robert B. Tanner** - The Do Everything Alternative. Environment and greenhouse gas not particular are and area wide transportation issues and intersections. Just want to make sure dealing with it correctly because I am only dealing with one part of the pie and there are other issues, pedestrians, bikes. **6-6**
3. **Ann Hancock** – What if the EIR highlights failing of the CTP, what can you do? **6-7**
   a. The comments on the EIR open the door to the CTP? **6-8**
   b. Is it okay that the EIR looks at the financially constrained list of projects? **6-9**

PMC *SCTA 2009 CTP EIR Meeting Minutes*

Page 1 of 2

MEETING MINUTES

c. Do you not necessarily have to provide benefits or analysis of the Alternatives? 6-10

d. Impacts are derived from financially constrained list of projects but there are alternatives as well? 6-11

e. Did you define what financially constrained is? 6-12

f. On slide six (of presentation) when it lists goals of the CTP, I think that some of the goals conflict. 6-13

g. On slide 13, lists milestones, what happens then? And then when you're done does it go before the SCTA board? Then what happens? 6-14

h. On slide 15, significant unavoidable environmental impacts – is this a highlight? 6-15

i. Or favorite significant unavoidable impacts – what about greenhouse gas emissions? Can you detail more – I find the math hard to grasp? 6-16

j. New terms? – Tiered and streamlines, and how it relates to the RTP, Sonoma County General Plan and City General Plans. – So is it tiered and streamlined a consistency thing? How does what we are saying here and the EIR, you said GP, with the RTP isn't? Does it mean finish one and they adopt it? What is the relationship between the two the CTP and RTP? Has the RATP been adopted? 6-17

k. Letter from Attorney General's office, October 1008, related to the RTP? Are some of the new things coming out of the AG's office did the document consider this? The interpretation of AB scoping plan and AG's perspective? 6-18

l. Would that also be true for the EPA position? But there are characteristics/data doesn't change the conclusion. 6-19

m. What about GHG and EPA finding that it does affect health? 6-20

n. Transportation and design and greenhouse gases? 6-21

o. What kind of overriding are the SCTA going to have to find in the findings? What will it take? 6-22

p. Ultimately it just has to be a vote of the Board? And then if someone wants to sue can they? 6-23

q. Doesn't that make the EIR vulnerable to attack in terms of the way it is laid out? 6-24

SCTA2009 CTP EIR **PMC**
Meeting Minutes

Page 2 of 2

Letter 6, Public Meeting May 13, 2009, 3:00 to 4:30 pm

Response 6-1: Climate change and GHG emission impacts are addressed in Draft EIR Section 5.0 (Cumulative Impacts). The commenter is also referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts) regarding updated fuel consumption estimates that are now consistent with future fuel economy assumptions used in the Draft EIR GHG emission estimates.

Response 6-2: The CTP is a long range planning document and the EIR is a Program EIR. Analysis of previous 1990 conditions is outside the cope of this Draft EIR as specifically noted in State CEQA Guidelines 15125(a). The environmental baseline conditions for an EIR analysis is as they exist at the time the Notice of Preparation is released, rather than a previous date. The Draft EIR provides an analysis of greenhouse gas emissions in Section 5.4 and is based on whether the CTP would be inconsistent with State efforts to address climate change (AB 32).

Response 6-3: The commenter is referred to Response to Comment 6-2 and Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 6-4: The commenter is also referred to Response to Comment 6-2 and Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 6-5: The commenter is referred to Response to Comment 6-2 and Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 6-6: Comment noted. Draft EIR Alternative 5 includes transportation improvements, transit improvements, bicycle and pedestrian improvements, land use and pricing strategies (see Draft EIR Appendix G and Section 4.0).

Response 6-7: The commenter is also referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts). The SCTA Board of Directors may consider Alternatives to the proposed 2009 CTP as part of its consideration to adopt the CTP.

Response 6-8: The commenter is also referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts). The SCTA Board of Directors may consider Alternatives to the 2009 CTP as part of its consideration to adopt the CTP.

Response 6-9: The commenter is referred to Draft ERI page 3.0-9, Overview of the 2009 Comprehensive Transportation Plan, specifically paragraph one which states:

> *The 2009 CTP is a multi-modal transportation plan that articulates how Sonoma County's transportation infrastructure (e.g., streets, highways, transit systems, and bicycle/pedestrian facilities) will be maintained and improved over the next 25 years. The CTP is financially constrained to project transportation revenues that are reasonably expected to be available over the 25-year planning*

period. However, the CTP may also include a set of illustrative transportation projects that would have benefits if additional revenue is secured in the future.

The Draft EIR project description and environmental analysis are conservatively based on projects and improvements that are feasible for SCTA to implement.

Response 6-10: Table 6.0-21, Summary of Alternatives Comparison, compares each Alternative against the 2009 CTP and provide information on whether there will be a less than significant impact, significant impact comparable with the proposed project, significant impact, with more potential impacts than the proposed project or a significant impact, with less potential impacts than the proposed project.

Response 6-11: The commenter is referred to page 6.0-30 through 6.0-63 of the Draft EIR. This section analyzes the Alternatives and compares the impacts associated with the proposed project against the Alternatives impacts. Moreover, Table 6.0-21, Summary of Alternatives Comparison, compares each Alternative against the 2009 CTP and provides information on whether there will be a less than significant impact, significant impact comparable with the proposed project, significant impact, with more potential impacts than the proposed project or a significant impact, with less potential impacts than the proposed project.

Response 6-12: The commenter is referred to page 3.0-1, first paragraph of the Draft EIR. Specifically the text states:

The project is financially constrained, includes capital highway and transit improvements listed in the Measure M Strategic Plan, constrained programs identified in the MTC's pending Transportation 2035 Plan, and includes trend-based assumptions for growth and pricing of the transportation system.

Draft EIR Section 3.0 also provides list of what projects are included in the proposed CTP.

Response 6-13: Since no comments on the analysis of the Draft EIR are provided, no further response is required.

Response 6-14: The SCTA will prepare written responses to comments received during the public comment period and include them in the Final EIR, the Draft EIR will then be presented to the SCTA Board for certification under State CEQA Guidelines.

Response 6-15: The commenter is correct, the slide summarizes the findings of the DEIR of the significant unavoidable impacts.

Response 6-16: The commenter is referred to Section 5.0 Cumulative Impacts, specifically pages 5.0-20 through 5.0-26, which addresses impacts from implementation of the proposed project on global climate change. The

Draft EIR found the proposed CTP would not have any significant unavoidable impacts on global climate change.

Response 6-17: The commenter is referred to Section 3.0, Overview of the 2009 Comprehensive Transportation Plan, specifically pages 3.0-16 through 3.0-17 which describes how subsequent lead agencies can streamline subsequent environmental assessments by "tiering" from the Program EIR by incorporating relevant discussion by reference and concentrating on issues specific to the later project that were not addressed in this document. The commenter is referred to page 3.0-9 for a discussion of the relationship between the CTP and the RTP, which notes that projects within the proposed CTP are incorporated into the 2009 RTP. The Draft EIR does utilize the environmental impact analysis provided in the Sonoma County General Plan Update EIR, while the traffic analysis for the proposed CTP is based on land uses set forth in local general plans (including the Sonoma County General Plan).

Response 6-18: The Draft EIR analysis of climate change was based on review of guidance provided by the California Attorney General's office and is similar to the conclusions of the MTC 2009 RTP Final EIR regarding climate change.

Response 6-19: The CTP and Draft EIR's analysis of climate change is consistent with the recent guidance on addressing climate change as part of the environmental review process under CEQA, including recommendations provided in the California Governor's Office of Planning and Research technical advisory entitled "CEQA and Climate Change: Addressing Climate Change Through California Environmental Quality Act (CEQA) Review" (June 2008). While not a general plan, the proposed CTP is also generally consistent with the recommended transportation, VMT reduction, transit improvement and pedestrian and bicycle policies identified in the California Air Pollution Control Officer Association's "Model Policies for Greenhouse Gases in General Plans" (June 2009).

Response 6-20: The environmental effects of climate change are anticipated to result in health effects. Draft EIR pages 5.0-11 through -16 specifically notes the environmental effects from climate change that are anticipated to impact transportation facilities in Sonoma County.

Response 6-21: The commenter is referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts).

Response 6-22: CEQA Findings of Fact that will be prepared and adopted for CTP approval will need to identify project benefits that outweigh the anticipated significant environmental effects identified in the Draft EIR as provided for under State CEQA Guidelines Section 15093.

Response 6-23: The comment is referred to Response to Comment 6-22.

Response 6-24: SCTA considers the Draft EIR adequate and meets the requirements of CEQA.

Letter 7

PMC

MEETING MINUTES

Meeting Date:	May 13, 2009 5:30 pm to 7:00pm	**Author:**	Danielle Griffith
Meeting Topic:	2009 CTP EIR	**Attendees:**	Steve Beck – Para transit Driver for Volunteer Wheels Willard Richards – SCTLC/CWUSC Zemo Swytink – Sonoma Wildlife/SSU Bill Kortum Steve Birdlebough, Friends of SMART
		Staff present:	Janet Spilman, SCTA Seana Gause, SCTA Chris Barney, SCTA Patrick Angell, PMC Danielle Griffith, PMC
Project Number:	28-0114	**Cc:**	Doug Kim

This memo summarizes the CTP EIR's Public Meeting for comment on the DEIR.

1. **Zemo Swytink -** Relationship between the EIR and CTP – if the EIR chooses to remove all analysis of bicycle trails and pedestrian paths would not be in CTP, with the exception of the Ferry service? 7-1

   a. Role of the Alternatives in CEQA and why we chose particular alternatives? Why we chose particular ones? If port of Sonoma is one, should alternative have the same analysis of the plan itself? Would consider analysis equally though – if Port is part of the Alternative? Then not part of Alternative? 7-2

   b. Do you consider green house impacts imbedded in road improvements or just use of road improvements? 7-3

   c. The alternatives and mitigation measures proposed needs all to be things the authority has authority over? So when you say it cannot be mitigated it is mitigation under control of authority? Is there any way this can be approached? Example of water agency – reduced greenhouse gas plan introduced greenhouse gas responses but could not do anything. 7-4

   d. Refer to possible greenhouse gas mileage benefits and approved mileage. Vague, considering smart growth and things that people are doing, the improved mileage, improved calculations, mobile emissions and greenhouse gas reduction is state mandated but not looking at it as a constraint in the model. 7-5

MEETING MINUTES

e. Who has the authority to establish gas taxes? Is it Bay Area wide to allow for gas taxes? Wasn't it done for the Bay Area – for 10 cents? **7-6**

2. **Willard Richards** – Rather pleased with the original plan that were proposed to reach the level of greenhouse gas, then when reading appendix E, were over 25% concluded further than the reduction. **7-7**

   a. Wouldn't Alternative Number 5 result in an increase that range from 19 to 25%? How do we get the 325,000 gallons per day to get to the 2025? **7-8**

   b. Where is the best place to get the list of projects and the adopted plan? Is it an overview or does it list specific projects? **7-9**

   c. As the technician you are required to address the comments? Will you address the comments? What weight do you give to the comments? This is a heavily weighted comment how are you going to do that? Interested in can you do more than (inaudible). What is the recourse if the connect doesn't do that? **7-10**

   d. Why doesn't the report (talks about reducing emissions) but all the people on the authority have more precise goal for achieving Sonoma County Transportation in the Climate Action Plan? **7-11**

   e. Greenhouse gas calculations doesn't measure goal of plan and actual impacts. **7-12**

3. **Steve Birdlebough** Seems to be a disconnect between what needs to be done and what happens. The alternatives are not weighted enough. There are things that could be alternatives or joint control by someone in Sacramento. **7-13**

   a. You mentioned the authority has no control over land use and they are integral to each other whereas it was done in the CTP, but the EIR doesn't? **7-14**

   b. If the rail started five years from now and within five years we have transit oriented and pedestrian oriented with 1,000's of people living that way. You can't account for that in your report? You don't account for greenhouse gas and other potential benefits. On the other hand some of your mitigations state vague things that could be done with some amount of money. You are talking about MTC giving certain amounts of money. **7-15**

4. **Steve Beck** - Looking at various impacts in the handout out and it is very vague about what would be done. Looking at impacts and mitigation measures from air quality, some of the mitigation measures are vague and the SCTA can do something about it. I am sure that they will (gives example of bus service reduction and Board of Supervisors) Have mitigation measures that are outside control of SCTA, but then can't consider things outside of SCTA? **7-16**

   a. Seems like use of public transit other than the train is getting short changed and there is a social impact with the reduction of buses and there are a number of people that won't be able to drive. What about Para transit, see no evidence the HOV lanes do anything to reduce to reduce traffic? **7-17**

SCTA2009 CTP EIR **PMC**
Meeting Minutes

Page 2 of 2

Letter 7, Public Meeting May 13, 2009, 5:30 to 7:00 pm

Response 7-1: The Draft EIR evaluates and discloses the physical environmental effects of the full implementation of the proposed CTP as described in Draft EIR Section 3.0. Potential modification of the proposed CTP may require additional environmental review under CEQA depending the extent of the changes.

Response 7-2: The commenter is referred to Master Response 3.4.6 (Adequacy of Alternatives Analysis and Additional Alternatives to be Evaluated) regarding how the range of alternatives were selected as well as Draft EIR Appendix G and Section 4.0 that identifies which alternatives include Port Sonoma project.

Response 7-3: The commenter should note that the Draft EIR evaluates the GHG emission impacts associated with the full implementation of the proposed CTP (construction and operation) (see Draft EIR pages 5.0-21 through -26).

Response 7-4: Various projects contained within the 2009 CTP are not under the jurisdiction of the SCTA, and the SCTA does not have the authority to impose mitigation measures on other jurisdictions. Thus, specific mitigation cannot be provided at the Program EIR level of analysis because project- and site-specific impacts cannot be identified. The commenter is referred to Master Response (3.4.2 Jurisdiction and Role of SCTA) and Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts) regarding feasibility of SCTA to implement some mitigation measures.

Response 7-5: The new fuel economy standards are included in the revised Cumulative Impacts Section 5.0., where vehicle fuel use could decrease due to significant improvements in fuel economy mandated by federal requirement and particularly by State Pavley regulations. These technological requirements will help reduce and even reverse the growth in reliance on petroleum-based fossil fuels that are not renewable in their nature. The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts, Master Response 3.4.2 (Role and Jurisdiction of the SCTA) as well as Draft EIR edits provided in Section 4.0 of this document that provides updated fuel consumption estimates (including estimates for the Draft EIR alternatives) that utilize future fuel economy assumptions that were used in GHG emission estimates in the Draft EIR.

Response 7-6: The commenter is referred to Master Response 3.4.2 (Jurisdiction and Role of the SCTA) and Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 7-7: The commenter is referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts) as well as Draft EIR edits provided in Section 4.0 of this document that provides updated fuel consumption estimates (including estimates for the Draft EIR alternatives) that utilize future fuel economy assumptions that were used in GHG emission estimates in the Draft EIR.

Response 7-8: Alternative 5 is the only Alternative that comes close to meeting the GHG reduction emissions goals, however there are programs contained within the Alternative 5 that are outside of the jurisdiction of the SCTA and are not able to be directly implemented as part of the 2009 CTP. The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts) as well as Draft EIR edits provided in Section 4.0 of this document that provides updated fuel consumption estimates (including estimates for the Draft EIR alternatives) that utilize future fuel economy assumptions that were used in GHG emission estimates in the Draft EIR.

Response 7-9: The existing CTP is available from SCTA. Draft EIR Section 3.0 provides a list of projects associated with the proposed CTP and Section 4.0 includes project list for the Draft EIR alternatives.

Response 7-10: All comments provided during the public meetings and submitted during the public comment period are reviewed and responded to herein. There is no preferential determination or weight given to any comments, all are reviewed and responded to accordingly.

Response 7-11: The commenter is referred to Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts and Master Response 3.4.2 (Jurisdiction and Role of the SCTA)

Response 7-12: The commenter is referred to Master Response 3.4.3 (Commitment of Funds), 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts) and Response to Comment 2-2.

Response 7-13: The commenter is referred to Master Response 3.4.2 (Jurisdiction and Role of the SCTA) and Master Response 3.4.6 (Adequacy of Alternatives Analysis and Additional Alternatives to be Evaluated) regarding how the range of alternatives were selected and evaluated, as well as Section 6.0 of the Draft EIR for the analysis of alternatives.

Response 7-14: The commenter is referred to Master Response 3.4.4 (Program EIR/Level of Detail) and Master Response 3.4.2 (Jurisdiction and Role of the SCTA).

Response 7-15: The commenter is referred to Master Response 3.4.3 (Commitment of Funds), Master Response 3.4.2 (Jurisdiction and Role of the SCTA) and Master Response 3.4.5 (Climate Change and Greenhouse Gas Emission Impacts).

Response 7-16: The commenter is referred to Master Response 3.4.4 (Program EIR/Level of Detail). Also, the Draft EIR includes mitigation measures that are feasible for SCTA to implement (though some require coordination with other agencies) and meet the requirements for mitigation under State CEQA Guidelines Section 15126.4.

Response 7-17: Comment noted. The commenter's statements are not related to the adequacy of the Draft EIR and no further response is required.

Letter 8

COMMENT CARD
Sonoma County Transportation Authority
Comprehensive Transportation Plan
Public Meeting
May 13, 2009

ROBERT B. TANNER

Affiliation: CITIZEN

Address: [redacted]

Comments: NEED TO MODIFY TRAFFIC CONTROL MEASURES TO REDUCE IDLING TRAFFIC, AND ENCOURAGE BIKE USE AND WALKING.

Written comments must be received no later than June 22, 2009 at the following address:
Sonoma County Transportation Authority
490 Mendocino Ave., Suite 206, Santa Rosa, CA 95407
707.565.5370 (facsimile)
Webscta@sctainfo.org

From: Mr. Robert B. Tanner
[redacted]

To: Senate Envoronmental and Public Works Committee
Washington, DC
FAX # (202) 224-1273

Ladies and Gentlemen:

Enclosed with this letter is an E-mail directed to Bruce@Elmwood Consulting at Elmwood Consulting. This firm is engaged with Land Use and Transportation issues in light of reducing transportation's impact on Green House Gases or GHG. This firm is working with the Metropolitan Transportation Commission, the Bay Area Air Quality Management District, and the Assoiciation of Bay Area Governments.

At their request for comments from the public, I sent them this E-mail, outlining how present intersection design and operation has a big impact on GHG. I also made a number of recommendations on how this situation could be improved.

I would like the staff at the Senate Environmental and Public Works to review the letter and I would like to see if the Senate would be interested in both mandating these changes I call for and providing a special Federal program to fund these changes to intersection traffic operations to reduce the generation of excess GHG due to idling vehicles waiting too long at traffic lights.

After reviewing these materials, should you have any questions, you can contact me in one of three ways:

By Post:
Robert B. Tanner
[redacted]

By Phone:
[redacted]

By E-mail:
[redacted]

I appreciate your time and interest

Sincerely,
Robert B. Tanner

robert tanner

From: "robert tanner" [redacted]
To: <bruce@elmwoodconsulting.com>
Sent: Monday, March 16, 2009 10:14 PM
Subject: Transportation Land Use and Greenhouse Gases

Dear Sir:

I want to comment on the proposed reduction to Green House Gases in the Bay Area of California.

For the last Twenty years, I have been studying traffic congestion at intersections. With the recent concern over vehicular generated GHG, my concern has only increased.

For far too long, Suburban California has insisted on building these huge, wide intersections with multi-phased traffic lights that forces traffic, pedestrian and bicycle as well as motor vehicles, to sit and sit for as much as 90 seconds to a full minute at a red light. This is caused by the insistance on 'multi-phased' signals with wait-for-the-arrow full left-turn control on all four directions, or one-direction-only-at a-time 'Split Phasing'.

This type of grossly inefficient traffic management is found in Suburban areas. (Larger cities like San Francisco and Los Angeles get along with basic 'Two-Phase' traffic signaling that is FAR more effective for moving traffic.)

With the need to reduce our carbon footprint, there is a need to END such practice!

The constant lines of dead-stopped idling traffic just sitting waiting, waiting for a green light is a big part of our GHG issue as much fuel is burned while providing no transportation benefit. Worse than that, such long red lights are a real disincentive to walking or bicycling. (Who wants to be standing there, waiting in the hot sun or cold rain, pounding on a push button?)

We can talk about 'syncronizing signals' all we want, but until we start REDESIGNING our intersection controls, we're not going to get the reduction in VMT or reduce our carbon footprint as much as we want.

There are five intersection controls that are much better than these multi-phase signal lights, some of which could inhance the operation of any sort of ITS sycronization system.

The intersection improvements are as follows:

1) ALL-WAY STOP SIGN CONTROL:

Don't laugh. The Manual on Uniform Traffic Control Devices (MUTCD) actually suggests this as an alternative to traffic lights in its Sec. 4b.04!

Smaller outlying communities that have inherited traffic signals from Caltrans, when the community had a bypass put in, could, and should, get rid of these 'legacy lights' and revert to Stop Signs. Many of these small towns need to make themselves more walking and bicycling friendly and Stop Signs are FAR friendlier to walking and bicycling over motor traffic and will encourage these modes. Larger communities could do this to lesser used corridors, making them more geared to walking and bicycling.

GHG reductions comes from not operating the uneeded signals and from VMT reductions.

ROUNDABOUTS:

Traffic more of less keeps moving with minimum delay. TheFHWA is becoming very pro-roundabout and in encouraging these instead of signals. They can handle more traffic than a set of stop signs. Best bet for use is in rural or suburban areas where there is the room for the 130' (40 meter) circle. Getting rid of isolated 'stand alone' signals will save us a ton of money and help reduce GHG gases by not operating the signal and by reducing or eliminating the long lines of dead stopped idling vehicles, typical at a lengthy 'stand alone' traffic light.

PROTECTIVE-PERMISSIVE LEFT TURN SIGNALING (PPLT):
PPLT signals allow left turns on the round green when opposing traffic permits but provides an arrow if necessary. There are far too many of the outdated 'Wait-For-The-Arrow' type left turn signals in California that really are not needed and either should be removed, (full permissive left-turn) or converted to Protected-Permissive Left-Turn (PPLT) operation. This change will reduce GHG gases by the reducing of long lines of dead-stopped vehicles and enhances the operation of a sycronized signal ITS system.

INTERCHANGES:
Getting rid of signals altogether on high traffic volume 'expressways' would get rid of the problem of high-speed traffic having to stop and then reaccelerate to a high speed again. The idling and accelerating traffic generate more GHG than having traffic maintain a steady pace. Expensive, yes. But the old 'Expressway' with both high speed and traffic signals is a grossly outdated road design in today's carbon sensitive environment!

CONTINUAL FLOW INTERSECTION (CFI):
This intersection has the left-turner cross the oncoming lanes about 500 feet before the intersection and come up to the intersecting road to the LEFT of the oncoming lane. It allows more efficient two-phase operating of the traffic signal and reduces GHG by reducing the delay over a typical multi-phase signal with left-turn signals. Both Missouri and Louisianna are experimenting with this concept. (Can only be used on lower traffic volume'expressways' with access limited to cross streets.)

I realize that we need to look at all methods of GHG control that is outlined in your report, but I strongly believe that widespread intersection control reform as I've outlined above must be a vital part of GHG reduction. Also, getting rid of lengthy red ligbts will have strong popular support! You've asked for input from the public and I trust that I've been of assistance to your report.

Thank you for this opportunity.

Sincerely,
Robert B. Tanner
[redacted]

4/25/09

Letter 8, Robert B. Tanner, citizen

Response 8-1: The commenter's statements are not related to the adequacy of the Draft EIR and no further response is required.

Letter 9

From: Willard Richards [redacted]
Sent: Monday, June 08, 2009 10:30 AM
To: Suzanne Smith; Janet Spilman; Seana Gause
Cc: Ann Hancock; Brant Arthur; Steve Birdlebough
Subject: FW: Proposed email to SCTA staff

To: Suzanne Smith, Janet Spilman, and Seana Gause:

This message is an informal communication and is not being submitted as a comment on the Draft EIR for the CTP. The comments will be submitted before the deadline. The purpose here is to give SCTA staff a brief outline of some of our findings.

It is a good rule of thumb that at present the average commuter vehicle emits about a pound per mile of CO2. This corresponds to a fuel efficiency of about 20 mpg and the EPA-recommended 19.4 pounds of emitted CO2 per gallon of gasoline burned (See http://www.epa.gov/otaq/climate/420f05001.htm) **9-1**

Table 5.0-3 on page 5.0-21 of the DEIR (pdf page 337 in the full DEIR) indicates that the daily VMT for all vehicles in Sonoma Co. is 11,441,811 miles per day. This same VMT value is also used in the DEIR for 2008. Since trucks, buses, etc. have higher emissions than commuter vehicles, we would expect emissions of more than 11 million pounds of CO2 per day. The value in the table is more than a factor of four too small, and this seems to be generally true of all CO2 emission values in the DEIR. This can be seen, for example, in the last row in Appendix F. **9-2**

I also believe there are some significant errors in the energy calculations. Table 5.0-3 projects that VMT will increase 26% by 2035, but it also projects that the fuel economy will increase by 62%. If a similar improvement in fuel economy is projected for all vehicles, gasoline (and diesel) consumption, and hence GHG emissions, will decrease by 22%. Let's assume those estimates are correct and compare them with Impact 4.3-1. **9-3**

The information that caught everyone's attention is stated in Impact 4.3-1, which appears on pages 4.13-10 (pdf 311) and again in the Executive Summary page 1.0-27 (pdf 36). It says, "By 2035, motor vehicles would consume 159,000 more gallons of gasoline and 5,000 more gallons of diesel fuel per day than under existing conditions. This represents a 20 percent increase in gasoline consumption and a 7 percent increase in diesel fuel." Depending on which population data from the DEIR are used, the population increase during this time is 15% to 18%. Thus, this impact projects a **per capita** increase in gasoline consumption. I have not found the source of these numbers in the DEIR. The point I want to make is that this impact is inconsistent with the numbers in Table 5.0-3. **9-4**

There is also an error in the fuel use by transit in Table 14.13-3 on page 4.13-11 (pdf 312). The footnotes indicate that the contractor's calculations began with annual data, and it appears the numbers were never converted to daily data. **9-5**

Appendix E on energy calculations does not contain enough information to enable understanding the calculations. That should be remedied in the Final EIR. The methods used to derive the multipliers should be documented and the role of the multipliers in the tables should be explained. Perhaps an efficient way for the contractor to explain the calculation methods would be to print one table from Appendix F with the formulas displayed in each cell **9-6** instead of the values calculated by the formulas. In Excel, this can be accomplished by using Tools/Formula Auditing/Formula Auditing Mode. This printout should also include the labels on the rows and columns to make the formulas understandable. If all tables use the same formulas, one example would do. 9-7

The "VMT Conversion" table at the top of page 3 of Appendix E needs explanation. The two VMT numbers are the same as at the top of page 1, but I was not able to reproduce any of the other numbers in that table. 9-8

Some numbers in Appendix F are reported to ten significant figures. That is not correct. 9-9

It appears that the calculations in Appendix E provide the basis for the energy use and hence GHG emission data in the DEIR. I would be happy to review those calculations when they are corrected and an explanation of them is made available. 9-10

I hope this information is helpful, and would be happy to answer questions.

Willard Richards

Letter 9, Willard Richards, citizen

Response 9-1: Comment noted. GHG emission modeling used in the Draft EIR was based on use of the ICLEI CACP software. See Response 2-44.

Response 9-2: The commenter is referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts) and Response to Comment 9-1.

Response 9-3: The commenter is referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts) as well as Draft EIR edits provided in Section 4.0 of this document that provides updated fuel consumption estimates (including estimates for the Draft EIR alternatives) that utilize future fuel economy assumptions that were used in GHG emission estimates in the Draft EIR.

Response 9-4: The commenter is referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts) as well as Draft EIR edits provided in Section 4.0 of this document that provides updated fuel consumption estimates (including estimates for the Draft EIR alternatives) that utilize future fuel economy assumptions that were used in GHG emission estimates in the Draft EIR.

Response 9-5: The commenter is referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts) as well as Draft EIR edits provided in Section 4.0 of this document that provides updated fuel consumption estimates (including estimates for the Draft EIR alternatives) that utilize future fuel economy assumptions that were used in GHG emission estimates in the Draft EIR.

Response 9-6: The commenter is referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts) as well as Draft EIR edits provided in Section 4.0 of this document that provides updated fuel consumption estimates (including estimates for the Draft EIR alternatives) that utilize future fuel economy assumptions that were used in GHG emission estimates in the Draft EIR.

Response 9-7: The commenter is referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts) as well as Draft EIR edits provided in Section 4.0 of this document that provides updated fuel consumption estimates (including estimates for the Draft EIR alternatives) that utilize future fuel economy assumptions that were used in GHG emission estimates in the Draft EIR.

Response 9-8: The commenter is referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts) as well as Draft EIR edits provided in Section 4.0 of this document that provides updated fuel consumption estimates (including estimates for the Draft EIR alternatives) that utilize future fuel economy assumptions that were used in GHG emission estimates in the Draft EIR.

Response 9-9: The commenter is referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts) as well as Draft EIR edits provided in

Section 4.0 of this document that provides updated fuel consumption estimates (including estimates for the Draft EIR alternatives) that utilize future fuel economy assumptions that were used in GHG emission estimates in the Draft EIR.

Response 9-10: The commenter is referred to Master Response 3.4.5(Climate Change and Greenhouse Gas Emission Impacts) as well as Draft EIR edits provided in Section 4.0 of this document that provides updated fuel consumption estimates (including estimates for the Draft EIR alternatives) that utilize future fuel economy assumptions that were used in GHG emission estimates in the Draft EIR.

References

Bay Area Air Quality Management District, *CEQA Guidelines*, 1999, pg. 22

California Office of Planning and Research (OPR). *2008.* CEQA and Climate Change: Addressing Climate Change Through California Environmental Quality Act (CEQA) Review. June 2008.

CAPOA, 2009. California Air Pollution Control Officer Association. Model Policies for Greenhouse Gases in General Plans. June 2009.

Tholen, Greg. 2009. Personal Communication (Telephone and e-mail), Bay Area Air Quality Management District. August 11, 2009. Danielle Griffith, Senior Environmental Planner, PMC

4.0 Minor Revisions to the Draft EIR

4.1 INTRODUCTION

This section includes minor edits to the Draft EIR. These modifications resulted from responses to comments received during the Draft EIR public review period as well as from staff-initiated changes.

Revisions herein do not result in new significant environmental impacts, do not constitute significant new information, nor do they alter the conclusions of the environmental analysis. Changes are provided in revision marks (<u>underline</u> for new text and ~~strike out~~ for deleted text).

4.2 MINOR CHANGES AND EDITS TO THE DRAFT EIR

1.0 EXECUTIVE SUMMARY

- Draft EIR page 1.0-29, TABLE 1.0-1, Projects Impacts Mitigation Table, please refer to FEIR Section 2.0, Executive Summary for changes to the Projects Impacts Mitigation Table.

3.0 OVERVIEW OF THE CTP

- Draft EIR page 3.0-14, the following changes are made to the Interchange Improvements list:
    - <u>Forestville bypass on Route 116</u>
    - <u>Mirabel Road and Route 116 signalization and channelization</u>

4.2 AIR QUALITY

- Draft EIR page 4.2-17, the following text change is made to the first paragraph under Impact 4.2-2:

  Running emissions from motor vehicles were analyzed as an indicator of the benefits of mobility-enhancing projects and programs in the CTP. Generally, reductions in congestion will improve average vehicle speeds on roadways that will reduce running emissions of air pollutants. As shown in **Table 4.2-9**, running emissions of ROG, NOx, and CO would be reduced between 2008 and the 2035 horizon for the 2009 CTP. The decrease in emissions results from a number of factors, including the CTP's reductions in travel activity combined with the turnover in autos, increasingly stringent emission controls, and related policies. ~~As noted in **Impact 4.2-1**, the CTP would reduce the rate of growth of VMT over existing conditions to a rate closer to the projected population growth rate. Nevertheless, t~~<u>The</u> proposed CTP would be consistent with the CAP population and VMT assumptions in the 2005 Ozone Strategy. These impacts are associated with the planned population growth of the region that is reflected in ABAG's regional forecasts that were used to develop BAAQMD's CAP.

- Draft EIR page 4.2-17, the following text is added to the end of the page:

  <u>In addition to these criteria air pollutants, County roadways would continue to include diesel-powered vehicles. Approximately 60 percent of California's diesel exhaust (a toxic air contaminant) is emitted on roadways by heavy-duty trucks, buses, and light-duty passenger vehicles. CARB adopted an Airborne Toxics Control Measure (ATCM) as part of the Particulate Matter Risk Reduction Plan to specifically deal with diesel emissions from school</u>

buses. This measure became effective July 16, 2003. The school bus–idling ATCM includes the following requirements:

a) The driver of a school bus or vehicle, transit bus, or heavy-duty vehicle (other than a bus) shall manually turn off the bus or vehicle upon arriving at a school and shall restart no more than 30 seconds before departing. A driver of a school bus or vehicle shall be subject to the same requirement when operating within 100 feet of a school and shall be prohibited from idling more than five minutes at each stop beyond schools, such as parking or maintenance facilities, school bus stops, or school activity destinations. A driver of a transit bus or heavy-duty vehicle (other than a bus) shall be prohibited from idling more than five minutes at each stop within 100 feet of a school. Idling necessary for health, safety, or operational concerns shall be exempt from these restrictions.

b) The motor carrier of the affected bus or vehicle shall ensure that drivers are informed of the idling requirements, track complaints and enforcement actions, and keep track of driver education and tracking activities. According to CARB, implementation of the above requirements would eliminate unnecessary idling for school buses and other heavy-duty vehicles, thus reducing localized exposure to TAC emissions and other harmful air pollution emissions at and near schools and protecting children from unhealthy exhaust emissions.

In addition to the school bus–idling ATCM, CARB adopted an idling-restriction ATCM for large commercial diesel-powered vehicles that became effective February 1, 2005. In accordance with this measure, affected vehicles are required to limit idling to no longer than 5 minutes under most circumstances. CARB is currently evaluating additional ATCMs associated with the CARB's Diesel Risk Reduction Plan, Emission Reduction Plan for Ports and Goods Movement, and implementation of AB 233 intended to further reduce TACs associated with mobile sources. Thus, existing state programs will continue to address and reduce TAC emissions associated with diesel and would not result in an increase in these emissions.

- Draft EIR page 4.2-19, the following bullets are added to mitigation measure MM 4.2-4:
  - Implement T-BACT (the Best Available Control Technologies for Toxics) for diesel construction equipment.
  - Idling times shall be minimized either by shutting equipment off when not in use or reducing the maximum idling time to 5 minutes (as required by the California airborne toxics control measure Title 13, Section 2485 of California Code of Regulations [CCR]).
  - All construction equipment shall be maintained and properly tuned in accordance with manufacturer's specifications. All equipment shall be checked by a certified mechanic and determined to be running in proper condition prior to operation.

4.3 TRAFFIC AND CIRCULATION

- Draft EIR page 4.3-14, existing Table 4.3-9 is removed and the following table will replace it:

~~TABLE 4.3-9~~
~~WEEKDAY CONGESTION LOCATIONS ON U.S. 101, RANKED BY DELAY (2002)~~

~~Rank in County~~	~~U.S. 101 Segment~~	~~Direction~~	~~Time Period~~	~~Delay (Vehicle Hours)~~
~~1~~	~~Santa Rosa Ave. & N. Todd Rd. to Steele Ln.~~	~~Northbound~~	~~2:30 PM – 6:45 PM~~	~~1,420~~
~~2~~	~~Hopper Ave. to Route 12~~	~~Southbound~~	~~2:35 PM – 6:25 PM~~	~~860~~
~~3~~	~~Golf Ave. to Baker Rd.~~	~~Northbound~~	~~7:10 AM – 9:15 AM~~	~~630~~
~~4~~	~~Redwood Hwy to Kastania Rd.~~	~~Southbound~~	~~5:45 AM – 8:05 AM~~	~~570~~
~~5~~	~~At Steele Ln.~~	~~Southbound~~	~~7:15 AM – 8:55 AM~~	~~210~~
~~6~~	~~Airport Blvd. to River Rd.~~	~~Southbound~~	~~7:15 AM – 8:50 AM~~	~~200~~
~~7~~	~~At Route 12~~	~~Southbound~~	~~6:25 AM – 9:20 AM~~	~~160~~
~~8~~	~~At Redwood Hwy~~	~~Northbound~~	~~3:50 PM – 6:10 PM~~	~~120~~
~~9~~	~~E. Washington Ave.~~	~~Northbound~~	~~4:25 PM – 6:25 PM~~	~~100~~

~~*Source: Caltrans, District 4 Office of Highway Operations. Information Memorandum, Year 2002 Bay Area Freeway Congestion Data, Tables 4A and 4B (accessed September 12, 2008)*~~

TABLE 4.3-9
WEEKDAY CONGESTION LOCATIONS ON U.S. 101, RANKED BY DELAY

Rank in County	U.S. 101 Segment	Direction	Time Period	Delay (Vehicle Hours)
1	East Washington St. to Kastania Rd.	Southbound	5:25 AM – 7:15 AM	1,880
2	Baker Ave. to College Ave.	Northbound	2:05 PM – 6:30 PM	1,220
3	Mendocino Ave. to 5th St.	Southbound	2:40 PM – 6:20 PM	1,180
4	Route 12 to College Ave.	Northbound	7:00 AM – 9:15 PM	590
5	At East Washington St.	Northbound	2:50 PM – 6:30 PM	290
6	Shilo Rd. to south of Mendocino Ave.	Southbound	7:30 AM – 9:00 AM	270
7	Route 116 to Wilfred Ave.	Northbound	2:30 PM – 4:50 PM	260
8	Steele Ln. to College Ave.	Southbound	7:20 AM – 9:30 AM	180
9	At Old Redwood Hwy	Northbound	3:10 PM – 5:00 PM	50

Source: MTC, Congested Freeway Locations – Morning and Evening Commutes, 2008 http://www.mtc.ca.gov/news/press_releases/congestion/2008/am_pm_peak_period_congestion.pdf. (accessed July 20, 2009).

- Draft EIR page 4.3-29, the following changes are made:

  It should be noted that when compared to a No Project scenario, the proposed CTP would reduce over ~~50,000~~ 350,000 daily VMT countywide in 2035.

- Draft EIR page 4.3-30, the following changes are made to impact statement 4.3-2:

Impact 4.3-2 Implementation of the 2009 CTP would not directly cause increases in daily vehicle hours traveled. However, the 2009 CTP would support growth in Sonoma County that would substantially increase daily vehicle hours ~~miles~~ traveled in 2035 by 282,874 over existing conditions. The impacts associated with the anticipated growth within the county (through 2020) were identified as significant and unavoidable in the County's General Plan 2020 Draft EIR. This impact is considered **significant and unavoidable**.

- Draft EIR page 4.3-33, the following changes are made to impact statement 4.3-4:

Impact 4.3-4 Implementation of the 2009 CTP would not directly increase PHD or ~~of~~ PHT on the county's roadway system. However, the 2009 CTP would support growth in Sonoma County that would substantially increase daily PHD by 250,102 and PHT by 335,166 over existing conditions. The traffic impacts associated with the anticipated growth within the county (through 2020) were identified as significant and unavoidable in the County's General Plan 2020 Draft EIR. This impact is therefore considered **significant and unavoidable.**

4.4 BIOLOGY

- Draft EIR page 4.4-25, mitigation measure MM 4.4-1a is revised as shown below:

MM 4.4-1a During the environmental review process for proposed CTP projects, project sponsors shall prepare a biological resources assessment ~~shall be prepared~~ for areas identified to contain or possibly contain special-status plant and animal species. Surveys shall be conducted as part of the environmental review process to determine the presence and extent of sensitive habitats and/or species in the project vicinity. Surveys shall be conducted during the appropriate seasons for proper identification of species. The assessment shall consider the potential for significant impacts on special-status plant and animal species and shall identify feasible mitigation measures to mitigate such impacts, as set forth in mitigation measure MM 4.4-1b below.

Formal protocol-level surveys may be required on a species-by-species basis to determine the local distribution of these species. Consultation with the USFWS and/or CDFG shall be conducted at an informal level for transportation projects that could adversely affect federal or state candidate, threatened, or endangered species to determine the need for further consultation or permitting actions.

- Draft EIR page 4.4-25, mitigation measure MM 4.4-1b, fourth bullet is deleted and replaced with the following text:

  - ~~Individual projects shall minimize the use of in-water construction methods in areas that support sensitive fish species, especially when fish are present.~~

  - Individual projects will avoid the use of in-water construction methods in all state of federally jurisdictional surface waters, where feasible.

- Draft EIR page 4.4-29, the following changes are made to the first paragraph:

Implementation of the proposed 2009 CTP may result in the loss of jurisdictional waters of the state and waters of the U.S., including wetlands.

- Draft EIR page 4.4-29, the following additions are made to the fourth paragraph:

  As described further above, Sonoma County and incorporated city general plans include numerous policies that regulate biological resource issues that are relevant to the 2009 CTP. Applicable goals, policies, and implementation programs from these general plans would assist in reducing any potential biological impacts to waters of the U.S. Additional mitigation measures are proposed below to further protect and minimize impacts to waters of the U.S. <u>The Regional Water Board has jurisdiction over surface waters, groundwater, and wetlands, and has jurisdictional authority over any projects which may impact surface waters, groundwater, and wetlands.</u>

4.5 CULTURAL RESOURCES

- Draft EIR page 4.5-15, the following text changes are made:

MM 4.5-2a During the environmental review process for proposed CTP projects, project sponsors<u>, in consultation with the appropriate culturally affiliated tribe(s),</u> shall determine if there is a potential for a significant impact to cultural resources to occur.

MM 4.5-2b If a potentially significant cultural resource is encountered during subsurface earthwork activities for the project, all construction activities within a 100-foot radius of the find shall cease until a qualified archaeologist<u>, in consultation with the appropriate culturally affiliated tribe(s),</u> determines whether the resource is significant. The project sponsor shall include a standard inadvertent discovery clause, <u>including a requirement for consultation with the appropriate culturally affiliated tribe(s),</u> in every construction contract to inform contractors of this requirement**.**

MM 4.5-2c The project sponsor shall implement the appropriate mitigation measures presented by a qualified archaeologist, <u>and developed in consultation with the appropriate affiliated tribes(s)</u>, for any discovery of significant resources, based on applicable state and federal regulations**.**

4.7 HAZARDS AND HAZARDOUS MATERIALS

- Draft EIR page 4.7-15, the following changes are made to mitigation measure MM 4.7-3:

  Subsequent projects under the CTP shall consult all known databases of contaminated sites and undertake a Phase I Environmental Site Assessment or other appropriate hazard assessment in the process of planning, environmental clearance, and construction for projects included in the 2009 CTP. <u>Prior to development on or near active cleanup sites, the project proponent shall coordinate with all appropriate agencies.</u> If contamination is found, the implementation agency shall coordinate remediation of contamination in accordance with applicable Sonoma County, Regional Water Quality Control Board, the <u>Department of Toxic Substances Control,</u> and state standards.

4.8 HYDROLOGY AND WATER QUALITY

- Draft EIR page 4.8-15, the following text change is made to the first bullet, last sentence:

MM 4.8-1a Revegetation shall emphasize ~~drought-tolerant perennial vegetation~~ native vegetation.

- Draft EIR page 4.8-16, the following text change is made to the first paragraph:

For unavoidable impacts to waters of the state, submittal of applications for 401 Water Quality Certification and/or Waste Discharge Requirements (Dredge/Fill) permits from the Regional Water Baard will be necessary. United States Army Corps of Engineers Clean Water Act Section 404 permits and Department of Fish and Game stream alteration agreements may also be necessary. Through the implementation of mitigation measures **MM 4.9-1a** through **MM 4.8-1d,** the CTP's impact on water quality would be considered **less than significant.**

- Draft EIR page 4.8-16, mitigation measure MM 4.8-1a, first bullet: first sentence is deleted and replaced with the following text:

~~BMPs such as those described above shall be in place and operational prior to major earthwork.~~

BMPs shall be in place and operational prior to any construction activities. Post- construction BMPs shall be in place prior to the commencement of any work within the vicinity of waters of the state.

- Draft EIR page 4.8-16 is revised to include mitigation measure MM 4.8-1e as follows:

MM 4.8-1e Where specific projects are located within or adjacent to a water body that is under the jurisdiction of the Regional Water Quality Control Board, the projects shall implement the following measures:

- Include construction BMPs specifically targeted toward retaining sediment on-site, preventing erosion of streambanks and pollution from construction vehicles, and collecting and treating stormwater runoff on-site.
- Utilize staging areas for vehicles that are removed from riparian areas and all construction should occur during the dry season. If such measures cannot be taken, the individual project should be required to analyze alternatives and provide mitigation measures for adverse impacts.
- Where feasible, avoid the removal of riparian vegetation. If not feasible, the individual project shall be required to demonstrate a plan for revegetation including a post-construction monitoring plan to determine the success of revegetation efforts. Monitoring and maintenance plans shall also be in place to ensure that runoff treatment mechanisms such as sediment basins or silt fences continue to function properly. Runoff from all areas of new impervious surfaces should be mitigated for potential impacts to receiving water quality and flow.
- Where feasible, specific projects shall incorporate Low Impact Development techniques to implement mitigation measure MM 4.8-1e.

4.11 POPULATION AND HOUSING

- Draft EIR page 4.11-2, last sentence, first paragraph the following text is added:

High projected job growth and the expected expansion of Santa Rosa Junior College and Sonoma State University enrollments by 2035 contribute to increased travel in the county .

4.12 PUBLIC SERVICES

- Draft EIR page 4.12-10, the following changes are made to impact statement 4.12-3:

Impact 4.12-3 ~~Construction of capital improvements in the proposed CTP will produce solid waste that will not impact the existing Central Landfill operated by Sonoma County.~~ Construction debris would need to be transported to other facilities outside of Sonoma County. These impacts are considered **significant and mitigable**.

4.13 ENERGY

- Draft EIR page 4.13-4, the following changes are made to the table:

TABLE 4.13-1
MOTOR VEHICLE ENERGY CONSUMPTION (2008)

2008	Passenger Cars	Light-Duty Trucks	Light-Duty Trucks	Medium-Duty Trucks	Heavy-Duty Trucks	Buses Total	School Buses	Urban Buses	Motor Homes	Motor Cycles	All
Vehicles	182,284	73,564	76,214	27,951	16,672	361	312	166	4,014	17,295	398,832
VMT/ 1000	5,026	2,097	2,360	989	765	17	11	18	42	122	11,442
Fuel Consumption (1,000 Gallons per Day)											
Gasoline	~~244~~ 252	~~118~~ 101	~~118~~ 140	79	35	1	0	1	3	4	~~625~~ 595
Diesel	1	5	0	0	57	1	2	3	1	0	~~70~~ 69
CNG	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1	n/a	n/a	4 1

n/a – Data not available
Sources: Sonoma County Transportation Model, 2008, and California Air Resources Board, Emfac2007 V2.3 BURDEN output (fuel consumption). CNG fuel usage data from Sonoma County Transit. (Assumes annual CNG fleet consumption-570,597 therms converted to diesel gallons. Max fleet size increase projected at a maximum of 10 buses during planning horizon [annual consumption of 9,122 diesel gallons per bus]. Assumes uniform rate of per capita bus CNG consumption over planning horizon.)

- Draft EIR page 4.13-10, the following changes are made to the first paragraph:

METHODOLOGY

The methodology for determining the significance of energy impacts compares existing conditions to the expected future energy consumption with the 2009 CTP, pursuant to CEQA Guidelines Section 15126.2(a). This analysis focuses on the increase in fuel consumption from the on-road vehicle fleet through 2035. The Sonoma County Transportation Model supplied vehicle activity data (i.e., VMT) for all analysis scenarios (i.e., existing 2008, No Project scenario 2035, and proposed CTP 2035) used to conduct energy impact assessments. The Air Resources Board's Emfac2007 model (version 2.3) was used to forecast consumption of petroleum-based gasoline and diesel fuels based on fuel economy assumptions provided by SCTA staff. Existing and projected natural gas consumption by Sonoma County Transit was derived from data from SCTA staff.

- Draft EIR page 4.13-10, the following changes are made starting with the fourth paragraph:

~~Increase in~~ Fuel Consumption from Transportation Sector

Impact 4.13-1 Implementation of the 2009 CTP would not directly cause increases in energy consumption from the transportation sector. ~~However, in addressing current and projected mobility challenges,~~ Though the 2009 CTP would accommodate planned growth in Sonoma County, ~~that will substantially increase~~ consumption of nonrenewable petroleum-based products like gasoline and diesel fuel are projected to decrease over existing conditions by 2035. By 2035, motor vehicles would consume 68,728 ~~159,000~~ fewer ~~more~~ gallons of gasoline and 11,286 ~~5,000~~ more gallons of diesel fuel per day than under existing conditions. This represents a 12 ~~20~~ percent decrease in gasoline consumption and a 16 ~~7~~ percent increase in diesel fuel. In addition, proposed commuter rail service and freight service on the SMART corridor will consume ~~916,000 gallons of diesel fuel daily~~ 30 billion BTUs of energy annually starting in 2014; however, any increases in diesel fuel for locomotives is expected to be more than offset by reductions in vehicle use from SMART riders. The CTP's cumulative ~~is~~ impact on energy consumption is **less than significant** ~~and unavoidable~~**.**

Over time, demand for energy and fuels from the transportation system ~~will increase~~ is expected to decrease overall, despite ~~based largely on~~ the 15 percent population growth in Sonoma County and a growing job base that will attract workers from outside Sonoma County.[1] By 2035, motor vehicles will consume 526,439 ~~782,000~~ gallons of gasoline and ~~74,000~~ 80,611 gallons of diesel fuel daily ~~by 2035~~ (see **Table 4.13-2**). This represents a 12 ~~15~~ percent ~~increase~~ decrease in gasoline use and 16 percent increase in diesel fuel use over existing conditions, excluding fuel use for the SMART system (see **Table 4.13-3**). ~~This is a worst-case scenario assumption, as some of this demand will be reduced with SMART rail service, NCRA freight service, and improved fuel economy standards.~~ The projected reduction in gasoline consumption is tied to federal and state fuel economy standards that will substantially reduce per capita fuel consumption. ~~However, countywide fuel consumption is still expected to increase over time.~~ Given that the bulk of the county's transportation system will continue to be fueled by gasoline, there would be an overall 9 percent reduction in

[1] Sonoma County Transportation Authority, *Draft 2009 CTP.*

petroleum-based fossil fuel consumption by the transportation sector. See **Appendix ~~D~~E** for CARB's BURDEN model documentation.

TABLE 4.13-2
TRANSPORTATION ENERGY CONSUMPTION (2035)

2035	Passenger Cars	Light-Duty Trucks	Light-Duty Trucks	Medium-Duty Trucks	Heavy-Duty Trucks	Buses	School Buses	Urban Buses	Motor Homes	Motor Cycles	All
Vehicles	251,319	100,464	107,010	39,399	22,867	507	403	214	5,431	24,008	551,621
VMT/ 1000	6,495	2,749	2,891	1,134	882	21	14	21	54	157	14,418
Fuel Consumption (1,000 Gallons per Day)											
Gasoline	197 ~~303~~	82 ~~16~~	92 ~~173~~	100 ~~92~~	44	1 ~~0~~	0	1	4	5	526 ~~782~~
Diesel	0	0	0	0	72	3	2	4	1	0	81 ~~74~~
CNG	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2	n/a	n/a	2 ~~502~~

n/a – Not Available
Sources: Sonoma County Transportation Model, 2008, and California Air Resources Board, Emfac2007 V2.3 BURDEN output (fuel consumption). CNG fuel usage data from Sonoma County Transit. (Assumes annual CNG fleet consumption-570,597 therms converted to diesel gallons. Max fleet size increase projected at a maximum of 10 buses during planning horizon [annual consumption of 9,122 diesel gallons per bus]. Assumes uniform rate of per capita bus CNG consumption over planning horizon.)

TABLE 4.13-3
2009 CTP TRANSPORTATION ENERGY CONSUMPTION (2008 AND 2035)

	2008	No Project (2035)	2008 CTP (2035)	Change 2008 to 2035	
				Annual	Percentage
VMT*	11,447,000 ~~11,447,811~~	14,768,411	14,417,956	+2,970,956 ~~2,970,145~~	+26%
Fuel Consumption (1,000 Gallons per Day)					
Gasoline	595 ~~625~~	539 ~~802~~	526 ~~782~~	-69 ~~157~~	-12% ~~+15%~~
Diesel	69 ~~70~~	82 ~~76~~	81 ~~74~~	+11 ~~-4~~	+16% ~~6~~
CNG **	1 ~~41~~	2 ~~51~~	2 ~~50~~	+~~9~~ 1	+~~22~~100%
~~Diesel from SMART System***~~	~~0~~	~~0~~	~~916~~	~~+916~~	~~Infinite~~
Total Consumption	665 ~~1,106~~	622 ~~1,390~~	609 ~~2,274~~	-56 ~~+1,168~~	-9% ~~+106%~~

Sources:
** Sonoma County Transportation Model, 2008, and California Air Resources Board, Emfac2007 V2.3 BURDEN output.*
***Sonoma County Transit. Annual CNG fleet consumption-570,597 therms converted to diesel gallons. Max fleet size increase projected at a maximum of 10 buses during planning horizon (annual consumption of 9,122 diesel gallons per bus). Assumes uniform per capita bus rate of CNG consumption over planning horizon.*
~~****Sonoma Marin Area Rail Transit. Draft SEIR, March 2008. Based on 2025 forecast for weekday and weekend service. Includes direct energy use from passenger vehicles, transit buses, heavy DMU passenger rail at 95,000 BTU/mile, plus indirect energy use, which includes maintenance vehicles. Assumes 130,500 BTUs are equal to one gallon of diesel. Consumption rates projected through 2025 only. SMART DMUs use 25 percent fewer BTUs per vehicle mile than traditional passenger rail vehicles. SMART is also considering operating the DMUs on a biodiesel fuel mixture. Biodiesel blends of 20 percent or less can be used in DMU vehicles without requiring any modifications to the vehicles. Fuel efficiency is expected to be slightly less than DMUs operated on conventional diesel – two miles*~~

~~per gallon for diesel fuel (Colorado Railcar Manufacturing, LLC, 2003) and 1.96 miles per gallon for biodiesel (EPA, 2002). A biodiesel consumption rate is not currently available.~~

Future SMART commuter rail service is expected to increase diesel fuel consumption for the Diesel Multiple Units. As noted in the Sonoma-Marin Area Rail Transit Draft SEIR (March 2008), locomotives are expected to consume about 30 billion BTUs annually. However, any increases in fuel consumption are projected to be more than offset from reduced vehicle use of commuters and other riders. SMART service is ultimately projected to consume 11,000 fewer barrels of oil annually by 2025 when compared to a No Project alternative.

It should be noted that the 2008 CTP would reduce fuel consumption from on-road motor vehicles when compared to a No Project scenario. In 2035, the CTP would reduce gasoline consumption by 2 percent and diesel fuel consumption by 2 ~~3~~ percent annually over a No Project scenario (see **Table 4.13-4**).

TABLE 4.13-4
2009 CTP TRANSPORTATION ENERGY CONSUMPTION (2035)
COMPARISON TO NO PROJECT SCENARIO

	No Project (2035)	2009 CTP (2035)	Change from No Project to 2009 CTP (2035)	
			Annual	Percentage
VMT*	14,768,411	14,417,956	-350,455	-2%
Fuel Consumption (1,000 Gallons)				
Gasoline	539 ~~802~~	~~782~~ 526	13 ~~20~~	-2%
Diesel	83 ~~76~~	81 ~~74~~	-2	-3%
CNG**	1 ~~52~~	2 ~~50~~	+0 ~~1~~	+100% ~~2%~~
Total Consumption	623 ~~2,306~~	609 ~~2,274~~	-15 ~~32~~	-2% ~~1%~~

Sources:
** Source: Sonoma County Transportation Model, 2008, and California Air Resources Board, Emfac2007 V2.3 BURDEN output.*
***Sonoma County Transit. Annual CNG fleet consumption-570,597 therms converted to diesel gallons. Max fleet size increase projected at a maximum of 10 buses during planning horizon (annual consumption of 9,122 diesel gallons per bus). Assumes uniform per capita bus rate of CNG consumption over planning horizon.*
*~~*** Sonoma-Marin Area Rail Transit. Draft SEIR, March 2008. Based on 2025 forecast for weekday and weekend service. Includes direct energy use from passenger vehicles, transit buses, heavy DMU passenger rail at 95,000 BTU/mile, plus indirect energy use, which includes maintenance vehicles. Assumes 130,500 BTUs are equal to one gallon of diesel. Consumption rates projected through 2025 only. SMART DMUs use 25 percent fewer BTUs per vehicle mile than traditional passenger rail vehicles. SMART is also considering operating the DMUs on a biodiesel fuel mixture. Biodiesel blends of 20 percent or less can be used in DMU vehicles without requiring any modifications to the vehicles. Fuel efficiency is expected to be slightly less than DMUs operated on conventional diesel - two miles per gallon for diesel fuel (Colorado Railcar Manufacturing, LLC, 2003) and 1.96 miles per gallon for biodiesel (EPA, 2002). A biodiesel consumption rate is not currently available~~*

- Draft EIR page 4.13-14, the following changes are made to the second paragraph:

  ~~Nevertheless, regional forecasts for Sonoma County and the greater Bay Area indicate that energy use and transportation-related fuel use in particular will increase substantially through the 2035 horizon year of the proposed 2009 CTP. If these trends continue, implementation of the proposed projects in the 2009 CTP would accommodate the increased use of petroleum fuels between the current conditions and 2035.[2]~~

- Draft EIR page 4.13-14, the following changes are made directly below the subheading "Mitigation Measures":

In addition to the mitigation measures specified below, mitigation measures identified in the Transportation Section for the impacts of transportation system usage would serve to further ~~mitigate~~ the impacts of ~~growing~~ transportation energy demand

- Draft EIR page 4.13-14, the following changes are made directly below mitigation measure MM 4.13-1c:

The countywide ~~increase~~ decrease in transportation-related energy demand (i.e., petroleum-based fuels) as a result of implementing the 2009 CTP would ~~remain~~ be considered **less than significant.** ~~significant and unavoidable impact, even with the above mitigation measures.~~

5.0 CUMULATIVE IMPACTS

- Draft EIR page 5.0-9, the following changes are made to the second paragraph:

SECTION 5.13 ENERGY

The proposed project would implement transportation projects and programs that would help address current and future mobility challenges within Sonoma County. This will help to reduce energy consumption from motor vehicles and their use of petroleum-based fuels and renewable fuels. However, while the rate of growth of VMT and other travel indicators will result in more vehicle activity, ~~lead to inevitable increases in~~ vehicle fuel use could decrease due to significant improvements in fuel economy mandated by federal requirement and particularly by State Pavley regulations. These technological requirements will help reduce and even reverse the growth in reliance ~~most of which is expected to rely~~ on petroleum-based fossil fuels that are not renewable in their nature. Proposed mitigation measures will help to further reduce ~~the continuing trend for increased~~ fuel consumption countywide ~~but major new reforms (e.g., higher federal CAFE fuel economy standards) would be needed to address the cumulative impacts of growth on fuel consumption~~. Thus, this impact is less than cumulatively considerable.

- Draft EIR page 5.0-20, the following sentence is added after the last paragraph under "Methodology":

Appendix F provides a summary of greenhouse gas emission modeling results for the proposed CTP as well as the Draft EIR alternatives evaluated in Section 6.0 (Project Alternatives).

- Draft EIR page 5.0-21, the following changes are made to Table 5.0-3:

TABLE 5.0-3
MOTOR VEHICLE FLEET TRAVEL AND GHG FORECASTS (2005 AND 2035)

Criterion	2005 Existing Conditions	2035 No Project Scenario	2009 CTP 2035 Conditions	Change 2005 to 2035	
				Numerical	Percentage
Daily Vehicle Miles of Travel (VMT)	11,441,811	14,768,411	14,417,956	+2,976,144	+26.0%
Daily Vehicle Miles Traveled per Capita	23.1	26.0	25.3	+2.2	+9.5%

Criterion	2005 Existing Conditions	2035 No Project Scenario	2009 CTP 2035 Conditions	Change 2005 to 2035	
				Numerical	Percentage
Fuel Economy (miles per gallon)*	19.86	32.15	32.15	+12.29	+61.9%
Carbon Dioxide Equivalent emissions (CO_2e ~~pounds per day~~ tons per year)	2,549,042	2,048,185	1,999,582	-549,460	-21.6%

** For light-duty autos and trucks*
Source: Sonoma County Transportation Authority; Sonoma County Transportation Model and Clean Air and Climate Protection Software

- Draft EIR page 5.0-26, the following change is made to Mitigation Measure MM 5.0-3:

MM 5.0-3 SCTA shall work with appropriate stakeholders to provide funding for ~~ensure that~~ future transportation plans and projects are consistent with AB 32 implementation standards and guidelines once they are developed.

6.0 PROJECT ALTERNATIVES

- Draft EIR page 6.0-1, the following text change is made to the last sentence on the page:

  A complete listing of projects by alternative is provided in Appendix G ~~F of the 2008 CTP~~, Draft EIR.

- Draft EIR page 6.0-4, (Alternative 2, Alternative 2, CTP Vision Scenario, Financially Unconstrained Capital Improvement Scenario) the following additions are made to the bulleted list:
  - Santa Rosa CityBus – Facilities Enhancement Program
  - Santa Rosa CityBus – Technology Enhancement Program
  - Sonoma County Transit – Facility Expansion
- Draft EIR page 6.0-7, (Alternative 2, CTP Vision Scenario, Financially Unconstrained Capital Improvement Scenario) the following additions are made to the bulleted list under the local road improvements heading:
  - South Healdsburg Avenue/Mill Street ~~Improvements~~ / Vine Street 5-way Intersection Improvements
- Draft EIR page 6.0-11, (Alternative 2, CTP Vision Scenario, Financially Unconstrained Capital Improvement Scenario) the following additions are made to the bulleted list under the local road improvements heading:
  - Southwest Blvd Corridor Improvements
  - Southern Crossing at Caulfield
  - HWY 101 I/C - Mendocino Ave/Hopper Ave

- Sebastopol Bypass – Llano Rd. Improvements & extension, HWY 116 to Occidental Rd.
- Traffic Calming of County ROW Countywide

- Draft EIR page 6.0-12, (Alternative 3, VMT Reduction – Transit Expansion/Smart Growth Focused Scenario) the following additions are made to the bulleted list under the transit improvements heading:
    - Santa Rosa CityBus – Facilities Enhancement Program
    - Santa Rosa CityBus – Technology Enhancement Program
    - Sonoma County Transit – Facility Expansion
- Draft EIR page 6.0-13, (Alternative 3, VMT Reduction – Transit Expansion/Smart Growth Focused Scenario) the following additions are made to the bulleted list under the transit improvements heading:
    - Golden Gate Transit – Decrease Headways
    - Petaluma Transit – Decrease Headways
    - SCT Route 66 (Windsor) – Decrease Headway
    - SCT Route 68 (Cloverdale) – Decrease Headway
    - Smart Rail – Decrease Headway

REVISED APPENDIX E - ESTIMATE OF FUEL CONSUMPTION FROM ON-ROAD MOTOR VEHICLES

Scenario: 2008 Existing												**Compared to Existing (2008)**		**Compared to No Project (2035)**	
	Passenger Cars	**Light-Duty Trucks**	**Light Duty Trucks**	**Medium-Duty Trucks**	**Heavy-Duty Trucks**	**Buses**	**School Buses**	**Urban Buses**	**Motor Homes**	**Motorcycles**	**All**	**Net Change**	**Percent**	**Net Change**	**Percent**
VMT	5,026,000	2,097,000	2,360,000	989,000	765,000	17,000	11,000	18,000	42,000	122,000	11,447,000	-	0%	(3,321,411)	-22%
Gasoline	252,039	101,297	118,832	79,000	35,000	1,000	-	1,000	3,000	4,000	595,167	-	0%	55,932	10%
Diesel	1,033	4,292	0	0	57,000	1,000	2,000	3,000	1,000	-	69,325	-	0%	(13,245)	-16%
Total	253,072	105,589	118,832	79,000	92,000	2,000	2,000	4,000	4,000	4,000	664,492	-	0%	42,688	7%
Fuel Economy Assumption for LDA and LDT											19.86				
Assumptions: *Based on ARB BURDEN2007 VMT and fuel consumption data for 2008 base year*															
Scenario: 2035 No Project/No Action (Alternative 1)															
	Passenger Cars	**Light-Duty Trucks**	**Light Duty Trucks**	**Medium-Duty Trucks**	**Heavy-Duty Trucks**	**Buses**	**School Buses**	**Urban Buses**	**Motor Homes**	**Motorcycles**	**All**				
VMT	6,484,322	2,705,456	3,044,767	1,275,964	986,969	21,933	14,192	23,223	54,187	157,399	14,768,411	3,321,411	29%	-	0%
Gasoline	201,690	84,151	94,705	101,922	45,155	1,290	-	1,290	3,870	5,161	539,235	(55,932)	-9%	-	0%
Diesel	-	-	0	0	73,539	1,290	2,580	3,870	1,290	-	82,570	13,245	19%	-	0%
Total	201,690	84,151	94,705	101,922	118,694	2,580	2,580	5,161	5,161	5,161	621,805	(42,688)	-6%	-	0%
Fuel Economy Assumption for LDA and LDT											32.15				
Assumptions: *VMT forecasts based on SCTA SCTM07 travel demand model output for the No Project alternative.* *Gasoline fuel consumption estimates based on projected 2035 fuel economy assumptions for LDT and LDA vehicles, assuming implementation of California Pavley regulations* *Gasoline and diesel fuel consumptions estimates for other on-road vehicles based on an extrapolation of consumption rates from 2008*															
Scenario: Proposed Project															
	Passenger Cars	**Light-Duty Trucks**	**Light Duty Trucks**	**Medium-Duty Trucks**	**Heavy-Duty Trucks**	**Buses**	**School Buses**	**Urban Buses**	**Motor Homes**	**Motorcycles**	**All**				
VMT	6,330,449	2,641,256	2,972,515	1,245,685	963,548	21,412	13,855	22,672	52,901	153,664	14,417,956	2,970,956	26%	(350,455)	-2%
Gasoline	196,904	82,154	92,458	99,504	44,084	1,260	-	1,260	3,779	5,038	526,439	(68,728)	-12%	(12,796)	-2%
Diesel	0	0	0	0	71,794	1,260	2,519	3,779	1,260	-	80,611	11,285	16%	(1,959)	-2%
Total	196,904	82,154	92,458	99,504	115,878	2,519	2,519	5,038	5,038	5,038	607,049	(57,443)	-9%	(14,755)	-2%
Fuel Economy Assumption for LDA and LDT											32.15				
Assumptions: *VMT forecasts based on SCTA SCTM07 travel demand model output for the 2009 CTP project alternative.* *Gasoline fuel consumption estimates based on projected 2035 fuel economy assumptions for LDT and LDA vehicles, assuming implementation of California Pavley regulations* *Gasoline and diesel fuel consumptions estimates for other on-road vehicles based on an extrapolation of consumption rates from 2008*															
Scenario: 2035 Vision Scenario (Alternative 2)															
	Passenger Cars	**Light-Duty Trucks**	**Light Duty Trucks**	**Medium-Duty Trucks**	**Heavy-Duty Trucks**	**Buses**	**School Buses**	**Urban Buses**	**Motor Homes**	**Motorcycles**	**All**				
VMT	6,338,250	2,644,511	2,976,178	1,247,220	964,736	21,439	13,872	22,700	52,966	153,853	14,435,724	2,988,724	26%	(332,687)	-2%
Gasoline	197,146	82,255	92,572	99,626	44,138	1,261		1,261	3,783	5,044	527,088	(68,080)	-11%	(12,147)	-2%
Diesel	0	0	0	0	71,882	1,261	2,522	3,783	1,261	-	80,710	11,385	16%	(1,860)	-2%
Total	197,146	82,255	92,572	99,626	116,020	2,522	2,522	5,044	5,044	5,044	607,797	(56,695)	-9%	(14,007)	-2%
Fuel Economy Assumption for LDA and LDT											32.15				
Assumptions: *VMT forecasts based on SCTA SCTM07 travel demand model output for the 2009 CTP project alternative.* *Gasoline fuel consumption estimates based on projected 2035 fuel economy assumptions for LDT and LDA vehicles, assuming implementation of California Pavley regulations* *Gasoline and diesel fuel consumptions estimates for other on-road vehicles based on an extrapolation of consumption rates from 2008*															

Scenario: 2035 Reduction – Transit Expansion/Smart Growth Focused Scenario (Alternative 3)

	Passenger Cars	Light-Duty Trucks	Light Duty Trucks	Medium-Duty Trucks	Heavy-Duty Trucks	Buses	School Buses	Urban Buses	Motor Homes	Motorcycles	All				
VMT	5,861,335	2,445,527	2,752,239	1,153,375	892,145	19,825	12,828	20,992	48,981	142,277	13,349,523	1,902,523	17%	(1,418,888)	-10%
Gasoline	182,312	76,066	85,606	92,130	40,817	1,166	-	1,166	3,499	4,665	487,427	(107,740)	-18%	(51,807)	-10%
Diesel	0	0	0	0	66,474	1,166	2,332	3,499	1,166	-	74,637	5,312	8%	(7,933)	-10%
Total	182,312	76,066	85,606	92,130	107,291	2,332	2,332	4,665	4,665	4,665	562,064	(102,428)	-15%	(59,740)	-10%
Fuel Economy Assumption for LDA and LDT											32.15				

Assumptions: *VMT forecasts based on SCTA SCTM07 travel demand model output for the 2009 CTP project alternative.*
Gasoline fuel consumption estimates based on projected 2035 fuel economy assumptions for LDT and LDA vehicles, assuming implementation of California Pavley regulations
Gasoline and diesel fuel consumptions estimates for other on-road vehicles based on an extrapolation of consumption rates from 2008

Scenario: 2035 VMT Reduction – Pricing Policy Focused Scenario (Alternative 4)

	Passenger Cars	Light-Duty Trucks	Light Duty Trucks	Medium-Duty Trucks	Heavy-Duty Trucks	Buses	School Buses	Urban Buses	Motor Homes	Motorcycles	All				
VMT	5,615,235	2,342,847	2,636,680	1,104,948	854,687	18,993	12,290	20,110	46,924	136,303	12,789,015	1,342,015	12%	(1,979,396)	-13%
Gasoline	174,657	72,872	82,012	88,262	39,103	1,117	-	1,117	3,352	4,469	466,962	(128,206)	-22%	(72,273)	-13%
Diesel	0	0	0	0	63,683	1,117	2,234	3,352	1,117	-	71,503	2,178	3%	(11,067)	-13%
Total	174,657	72,872	82,012	88,262	102,786	2,234	2,234	4,469	4,469	4,469	538,465	(126,028)	-19%	(83,340)	-13%
Fuel Economy Assumption for LDA and LDT											32.15				

Assumptions: *VMT forecasts based on SCTA SCTM07 travel demand model output for the 2009 CTP project alternative.*
Gasoline fuel consumption estimates based on projected 2035 fuel economy assumptions for LDT and LDA vehicles, assuming implemenation of California Pavley regulations
Gasoline and diesel fuel consumptions estimates for other on-road vehicles based on an extrapolation of consumption rates from 2008

Scenario: 2035 Comprehensive/"Do Everything" Scenario (Alternative 5)

	Passenger Cars	Light-Duty Trucks	Light Duty Trucks	Medium-Duty Trucks	Heavy-Duty Trucks	Buses	School Buses	Urban Buses	Motor Homes	Motorcycles	All				
VMT	5,180,012	2,161,259	2,432,318	1,019,306	788,442	17,521	11,337	18,552	43,287	125,738	11,797,772				
Gasoline	161,120	67,224	75,655	81,421	36,073	1,031	-	1,031	3,092	4,123	430,769		-28%		
Diesel	0	0	0	0	58,747	1,031	2,061	3,092	1,031	-	65,961				
Total	161,120	67,224	75,655	81,421	94,819	2,061	2,061	4,123	4,123	4,123	496,730				
Fuel Economy Assumption for LDA and LDT											32.15				

Assumptions: *VMT forecasts based on SCTA SCTM07 travel demand model output for the 2009 CTP project alternative.*
Gasoline fuel consumption estimates based on projected 2035 fuel economy assumptions for LDT and LDA vehicles, assuming implemenation of California Pavley regulations
Gasoline and diesel fuel consumptions estimates for other on-road vehicles based on an extrapolation of consumption rates from 2008

REVISED APPENDIX F

ESTIMATE OF SHORT-TERM CONSTRUCTION EMISSIONS OF GHG									
	2008				2035				
	Tons per year	Pounds per year	Pounds per day	Pounds per day	Tons per year	Pounds per year	Pounds per day	Pounds per day	Increase in lb/day
				Weekdays				Weekdays	
Fine grading	76.36	152,720	1,697	2,376	76.37	152,740	1,697	2,376	0.31
Asphalt	37.78	75,560	840	1,175	37.80	75,600	840	1,176	0.62
Building	45.48	90,960	1,011	1,415	44.82	89,640	996	1,394	(20.53)
Coating	0.28	560	6	9	0.28	560	6	9	-
TOTAL	**159.9**	**319,800**	**3,553**	**4,975**	**159.27**	**318,540**	**3,539**	**4,955**	**(19.60)**
ESTIMATE OF LONG-TERM MOBILE SOURCE EMISSIONS OF GHG									
Greenhouse Gas Emissions Estimates									
			Current	2009 CTP	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
	Goal		2005	2035	2035	2035	2035	2035	2035
Daily Vehicle Miles of Travel per Person	20.8		23.1	25.3	26.0	25.4	23.5	22.5	20.7
Person Hours Delay	42,580		53,226	337,074	390,689	265,769	256,375	287,246	163,084
Fleet MPG Assumption	32.15		19.86	32.15	32.15	32.15	32.15	32.15	32.15
Tons GHG Emissions*	1,240,538		2,549,042	1,999,582	2,048,185	2,002,046	1,851,404	1,773,669	1,636,196

Notes:
**ICLEI CACP software used to convert VMT to GHG emissions using all standard assumptions and conversion rates and the Fleet Wide MPG assumptions shown for each alternative/scenario.*
Alternatives are defined as:
Alternative 1: No Project/No Action Alternative
Alternative 2: CTP Vision Scenario, Financially Unconstrained Capital Improvement Scenario
Alternative 3: VMT Reduction - Transit Expansion/Smart Growth Focused Scenario
Alternative 4: VMT Reduction - Pricing Policy Focused Scenario
Alternative 5: Comprehensive/"Do Everything" Scenario

REVISED APPENDIX G

Alternative 1: No Project/"No Build" (CTP Scenario 1):				
Land Use: Projections 2007, Baseline Land Use				
Pricing: Keeps pace with inflation. Fuel cost increases offset by fuel economy increases.				
Project	**Project (in millions)**	**Funds**	**Notes**	**M**
Local Road Rehabilitation	$1,947.9			M
Widen U.S. 101 for HOV lane (one in each direction) between Rohnert Park Expressway to Santa Rosa Avenue	$85.0		Committed	M
Widen U.S. 101 for HOV lane (one in each direction) between Steele Lane and Windsor River Road - North Phase A	$120.0		Committed	M
Widen U.S. 101 for HOV lanes Central Phase A (one in each direction) from Pepper Road to Rohnert Park Expressway	$118.0		Committed	M
MSN Phase 1 - Petaluma Blvd South I/C and frontage				
Total Estimated Cost:	$2,270.9			

CTP/Constrained Project (CTP Scenario 2):				
Land Use: Projections 2007, Baseline Land Use				
Pricing: Keeps pace with inflation. Fuel cost increases offset by fuel economy increases.				
Project	**Project**	**Funds**	**Notes**	**M**
ALL SCENARIO 1: NO PROJECT/NO BUILD PROJECTS	$2,270.9			
Widen U.S. 101 for HOV lanes (one in each direction) from Old Redwood Highway to Pepper Road - Central Phase B	$50.0	$50.0		M

CTP/Constrained Project (CTP Scenario 2):				
Land Use: Projections 2007, Baseline Land Use				
Pricing: Keeps pace with inflation. Fuel cost increases offset by fuel economy increases.				
Project	**Project**	**Funds**	**Notes**	**M**
U.S. 101/Airport Boulevard interchange improvements and Airport Boulevard widening - North Phase B	$30.0	$30.0		M
U.S. 101 Traffic Operations System (TOS)	$25.0	$25.0	Elements included in all 101 projects, this is in addition	
U.S. 101 ramp metering and fiber optic cable in Sonoma County	$25.0	$25.0	Elements included in all 101 projects, this is in addition	
Widen U.S. 101 (adding an HOV lane in each direction) from the Route 37 in Novato north to Old Redwood Highway in Petaluma and convert some highway sections from expressway to freeway - MSN	$400.0	$400.0	Sonoma County share listed based on 50% of total cost; $200M committed for complete project	
Penngrove local road improvements including Railroad Avenue interchange	$38.0	$38.0		M
Brickway Blvd Connect Airport Blvd.-River Rd	$7.50			
Hwy 116/Hwy 121 intersection improvements and Arnold Drive improvements	$14.8	$14.8		M

CTP/Constrained Project (CTP Scenario 2):				
Land Use: Projections 2007, Baseline Land Use				
Pricing: Keeps pace with inflation. Fuel cost increases offset by fuel economy increases.				
Project	**Project**	**Funds**	**Notes**	**M**
U.S. 101/Old Redwood Highway interchange improvements	$27.6	$27.6		M
U.S. 101/Hearn Avenue interchange improvements, including widening overcrossing and ramps	$28.0	$28.0		M
Extend Farmers Lane as a 3-lane or 4-lane arterial from Yolanda Avenue to Route 12	$41.4	$41.4		M
Mark West Springs Road/Porter Creek Road safety improvements	$4.8	$4.8		M
Forestville bypass on Route 116	$13.7	$13.7		M
Mirabel Road and Route 116 signalization and Channelization	$3.0	$3.0	new project for RTP	M
River Road channelization and improvements	$4.0	$4.0		M
Bodega Highway improvements west of Sebastopol	$2.0	$2.0		M
Route 12/Fulton Road interchange and widen Fulton Road from 2 lanes to 4 lanes north of Guerneville Road to south of Route 12	$38.0	$38.0		M
Route 121 traffic signal system and channelization at 8th Street	$3.1	$3.1		
Healdsburg Bridge	$23.0	$23.0	new project for RTP	

CTP/Constrained Project (CTP Scenario 2):				
Land Use: Projections 2007, Baseline Land Use				
Pricing: Keeps pace with inflation. Fuel cost increases offset by fuel economy increases.				
Project	**Project**	**Funds**	**Notes**	**M**
Realign Route 116 (Stage Gulch Road) along Champlin Creek and widen remaining segments to accommodate pedestrians and bicyclists	$38.0		SHOPP	
Rehabilitate and widen Route 116 from Elphick Road to Redwood Drive (involves realignment, new shoulders and channelization improvements)	$83.0		SHOPP	
U.S 101 Interchange Improvements (Steele Ln., Arata, E. Washington, Mill St., Dry Creek, Bellevue, River Rd., Todd Rd.)	$142.5			M
Petaluma crosstown connector and Rainier interchange	$58.7	$58.7	City of Petaluma has committed $11.306 toward project	
Convert bridges of Sonoma County from one-lane to two-lane bridges	$16.9	$16.9	Funded through HBRR Program	
SMART RAIL - EIR schedule	$541			
SRCB - Decrease Headways (Routes 4,5,7,9,14,19)	$7.1			
SRCB - North/South - East/West Rapid Bus Corridor	$39			
Total Estimated Cost:	**$3,975.9**			

Alternative 2: Unconstrained Project (CTP Scenario 3):				
Land Use: Projections 2007, Baseline Land Use				
Pricing: Keeps pace with inflation. Fuel cost increases offset by fuel economy increases.				
Project	**Project**	**Funds**	**Notes**	**M**
ALL SCENARIO 1 & 2 PROJECTS (No build and financially constrained projects)	$3,975.9			
Old Redwood Hwy improvements from Petaluma to Cotati	$6.00			
Adobe Road Reconstruction - reconstruct portions of Adobe Rd from Hwy 116 to Penngrove	$11.50			
Petaluma Hill Rd -Santa Rosa to Roberts (sections) - widen from Santa Rosa to Roberts	$13.00			
Snyder Lane Widening - widen to 4 lanes from Southwest Blvd to Keiser Lane	$1.00			
Petaluma Hill Rd in Santa Rosa - widen and reconstruct from Snyder Lane to Kawana Springs Rd	$8.70			
Cloverdale Blvd/South Interchange Improvement near Hwy 101	$0.50			
E Cotati Ave Hwy 101 to Snyder – implement arterial management	$1.10			
Bennett Valley Rd Santa Rosa - Grange – reconstruct & widen	$3.80			
Healdsburg Ave./Mill St./Vine Ave. 5-way Intersection Improvements	$0.50			
Old Redwood Hwy - Hembree Ln to Shiloh Road	$5.40			
Shiloh Rd - Hembree Ln to Old Redwood Hwy	$2.50			
Windsor River Rd - widen & reconstruct from Windsor Rd to Starr Rd	$0.50			
Railroad Ave Improvements - from Hwy 101 to Petaluma Hill Road	$0.55		Change to County Project	
Southern Crossing of the Petaluma River	$33.00			
Starr Rd/NWPRR rebuild Grade Crossing**	$0.40			
Dry Creek Road - Safety Improvements	$4.10			
First Street Improvement - widen from Crocker Road to Asti Road & install sidewalk	$0.22			
Bellevue Ave extension to Petaluma Hill Road	$5.00			
Todd Road - reconstruct from Stony Point Road to Llano Road extend east to Petaluma Hill Road	$5.80			

Alternative 2: Unconstrained Project (CTP Scenario 3):				
Land Use: Projections 2007, Baseline Land Use				
Pricing: Keeps pace with inflation. Fuel cost increases offset by fuel economy increases.				
Project	**Project**	**Funds**	**Notes**	**M**
W Sierra Arterial Improvements – Old Redwood Hwy to Stony Point Road signalization & bike lanes	$0.83			
6th st. undercrossing, Davis Street & 6th Street Traffic Signal Installation	$1.50			
New traffic signals - citywide in Santa Rosa	$2.40			
Dutton Meadows - widen & reconstruct from Hearn Ave to Bellevue Avenue	$4.50			
West Avenue - reconstruct and widen from Sebastopol Road to South Avenue	$1.40			
Old Redwood Hwy - widen from Arata Lane to North Town Limits	$1.64			
Old Redwood Hwy - Windsor Road to Windsor River Road	$0.45			
Shiloh Rd - widen to four lanes from Hwy 101 to Skylane Blvd	$2.40			
Petaluma Blvd North-Hwy 101 to city limits (approx 300 ft north of Gossage)	$3.80			
Alexander Valley Rd - shoulder widening for bikes & sight distance, eliminate safety issues	$4.10			
Calistoga Rd - Montecito to Hwy 12 - traffic calming	$0.25			
Lakeville Rd Widen to 4 Lanes from Hwy 37 to Hwy 116	$22.00			
Arnold Drive - construct center turn lane Country Club to Madrone	$2.50			
Hwy 12 - widen from Los Alamos to Pythian	$15.00			
Arnold Drive - Verano to Petaluma Street	$2.30			
8th Street East/Hwy 121 intersection	$0.40			
Farmers/4th Street - intersection improvements	$1.50			
8th Street East widening Napa Rd to Napa Street	TBD			
Intersection Control on Hwy 116 at 4 locations in Sebastopol	$1.40			
River Rd/Mark West Springs – construct 2 additional lanes from Fulton to Old Redwood Hwy.	$2.60			
Bellevue Ave/Ludwig Ave Connector - realignment of Bellevue from Ludwig to Stony Point Road	$2.90			

Alternative 2: Unconstrained Project (CTP Scenario 3):				
Land Use: Projections 2007, Baseline Land Use				
Pricing: Keeps pace with inflation. Fuel cost increases offset by fuel economy increases.				
Project	**Project**	**Funds**	**Notes**	**M**
Hwy 12 widening Llano Road to South Wright	TBD			
Todd Rd - widen from Stony Point Road to Llano Road extend east to Petaluma Hill Road	$5.80			
W College Ave Fulton to Stony Point Road- widen and reconstruct (includes storm drain)	$1.50			
Bodega Ave. Curb Gutter & Sidewalk Improvements - Golden Ridge to Pleasant Hill	$0.46			
Hwy 116 Curb Gutter & Sidewalk Improvements (Healdsburg Avenue, Live Oak to Hurlbut)	$6.00			
Phase 1-2 Stony Point Rd widen & reconstruct	$10.00		Rephased	
Phase 1-3 Hearn Ave realignment	$6.00		Rephased	
Sebastopol Road. - upgrade and reconstruct from Olive to Dutton Avenue	$3.00			
West 9th St - widen and reconstruct from Dutton Avenue to Morgan Avenue	$2.50			
5 way intersection at Healdsburg, Mill & Westside Roads	TBD			
Wilfred Ave widening between 1999 city limits & urban growth boundary	TBD			
Rohnert Park expressway widening between Snyder & Petaluma Hill Road	TBD			
Dowdell Reconstruction & Extension between Wilfred Ave & Business Park Drive	TBD			
Bodway Parkway Extension - between Valley House Drive and Railroad Avenue	TBD			
State Farm Drive Corridor Improvements	TBD			
Commerce Drive corridor improvements	TBD			
City Center Drive & Pedestrian improvements at State Farm Drive	TBD			
Neighborhood traffic calming program	TBD			
College Ave improvements between Cleveland & Morgan	$8.00			
Hwy 12/Farmers Lane ROW	TBD	2023-2033		
Route 12 at 4th Street	$3.5			
Gravenstein Hwy South (Hwy 116) from Spooner Park to HWY 101				

Alternative 2: Unconstrained Project (CTP Scenario 3):				
Land Use: Projections 2007, Baseline Land Use				
Pricing: Keeps pace with inflation. Fuel cost increases offset by fuel economy increases.				
Project	**Project**	**Funds**	**Notes**	**M**
Old Redwood Highway - Widen from Shiloh Rd to SR City Limits			GP Project	
Old Redwood Highway - Widen from Railroad to Petaluma City Limits			GP Project	
Fulton Rd - Widen from ORH to Piner Rd			GP Project	
HWY 12 - Widen from Llano to 116 in Sebastopol			GP Project	
Bodega Hwy - Widen from Sebastopol City Limits to Jonve Rd	5.5		GP Project	
Stony Point Rd - widen from Santa Rosa City Limits to Petaluma City Limits			GP Project	
Santa Rosa Ave - Widen from SR City limits to HWY 101			GP Project	
Ely Rd - center turn lane ORH to Petaluma			GP Project	
Corona Rd - center turn lane Adobe to Ely			GP Project	
Lakeville Hwy - Widen from Hwy 101 to Hwy 37			GP Project	
HWY 37 - Widen to 4 Lanes			GP Project	
Stage Gulch - center turn lane from Adobe to Arnold Dr			GP Project	
HWY 12 - center turn lane from SR to Sonoma			GP Project	
Arnold Dr - center turn lane from Madrone to Petaluma Ave			GP Project	
Madrone Rd - center turn lane from Aronold to HWY 12			GP Project	
Aqua Caliente - center turn lane from Aronold to HWY 12			GP Project	
Verano Ave - center turn lane from Aronold to HWY 12			GP Project	
Petaluma Ave - center turn lane from Aronold to HWY 12			GP Project	
Northpoint Pkwy - Extend from Fresno to S Wright			GP Project	
Northpoint Pkwy - widen from Stony Point to Frenso			GP Project	
Frenso Ave - Extend From Northpoint Pkwy to Finley			GP Project	
Corporate Pkwy - widen from Northpoint Pkwy to Seb. Rd			GP Project	

Alternative 2: Unconstrained Project (CTP Scenario 3):				
Land Use: Projections 2007, Baseline Land Use				
Pricing: Keeps pace with inflation. Fuel cost increases offset by fuel economy increases.				
Project	**Project**	**Funds**	**Notes**	**M**
Stony Point Rd - Widen to four lanes from Hearn Ave to Santa Rosa city limits			GP Project	
Maureen Dr realignment and Widening - Dutton Dr to Dutton Mdw			GP Project	
Dutton Ave - Extend to Dutton			GP Project	
Hearn Ave relignment from Burbank to Northpoint Pkwy			GP Project	
Sebastopol Road - Dutton to Stony Point			GP Project	
Corby Ave - widen from Baker to Hearn			GP Project	
Baker Overcrossing Widen			GP Project	
Santa Rosa Ave - Baker to Colgan			GP Project	
Petaluma Hill Rd - widen from Aston to SR Citylimes			GP Project	
Kawana Springs Rd - widen from SR Ave to Pet. Hill Rd			GP Project	
Stony Point Rd - widen from 3rd St to Hwy 12			GP Project	
W 3rd St - widen from Senna to Fulton			GP Project	
W 9th St - widen from Dutton to Link			GP Project	
Cleveland Ave - College to W 9th St			GP Project	
Range Ave - widen from Steele to Russel			GP Project	
Piner - widen from Marlow to Fulton			GP Project	
Hopper Ave - widen from Cleveland to Coffey Ln			GP Project	
Courthouse Square Closure			GP Project	
3rd St - widen from Morgan to B St			GP Project	
Morgan - widen from 3rd St to 5th St			GP Project	
North St - widen from Carr to College			GP Project	
Franklin - widen from Lewis to North St			GP Project	

Alternative 2: Unconstrained Project (CTP Scenario 3):				
Land Use: Projections 2007, Baseline Land Use				
Pricing: Keeps pace with inflation. Fuel cost increases offset by fuel economy increases.				
Project	**Project**	**Funds**	**Notes**	**M**
Chanate - widen from Humboldt to Mendocino			GP Project	
Old Redwood Hwy rehab - Plaza to Gravenstein Hwy	$8.50			
Southwest Blvd Corridor Improvements				
Southern Crossing @ Caulfied	$72.0			
Mendocino Ave/Hopper Ave -Hwy 101 I/C				
Sebastopol Bypass - Llano Road improvements & extension, Hwy 116 to Occidental Road	$3.00			
Traffic Calming of County ROW Countywide				
SRCB - Decrease Headways (Routes 1-3,6,8,10-12,15-18)	$12.4			
SCT - Decrease Headway (Routes 20,25,30,40,44/48,60,62)				
Santa Rosa CityBus - Technology Enhancement Program	$10.70			
Santa Rosa CityBus - Facilities Enhancement Program	$7.80			
Sonoma County Transit - Facility Expansion	TBD			
Port Sonoma				
Total Estimated Cost:	$4314.72*			

**Please note that many of the projects in the unconstrained project list are in the conceptual stage only and no estimated cost is available. The full project cost for this project if fully implemented would be many times greater than the estimated cost provided here if project cost estimates for all conceptual projects were available.*

Alternative 3: VMT Reduction Alternative 1 - Transit/Smart Growth Focused (CTP Scenario 4):			
Land Use: All future growth is assumed to be focused in county Priority Development Areas, around rail/transit stations, and local designated pedestrian or special development districts. Future growth is projected to be at higher densities. SCTA does not have the authority to implement land use policy and could only advocate for this type of future land development.			
Pricing: Keeps pace with inflation. Fuel cost increases offset by fuel economy increases.			
Project	**Project**	**Funds**	**Notes**
ALL SCENARIO 1 & 2 PROJECTS (No build and financially constrained projects)	$3,975.9		
Transit Priority Measures (signal prioritization, dedicated bus/HOV lanes, queue jumpers, left turn bays, etc.)			
SCT Decrease Headways (Routes 10,12,14,28,32,42,64,66,68)			
SMART RAIL - Decrease Headway			
Petaluma Transit - Decrease Headways			
Golden Gate Transit - Decrease Headways			
Total Estimated Cost:	$3975.9*		

**Please note that many of the projects in the unconstrained project list are in the conceptual stage only and no estimated cost is available. The full project cost for this project if fully implemented would be greater than the estimated cost provided here if project cost estimates for all conceptual projects were available.*

Alternative 4: VMT Reduction Alternative 2 - Pricing Focused (CTP Scenario 5):			
Land Use: Projections 2007, Baseline Land Use			
Pricing: $.25/mile peak hour congestion fee, parking charges in all downtown and large commercial areas. Tolls and transit fares expected to increase with inflation. Per mile cost (operating costs including gas, maintenance and tires, but not including ownership costs such as insurance, depreciation, taxes, etc.) to go from $0.23 per mile ($4.25 per gallon—2008 average) to $1.27 per mile in 2035 ($7.47 per gallon plus $5.50 per trip congestion charge). SCTA does not have the authority to implement pricing policy and could only advocate for the future implementation of these policies.			
Project	**Project**	**Funds**	**Notes**
ALL SCENARIO 1 & 2 PROJECTS (No build and financially constrained projects)	$3,975.9		
Convert HOV lanes to HOT lanes.			
Total Estimated Cost:	3975.9*		

**Please note that this project is focused on pricing policy and not additional capital projects beyond those proposed in the financially constrained project list. Costs associated with the implementation of pricing policy are unknown at this time.*

Alternative 5: Comprehensive/"Do Everything" (CTP Scenario 6):			
Land Use: All future growth is assumed to be focused in county Priority Development Areas, around rail/transit stations, and local designated pedestrian or special development districts. Future growth is projected to be at higher densities. SCTA does not have the authority to implement land use policy and could only advocate for this type of future land development.			
Pricing: $.25/mile peak hour congestion fee, parking charges in all downtown and large commercial areas. Tolls and transit fares expected to increase with inflation. Per mile cost (operating costs including gas, maintenance and tires, but not including ownership costs such as insurance, depreciation, taxes, etc.) to go from $0.23 per mile ($4.25 per gallon—2008 average) to $1.27 per mile in 2035 ($7.47 per gallon plus $5.50 per trip congestion charge). SCTA does not have the authority to implement pricing policy and could only advocate for the future implementation of these policies.			
Project	**Project**	**Funds**	**Notes**
ALL SCENARIO 1-3 PROJECTS (No build, financially constrained, and financially unconstrained projects)	$4314.72*		
Transit Priority Measures (signal prioritization, dedicated bus/HOV lanes, queue jumpers, left turn bays, etc.)			
SCT Decrease Headways (Routes 10,12,14,28,32,42,64,66,68)			
SMART RAIL - Decrease Headway			
Petaluma Transit - Decrease Headways			
Golden Gate Transit - Decrease Headways			
Convert HOV lanes to HOT lanes.			
Total Estimated Cost:	$4314.72*		

**Please note that many of the projects in the unconstrained project list are in the conceptual stage only and no estimated cost is available. The full project cost for this project if fully implemented would be many times greater than the estimated cost provided here if project cost estimates for all conceptual projects were available.*

APPENDIX

Appendix A- BAAQMD
PM Implementation Schedule

Bay Area Air Quality Management District
939 Ellis Street
San Francisco, CA 94109

November 9, 2005

Staff Report

Particulate Matter Implementation Schedule

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Planning and Research Division

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TABLE OF CONTENTS

Tables and Figures

Appendices

I. BACKGROUND

A. What is Particulate Matter (PM)?

Particulate matter (referred to as PM) consists of very small liquid and solid particles suspended in the air, and includes particles smaller than 10 microns in size (PM_{10}) as well as finer particles smaller than 2.5 microns in size ($PM_{2.5}$). Particles with a size between 2.5 and 10 microns are sometimes referred to as "coarse particles".

Ambient PM is made up of particles that are emitted directly, such as soot and fugitive dust, as well as secondary particles that are formed in the atmosphere from reactions involving precursor pollutants such as oxides of nitrogen, sulfur oxides, volatile organic compounds, (NOx, SOx, and VOC), and ammonia. Secondary PM and combustion soot tend to be fine particles ($PM_{2.5}$) while fugitive dust is mostly coarse particles.

Some particles are directly emitted into the air. They come from a variety of sources such as cars, trucks, buses, industrial facilities, cooking, power plants, construction sites, tilled fields, unpaved roads, stone crushing, and burning of wood.

Other particles may be formed indirectly when gases from burning fuels react with sunlight and water vapor. These can result from fuel combustion in motor vehicles, at power plants, and in other industrial processes. Many combustion sources, such as motor vehicles and power plants, emit PM directly and also emit pollutants that form secondary PM.

B. What Kinds Of Problems Does PM Cause?

1. Human Health

Exposure to particulate pollution is linked to increased frequency and severity of asthma attacks and even premature death in people with pre-existing cardiac or respiratory disease. Those most sensitive to particulate pollution include infants and children, the elderly, and persons with heart and lung disease.

When we inhale, we breathe in air along with any particles that are in the air. The air and the particles travel into our respiratory system (the lungs and airway). Along the way the particles can stick to the sides of the airway or travel deeper into the lungs. The farther particles go, the worse the effect. Smaller particles can pass through the smaller airways.

Many scientific studies have linked breathing PM to a series of significant health problems, including:

- aggravated asthma
- increases in respiratory symptoms like coughing and difficult or painful breathing
- chronic bronchitis
- decreased lung function
- premature death

2. Visibility impairment

PM is the major cause of reduced visibility (haze) in the United States, including both urban and rural areas. PM reduction programs are underway in cities as well as places like the Grand

Canyon and the Great Smokey Mountains National Parks where millions of tourists come every year to take in the views.

3. Atmospheric deposition

The smaller particles are lighter and stay in the air longer and travel farther. PM_{10} particles can stay in the air for minutes or hours while $PM_{2.5}$ particles can stay in the air for days or weeks before settling as deposition on surfaces. PM_{10} particles can travel as little as a hundred yards or as much as 30 miles. $PM_{2.5}$ particles can go even farther; many hundreds of miles before settling out. The effects of this settling include:

- making lakes and streams acidic
- changing the nutrient balance in coastal waters and large river basins
- depleting the nutrients in soil
- damaging sensitive forests and farm crops

4. Aesthetic damage

Certain types of PM, such as soot, can stain and damage stone and other materials, including culturally important objects such as historic buildings, monuments, and statues. Cleaning up these landmarks is expensive and time consuming.

5. Public Nuisance

PM can become a public nuisance when it is concentrated at the local level. The nuisance effects can include soiling of personal property, increased respiratory ailments, reduced visibility, odor, or other problems. These effects can have the most impact on sensitive populations, such as children, the elderly and those with existing respiratory illness or compromised immune systems.

II. WHAT ARE PM CONDITIONS IN THE BAY AREA?

The U.S. Environmental Protection Agency (U.S. EPA) and the California Air Resources Board (ARB) have adopted ambient air quality standards for PM_{10} and $PM_{2.5}$ (Table 1). California's standards are the most health-protective standards in the nation and are designed to provide additional protection for the most sensitive groups of people. According to ARB, attainment of California's standards is expected to result in the prevention of premature deaths, incidences of asthma among children, and over millions of lost work days per year.

TABLE 1: STATE AND NATIONAL PM STANDARDS AND BAY AREA ATTAINMENT STATUS

	California Standard ($\mu g/m^3$)	Bay Area Status	National Standard ($\mu g/m^3$)	Bay Area Status
PM_{10} - Annual	20	Nonattainment	50	Attainment
PM_{10} - 24-hour	50	Nonattainment	150	Unclassified
$PM_{2.5}$ - Annual	12	Nonattainment	15	Attainment
$PM_{2.5}$ - 24-hour	--	--	65	Attainment

State and National particulate matter ambient air quality standards. The levels of the standards are expressed in micrograms per cubic meter ($\mu g/m^3$). Status of Bay Area based on data available as of 11/23/2004.

Today, virtually all of California is considered to be in "nonattainment" for the State PM_{10} standard, with most urban areas, the Central Valley, and several other areas in nonattainment for the State $PM_{2.5}$ standard. The Bay Area is currently in attainment of the Federal PM_{10} and $PM_{2.5}$ standards.

III. WHAT IS BEING DONE TO REDUCE PM POLLUTION IN THE BAY AREA?

The Bay Area Air Quality Management District (Air District) implements a number of regulations and programs to reduce PM emissions. These include rules limiting direct PM emissions from open burning of agricultural and non-agricultural waste, controlling dust from earthmoving and construction/demolition operations, limiting emissions from various combustion sources such as cement kilns and furnaces, and reducing PM from composting and chipping activities. In addition, the Air District also enforces rules that limit indirect PM precursor emissions such as NO_x from power plants, industrial facilities, and other combustion sources, and VOCs from petroleum refineries, coatings and solvents, product manufacturing, fuel storage, transfer and dispensing activities, and many other industrial and commercial facilities.

The Air District also administers programs that deal specifically with emissions from wood-burning appliances such as fireplaces, wood stoves and heaters. These programs include the Spare the Air Tonight campaign that advises Bay Area residents not to burn wood on evenings that are forecast to have conditions favorable for increased PM levels. The Air District has also developed a model wood burning ordinance for cities and counties, and administers incentive programs to replace older and dirtier wood-burning equipment with EPA-certified devices.

To reduce PM emissions from mobile sources, the Air District implements a variety of incentive programs to encourage fleet operators and the public to voluntarily replace or retrofit older higher polluting vehicles/equipment with newer lower polluting vehicles/equipment. The types of projects funded include purchasing low-emission vehicles, re-powering old polluting heavy duty diesel engines, and installing after market emissions control devices that reduce particulates and NOx emissions. These incentives are available for a wide variety of on-road and off-road equipment. In addition, one program focuses specifically on school buses while another deals specifically with refuse trucks. The Air District also operates a vehicle buy-back program to provide financial incentives to remove the oldest most polluting light-duty vehicles from Bay Area roadways.

IV. SB 656 PM IMPLEMENTATION SCHEDULE

A. What is the SB 656 PM Schedule?

In 2003 the California Legislature enacted Senate Bill 656 (SB 656) to reduce public exposure to PM_{10} and $PM_{2.5}$. SB 656 requires ARB, in consultation with local air districts, to develop and adopt, by January 1, 2005, a list of the most readily available, feasible, and cost-effective control measures that could be used by ARB and the air districts to reduce PM_{10} and $PM_{2.5}$. The goal of SB 656 is to make progress in the near-term toward attainment of State and national PM_{10} and $PM_{2.5}$ standards.

The potential PM control measures on ARB’s list are based on rules, regulations, and programs existing in California as of January 1, 2004 to reduce emissions from new, modified, and existing stationary, area, and mobile sources.

For more information about SB 656 and to view related documents, please go to www.arb.ca.gov/pm/pmmeasures/pmmeasures.htm.

B. The SB 656 Process

As required by SB 656, ARB compiled a list of existing PM rules, regulations, and programs in California as of January 1, 2004. This list included 103 different measures that are being implemented by any air district to address both direct and indirect PM emissions. Local districts must review the ARB list and identify the measures most appropriate for their respective regions. Air Districts must adopt an implementation schedule that prioritizes the appropriate measures based on cost effectiveness and their effects on public health, air quality, and emissions reductions. The SB 656 legislation and ARB guidance directs each air district to base their evaluation of potential PM reduction measures on the nature and severity of the PM problem in their area.

SB 656 requires that local air districts not include measures on the implementation schedule if they are substantially similar to measures already adopted by the air district or if they are scheduled to be adopted within two years of adoption of the PM implementation schedule, or if the air district has determined that there are readily available, feasible, and cost-effective alternative control measures that will achieve equivalent or greater reductions.

C. Sources of PM in the Bay Area

Air District staff has analyzed both direct and indirect sources of PM throughout the Bay Area. Based on 2000-2003 ambient air monitoring data, the Air District and ARB estimated that the $PM_{2.5}$ fraction of total PM accounted for approximately 60% of PM_{10} during the winter and approximately 45% during the rest of the year. On days when the PM standards are exceeded, $PM_{2.5}$ can account for as much as 90% of PM_{10}. On an annual basis, the ARB estimated that $PM_{2.5}$ comprised approximately 50% of the PM_{10} levels. Therefore, $PM_{2.5}$ is seen a significant component of the region's total PM problem.

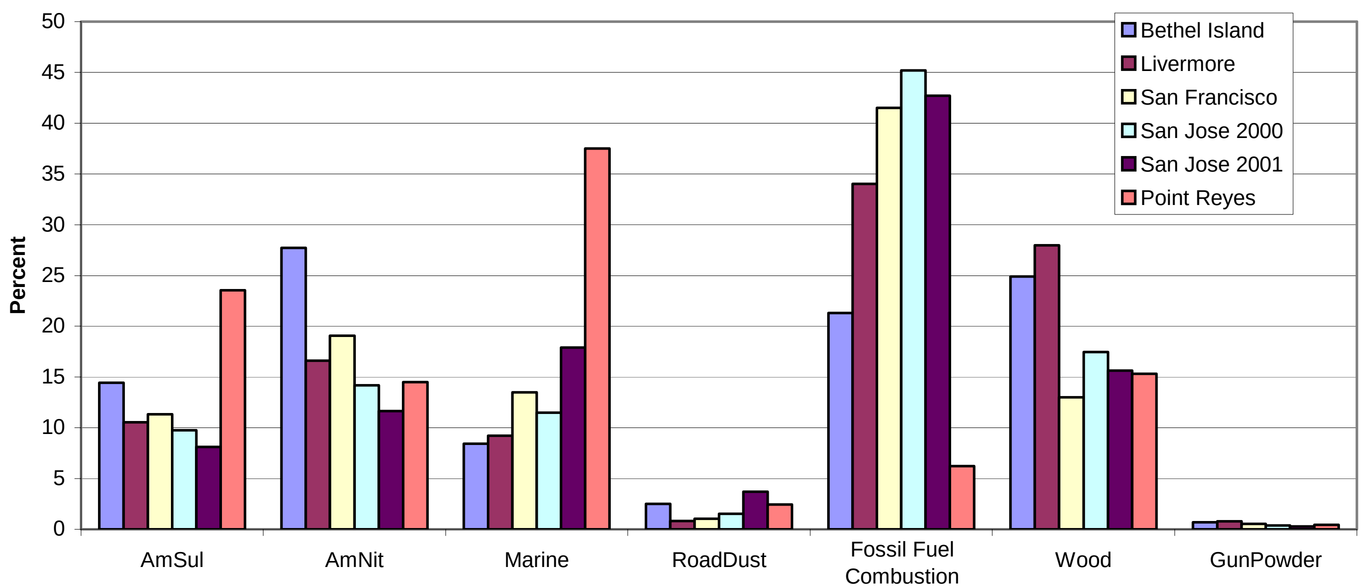
Air District staff and ARB staff have been working on ways to determine the sources of PM in the region. One method was to evaluate the Air District's source inventory for specific stationary and area sources. Another method was to analyze the nature of the PM collected as part of the region's participation in the state's $PM_{2.5}$ speciation network of ambient air monitors.

The emissions inventory data collected by the Air District reflects $PM_{10.}$ Based on the inventory data, combustion activities such as residential wood burning, construction/demolition activities, road dust, and emissions from on and off-road engines have been identified as significant sources of PM_{10} emissions. While the inventory is helpful in determining potential PM_{10} sources in the region, it does not provide the full picture of the makeup of the region's PM. The nature of particulates is that larger, coarser particles tend to settle out of the air closer to their emission source while smaller particles, such as the size of $PM_{2.5}$, tend to remain suspended in the air longer and travel further. In addition, direct and indirect sources of PM needed to be distinguished. Therefore, further evaluation of the sources of PM was needed.

The data collected from ambient air monitoring in the region reflects both PM_{10} and $PM_{2.5}$. Recent scientific studies have found specific chemical components of PM to be associated with likely emission source categories. To help determine the sources of PM collected from ambient air monitors Air District staff applied an approach called the chemical mass balance (CMB) analysis using a computer model to apportion ambient PM collected on filters to a set of source categories, such as fossil fuel combustion, wood smoke, and geological dust. The CMB model found the mix of sources that best matches the ambient PM samples collected at monitoring sites, chemical species by chemical species. The results were then compared to the Air District's emissions inventory to further refine the source categories.

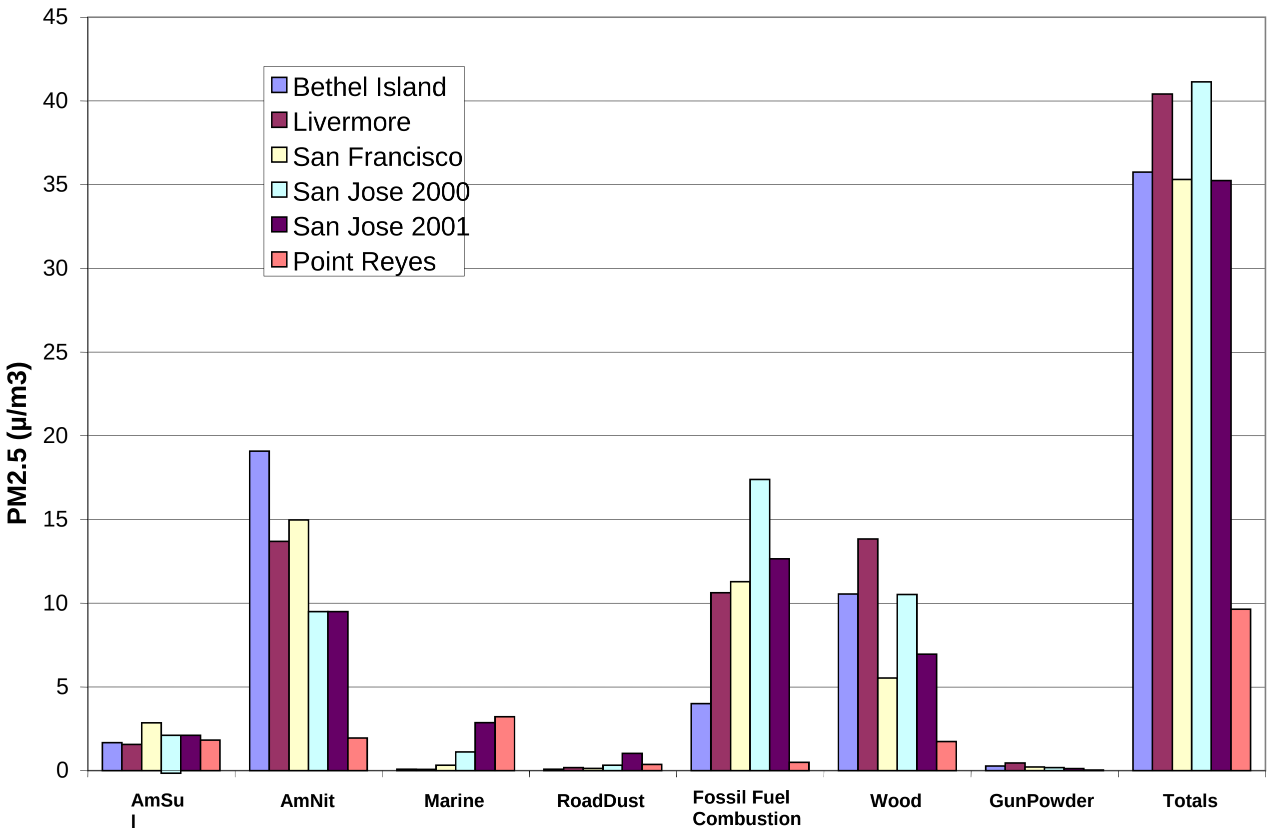
The combined analysis showed that for annual average $PM_{2.5}$ the largest source categories are on and off road motor vehicle exhaust and carbon from cooking and wood-burning activities. These categories include both directly emitted PM and secondary PM, such as ammonium nitrate formed by atmospheric reactions of ammonia with nitrogen oxides from motor vehicles and other combustion sources. Geological dust was found to be a minor component of ambient PM. During the winter, residential wood smoke and cooking are major contributors to ambient PM. Combustion $PM_{2.5}$, which includes vehicle exhaust, is the second major component of $PM_{2.5}$ and a significant component of PM_{10}. Ammonium nitrate is also a principal component of ambient PM. Winter conditions – cool temperatures, low-wind speeds, low inversion layers, and high humidity – favor the formation of ammonium nitrate and the buildup of PM in the region. Road dust and other dust producing activities also contribute to ambient PM_{10}, but not $PM_{2.5}$, and have a more local impact. The Figures 1 and 2 below summarize the results of the CMB analysis to determine source categories for both annual $PM_{2.5}$ and peak $PM_{2.5}$.

FIGURE 1
Annual Percentage $PM_{2.5}$ Contributions from Various Source Categories



The values shown are the mass from individual source categories as a percentage of the total estimated mass. Thus, the percentages sum to 100% for each site. Fossil Fuel Combustion category includes on-road and off-road vehicles, aircraft, refineries, and power generation sources.

FIGURE 2
Source Contributions to Peak Bay Area Ambient $PM_{2.5}$



Values are averages from 10 days with highest PM at each site. Totals are sums of individual source contributions. The Fossil Fuel Combustion category includes on-road and off-road vehicles, aircraft, refineries, and power generation sources.

V. SB 656 MEASURES EVALUATION PROCESS

To address the requirement of SB 656, the ARB compiled a list of existing PM rules, regulations, and programs in California as of January 1, 2004. This list included 103 different measures that are being used by various air districts to address both direct and indirect PM emissions. Each air district in the state has characteristics and emissions sources specific to the region. For this reason, not every item on the ARB's list of 103 measures would be applicable to every region. The SB 656 legislation directed each air district to base their further reduction measures on the nature and severity of the PM problem in their area. For example, the San Joaquin Valley has a significant PM problem and is considered to be in non-attainment of the federal PM_{10} and $PM_{2.5}$ standards. The San Joaquin Valley Air Pollution Control District (SJVAPCD) has had to create PM Plans to address how they will achieve attainment, and the severity of their region's problem necessitated very aggressive regulations. The Bay Area, however, is in attainment of the federal PM standards and the PM problem here is not as extreme. Therefore, some measures that may be necessary to address the PM problem in San Joaquin Valley may not be as necessary or cost effective in the Bay Area.

In addition, the most important sources of PM vary from region to region. For example, District and ARB analysis indicate that geologic dust (e.g. from agricultural activities, unpaved roads, etc.) is not a major source of PM in the Bay Area. Therefore, control measures for those sources are less important for the Bay Area than in other regions. The SB 656 legislation and ARB guidance states that the Air District should not include measures if they are substantially similar to those scheduled to be adopted within two years of the Implementation Schedule or if the Air District has determined that there is a readily available, feasible, and cost-effective alternative control measure that will achieve equivalent or greater reductions. Therefore, measures that reduce PM precursors that are included in the Air District's Bay Area 2005 Ozone Strategy are not included in the Implementation Schedule.

Following ARB's SB 656 guidance, Air District staff compared each of the 103 measures on ARB's list with existing Air District rules, regulations and programs to determine if equivalent measures are already being implemented or are being addressed in other ways. The evaluation results categories are described below. The results of the District's evaluation are represented in Table 2. In addition, Appendix A describes each measure and, where appropriate, lists any applicable District rule, regulation or program that corresponds to the measure listed by the ARB. For a full description of each ARB measure, please visit www.arb.ca.gov/pm/pmmeasures/board_approved_list.pdf.

EVALUATION RESULTS CATEGORIES

Equivalent measures that are already being implemented by the District

District staff compared each of the 103 control measures on the ARB list with existing District rules, regulations and programs to determine if equivalent control measures are already being implemented or if the emission sources are being addressed in other ways. The measures listed in this category were found to have equivalent District rules, regulations or programs that accomplished the same or similar emission reductions.

No Bay Area sources

Each measure on the ARB list applies to a specific emissions source category. In some cases, those types of sources do not exist in the Bay Area and so the District does not need to employ rules, regulations or programs to address that particular source category.

Insignificant potential emissions reductions

This category includes several kinds of measures:

- The difference in the specific requirements of the ARB listed measures, such as specific emission standards or operational requirements was found to have limited potential additional emissions reduction benefits compared to the existing District rule, regulation or program.
- The number of facilities in the Bay Area that would be impacted by the measure was so small that the new rule, regulation or program would not provide significant emissions reductions.
- The source category affected by the measure would not provide significant regional emissions reductions and provide relatively little local reductions to warrant implementation.

Proposed in the Ozone Strategy Control Measures

The Health and Safety Code and ARB's SB 656 guidance indicate that air districts may not include on their PM Implementation Schedule any measures that are scheduled for adoption within two years of the adoption of the PM Implementation Schedule. The measures in this category are already proposed for adoption in the next two years in the District's Draft 2005 Ozone Strategy. Therefore, they are not being included as part of this PM Implementation Schedule. For a full list of the 2005 Ozone Strategy Control Measures and the timing of rule adoption, please see the Draft 2005 Ozone Strategy, Table 10: Regulatory Agenda 2005-2007 (pg. 49 of the Draft Bay Area 2005 Ozone Strategy).

Identified as further study measures in the Ozone Strategy

This category of measures includes measures that are also being addressed in the District's Draft 2005 Ozone Strategy as further study measures. In most cases, these are sources that the District already addresses in some way through existing rules, regulations, or programs, but needs to conduct further analysis to determine whether it is feasible and beneficial to amend existing rules or adopt new rules or programs. The District does not currently have enough information to determine whether these ARB listed measures meet the appropriate standards for improving air quality, public health, cost effectiveness, and technical feasibility for implementation at this time. The District will continue to evaluate these further study measures to determine whether they are viable PM and/or ozone control measures for adoption at some point in the future.

Identified for enhancement/amendment

Measures identified for enhancement and amendment include existing District rules, regulations and/or programs that the District believes could be significantly improved to further reduce emissions and increase protection of public health. These measures have been added to the Proposed PM Implementation Schedule for adoption beginning in 2005.

Identified for new rulemaking

These measures address significant PM emission sources in the region and are expected to produce emission reduction benefits that have been proven to be cost-effective and technologically feasible. These measures have been added to the Proposed PM Implementation Schedule for adoption beginning in 2006 and will undergo a full rule-making process.

Identified for further study and evaluation

The District has determined that insufficient information currently exists to determine that the measures in this category meet the appropriate standards of technical feasibility, total emission reduction potential, rate of emissions reduction, public acceptability, enforcement and cost-effectiveness per Health and Safety Code Section 40922 and ARB's SB 656 guidance to include in the PM Implementation Schedule at this time. The District will be gathering additional information and will further evaluate these measures to determine if they would be appropriate to adopt in the future.

Table 2: Measures Evaluation Results

Measure Evaluations Results	ARB Control Measure Number
Equivalent measures that are already being used by the Air District	1, 3, 13-18, 20-32, 36, 39-41, 49, 51, 52, 54, 57-60, 63, 65, 68, 71, 73-78, 81, 85-98,100-103 (62 total)
No Bay Area Sources	19, 35, 48, 61, 66 (5 total)
Insignificant potential emissions reductions	33, 34, 37, 38, 42-44, 50, 69, 72 (10 total)
Already being proposed in Ozone Strategy Control Measures	45, 46, 64, 70, 79, 80, 82, 84 (8 total)
Identified as further study measure in Draft Bay Area 2005 Ozone Strategy	55, 56, 62, 67, 83, 99 (6 total)
Identified for further study and evaluation.	2, 4-12 (10 total)
Identified for enhancement/amendment – wood burning. Added to Implementation Schedule.	1 and 3 (2 total)
Identified for new rulemaking – combustion emissions from stationary and portable IC engines and charbroiling operations. Added to Implementation Schedule.	47 and 53 (2 total)

VI. PROPOSED PM IMPLEMENTATION SCHEDULE

The next step in the process was to evaluate the potential air quality and health benefits, cost effectiveness, and feasibility of the measures that are not currently being used by the Air District and propose additional measures for the Air District to adopt. The proposed new or amended measures are listed in Table 3.

Table 3: PROPOSED PM IMPLEMENTATION SCHEDULE

Measure	ARB Control Measure Number	Adopt/ Amend	Full Implementation
Further limit NOx and VOC emissions from stationary and portable internal combustion engines.	47	2006	TBD
Limit PM and VOC emissions from commercial broiling operations that use chain-driven broilers.	53	2006	TBD
Amend existing public awareness program to provide additional outreach and educational resources. Enhance existing wood-burning ordinance program.	1	2005	2005
Amend existing program aimed at voluntary curtailment of wood burning during periods of predicted high PM by adjusting the threshold for "Spare the Air Tonight" alerts.	3	2005	2005

Internal Combustion Engines (ICE) – Measure 47

Through an extensive rule development process, the District will consider new standards that will address NOX, PM and VOC emissions from stationary and portable internal combustion engines. The new standards will address a variety of engine sizes and types and will complement the ARB standards currently under development.

Broiling Operations – Measure 53

The District will develop a new rule that will require the installation of emissions control devices on new and existing chain driven commercial broiling operations preparing food for human consumption. The most likely devices, catalytic oxidizer control devices, are used to limit PM and VOC emissions and have been proven to be very cost-effective and to create significant emissions reductions in other regions. The District will conduct an extensive rule development process prior to the adoption of the new rule.

Wood Burning Program Enhancements – Measures 1 and 3

The District currently operates two programs that address wood burning. One is the District's Model Wood Burning Ordinance program and the other is the Spare the Air Tonight voluntary wood burning curtailment and public awareness program. These programs will be enhanced beginning in November 2005.

The District plans to expand its public awareness program by increasing outreach activities and dissemination of educational materials to inform the public about the potential health hazards associated with wood smoke, to encourage better wood burning practices and use of more environmentally friendly heating devices in lieu of wood burning. The District will also increase efforts to have more cities and counties adopt its Model Wood Burning Ordinance. The District will also significantly expand outreach to print and electronic media regarding health effects and costs of wood burning and regarding the Spare the Air Tonight program.

The Spare the Air Tonight program enhancements will include lowering the Air Quality Index (AQI) threshold for issuing Spare the Air Tonight alerts from 150 AQI to 130 AQI. The lower AQI represents a more health-protective threshold and more alerts are anticipated than in previous years. Increased media outreach, newspaper advertisements and internet-based communication at the District website will be used to notify the public when high particulate matter levels are anticipated and Spare the Air Tonight advisories are issued.

VII. ADDITIONAL PM REDUCTION EFFORTS

The process prescribed by SB 656 focuses on the measures list compiled by the ARB. However, in addition to the measures included on the Implementation Schedule through that process, the Air District plans to address PM emissions through other programs.

A. Community Air Risk Evaluation (CARE) Program

The Air District has initiated a Community Air Risk Evaluation (CARE) program to evaluate health risk associated with toxic air pollutants in the Bay Area. When completed, the study will be a tool the Air District can use to reduce toxic air pollution in areas with the highest health risk. The program will look at all toxic air pollutants with an emphasis on diesel particulate matter, which is considered to be the major source of airborne health risk in California.

The program includes enhanced air monitoring that will better determine the relative contribution of air pollution sources, including vehicles, industrial emissions and/or wood burning to ambient particulate levels. As a result of the study, a "gridded" emission inventory (2 km x 2 km grid) for air toxics will be developed for the Bay Area. Based on the technical analyses, the Air District can focus on reducing toxic pollutants in areas with the highest health risk by using incentives, grant program funding and regulatory controls. A CARE Task Force of diverse stakeholders is assisting the Air District in its efforts.

B. Vehicle Incentive Programs

The Air District currently operates a variety of vehicle incentive programs aimed at reducing mobile sources of emissions. These programs address light-duty fleet and heavy-duty vehicles as well as school buses and off-road engines.

The Carl Moyer program, for example, provides funds on an incentive basis for the incremental cost of cleaner than required engines and equipment. Eligible projects include cleaner on-road, off-road, marine, locomotive and stationary agricultural pump engines, as well as forklifts, airport ground support equipment, and auxiliary power units. The program achieves near-term reductions in emissions of oxides of nitrogen (NOx) and reduces PM. The types of projects and the available funding under this program have recently been expanded. In addition, the District operates other incentive programs such as the Low-Emission School Bus and the Solid Waste Collection Vehicle programs which address emissions from specific categories of heavy duty diesel vehicles as well as the Transportation Fund for Clean Air grant program and the Vehicle Buy-Back program.

The incentive programs are all contingent on funding available to the Air District. In some cases the funding comes from the Air Resources Board and in other cases the funding comes from local vehicle registration fees. The Air District looks for opportunities to garner additional funds that can be used for emission reduction projects in the Bay Area. Air District staff will continue to pursue additional resources for the region which can then be disbursed to applicable PM reduction programs.

C. Wood Burning

In addition to the enhanced wood burning activities listed in the SB 656 Implementation Schedule in Table 3, the District will also be implementing a number of additional activities to reduce emissions, gain a better understanding of the nature and severity of wood smoke in the Bay Area and to help inform potential emission reduction strategies.

The table below provides a summary of the additional methods that the District will use to address residential wood burning in the Bay Area:

Program	Approach	Target Audience Scale of Program
Wood smoke air monitoring	Identify areas particularly affected by wood burning and estimate local PM concentrations	Neighborhood level
Fireplace Change-outs	Provides funding incentives for voluntary wood burning appliance changes	Public at-large /County
Enforcement Response	Education, curtailment request and solution guidance	Wood burning household/individual
Wintertime Public Survey	Solicits information about wood burning activities, public attitudes, and effectiveness of District Spare the Air Tonight program	Public at-large/Regional
Study additional activities	Monitor programs in other regions such as enhanced incentive programs and regulatory wood burning programs	Public at-large/individual

Wood Smoke Air Monitoring

In order to improve the emission inventory for wood smoke and to better identify areas that may be particularly affected by wood smoke, the District will be conducting a focused air monitoring study in specific neighborhoods. This data, supplemented by survey data discussed below, will help identify factors that are conducive to high PM concentrations in residential neighborhoods, where such neighborhoods are located, and what PM levels may be experienced.

Fireplace Change-Outs

The District provides financial incentives in specific locations within the Bay Area for residents to remove non-EPA certified wood burning devices and install EPA certified devices and to replace wood burning fireplaces with natural gas fireplaces.

Enforcement Response

When air pollution complaints about wood smoke are received about a residential source the District attempts to obtain a mailing address for the responsible party and then an information packet of materials is mailed. Included in the packet are the District's "Wood Burning Handbook", educational materials that describe the adverse health effects attributed to wood smoke, and a request that the wood burning be reduced or eliminated. The educational materials also include specific tips on how to burn cleanly.

Wintertime Survey

Wintertime surveys have been conducted the day after a Spare the Air Tonight advisory was issued. The purpose of the study is to better understand the public's attitudes and behavior with respect to burning wood, their awareness of the Spare the Air Tonight Program, as well as the impact that the Program has had on awareness, opinions and behavior relevant to burning wood and air quality. The 2005 Wintertime Survey will be expanded to gather information about wood burning activities, including the quantities of wood being burned, the types of appliances being used, and the frequency of burning.

Monitor Additional Activities

The District will also continue to examine programs in other regions, such as enhanced incentive programs and regulatory limits to wood burning, for potential applicability in the Bay Area.

D. Ozone Strategy Further Study Measures

The Air District, in cooperation with the Metropolitan Transportation Commission and the Association of Bay Area Governments, has prepared the Draft Bay Area 2005 Ozone Strategy. The Ozone Strategy addresses California air quality planning requirements. A critical component of the Ozone Strategy is the set of control measures to further reduce ozone precursor emissions in order to reduce ozone levels in the Bay Area and to reduce transport of pollution to neighboring regions. The control strategy includes stationary source measures, mobile source measures and transportation control measures. In addition, the Air District has also identified a number of further study measures. Some of the further study measures identified in the Ozone Strategy are also on the ARB's list of 103 control measures for indirect PM emissions. The further study measures in the Ozone Strategy need to be researched in greater depth to determine their potential impact on air quality and public health, cost effectiveness, and feasibility. The Air District will continue to evaluate the further study measures to determine whether they are viable PM control measures as well as ozone control measures. For more information and to view a copy of the Draft Bay Area 2005 Ozone Strategy please visit www.baaqmd.gov/pln/plans/ozone/2005_strategy/index.htm.

Appendix A: BAAQMD Review of SB 656 List of Air District Measures

Measure #	Strategy	District Rule	BAAQMD Rule/Measure	Evaluation Result[1]
1.	Wood Burning Public Awareness Program Informs the public about the indoor wood combustion control program. The goal is to inform the public about potential health hazards of wood smoke and to encourage better wood burning practices or use of heating devices.	SJVAPCD Rule 4901	BAAQMD Spare the Air Tonight program	Equivalent Measure
2.	Mandatory Curtailment During Periods with Predicted High PM Levels a) Exempts households that use wood as primary sole source of heat and households in areas where natural gas service is not available. b) Exempts U.S. EPA certified wood-burning appliances. A secondary source of heat is required in all dwellings.	a) SJVAPCD Rule 4901 b) GBUAPCD Town of Mammoth Lakes Rule 431	BAAQMD Model Wood Burning Ordinance contains this provision[2] Currently adopted by 7 cities	Identified for further study and evaluation
3.	Voluntary curtailment during periods with predicted high PM levels.	SCAQMD, YSAQMD SLOAPCD Programs	BAAQMD Spare the Air Tonight program	Equivalent Measure
4.	Require All U.S. EPA-certified or equivalent Wood-Burning Heaters.	SJVAPCD Rule 4901	None	Identified for further study and evaluation
5.	Require All U.S. EPA-certified or equivalent Wood-Burning Heaters and Wood-Burning Fireplaces.	NSoCAPCD Reg. 4-1-400 SLOAPCD Rule 504	BAAQMD Model Wood Burning Ordinance contains this provision Currently adopted by 39 cities and 7 counties	Identified for further study and evaluation

[1] For a full description of each evaluation category, please see the Particulate Matter Implementation Schedule Staff Report.
[2] The District's Model Wood Burning Ordinance contains a variety of provisions that correspond to measures 2, 5, 7-10, and 12 which can be adopted by cities and counties in the region. Each city and county has chosen to adopt specific elements of the Model Wood Burning Ordinance. The number of cities and counties that have adopted each element of the model ordinance is represented for each measure.

6.	Prohibits the Installation of Non-EPA Certified Wood-Burning Appliances & Wood-Burning Fireplaces (except pellet stoves).	GBUAPCD Town of Mammoth Lakes Rule 431	Federal New Source Performance Standards	Identified for further study and evaluation
7.	Limits Number of wood-burning fireplaces and wood-burning heaters in new residential developments.	SJVAPCD Rule 4901	BAAQMD Model Wood Burning Ordinance contains this provision Currently adopted by 38 cities and 7 counties	Identified for further study and evaluation
8.	Limits the number of wood-burning appliances that may be installed in new nonresidential properties.	GBUAPCD Town of Mammoth Lakes Rule 431	BAAQMD Model Wood Burning Ordinance contains this provision Currently adopted by 2 cities	Identified for further study and evaluation
9.	Limits the number of additional wood-burning appliances that may be installed in existing residential and nonresidential properties**.**	GBUAPCD Town of Mammoth Lakes Rule 431	BAAQMD Model Wood Burning Ordinance contains this provision Currently adopted by 24 cities and 3 counties	Identified for further study and evaluation
10.	a) Replacement of Non-EPA Certified Appliances Upon Sale of Property - Non-complying devices must be removed or rendered inoperable. b) Requires replacing, removing or rendering inoperable any non-U.S. EPA certified wood-burning appliance upon sale of a dwelling (excluding pellet stoves, but including fireplaces).	a) SJVAPCD Rule 4901 b) GBUAPCD Town of Mammoth Lakes Rule 431	BAAQMD Model Wood Burning Ordinance contains this provision a) Adopted by Sebastopol, CA	Identified for further study and evaluation
11.	Sets moisture standard for “seasoned wood” offered for sale.	SJVAPCD Rule 4901	None	Identified for further study and evaluation

12.	Prohibits the burning of materials not intended for use in wood-burning fireplaces and wood-burning heaters.	SJVAPCD Rule 4901	BAAQMD Model Wood Burning Ordinance contains this provision Currently adopted by 39 cities and 7 counties	Identified for further study and evaluation
13.	Prohibition of All Residential Open Burning.	SJVAPCD Rules 4103 & 4106	BAAQMD Regulation 5	Equivalent Measure
14.	Prohibition of Residential Open Burning where waste service is available.	MBUAPCD Rule 438	BAAQMD Regulation 5	Equivalent Measure
15.	Prohibition of Residential Open Burning in specified highly populated areas.	SMAQMD Rule 407	BAAQMD Regulation 5	Equivalent Measure
16.	Prohibition of Residential Open Burning within small lots and setbacks.	LCAQMD Rule 433	BAAQMD Regulation 5	Equivalent Measure
17.	Mandatory Curtailment of Non-Agricultural Open Burning during periods of predicted high PM or Ozone levels.	MBUAPCD Rule 438	BAAQMD Regulation 5	Equivalent Measure
18.	Limits during Burn Days in Smoke Sensitive Areas.	MBUAPCD Rule 438	BAAQMD Regulation 5	Equivalent Measure
19.	Emission Limits for Mechanized Burners.	SCAQMD Rule 2.6	None	No Bay Area Sources
20.	Establishes minimum drying times for any green waste to be burned and pile size limits.	BAAQMD Regulation 5 (to be consistent)	BAAQMD Regulation 5	Equivalent Measure
21.	Restricts ignition hours and requires smoldering fires to be extinguished.	LCAQMD Rules 431-433.5	BAAQMD Regulation 5	Equivalent Measure
22.	a) Sets requirements for burn piles prior and during burning. b) Sets requirements for burns on land to be cleared for residential or commercial development. APCO can restrict or prohibit the burning of poison oak.	a) MaCAPCD Rule 300 b) MBUAPCD Rule 438	BAAQMD Regulation 5	Equivalent Measure

23.	Requires permits for all types of outdoor burning.	NCUAQMD Regulation 2	BAAQMD Regulation 5	Equivalent Measure
24.	Fugitive Dust – Construction Earthmoving a) Requires water or chemical stabilizers/dust suppressants be applied, in conjunction with optional wind barriers, to limit visible dust emissions to 20% opacity. Specifies that a Dust Control Plan must be submitted. b) Sets standards for visible dust emissions, requires BACM for all sources of visible dust, lists BACM, requires dust control plan, and other requirements.	a) SJVAPCD Rule 8021 b) SCAQMD Rule 403	BAAQMD Regulation 6	Equivalent Measure
25.	Fugitive Dust – Construction/Demolition a) Requires application of dust suppressants to limit VDE. b) Prohibits VDE beyond property line. Requires application of BACM. Specifies that upwind-downwind PM10 levels, Sets bulk material and track-out requirements.	a) SJVAPCD Rule 8021 b) SCAQMD Rule 403	BAAQMD Regulation 6	Equivalent Measure
26.	Fugitive Dust – Construction/Grading Operations a) Requires pre-watering to limit VDE. Requires phasing of work to reduce disturbed soil. b) Requires water application to increase moisture content to proposed cut, and grading each phase separately to coincide with the construction phase. Specifies that chemical stabilizers are to be applied to graded areas where construction will not begin for more than 60 days after grading.	a) SJVAPCD Rule 8021 b) SCAQMD Rule 403	BAAQMD Regulation 6	Equivalent Measure
27.	Fugitive Dust – Inactive Disturbed Land a) Requires restricting vehicle access. Specifies that water/dust suppressants must be applied. b) Prohibits VDE beyond property line and an upwind/downwind Requires BACM at all times and high wind measures.	a) SJVAPCD Rule 8021 b) SCAQMD Rule 403	BAAQMD Regulation 6	Equivalent Measure

28.	Bulk Materials: Handling/Storage a) Establishes wind barrier and watering or stabilization requirements. Specifies bulk materials must be stored in accordance with the definition for stabilized surface. Requires outdoor materials be covered with tarps or plastic. b) Prohibits VDE beyond property line and an upwind/downwind PM10 differential. Requires use of BACM.	a) SJVAPCD Rule 8031 b) SCAQMD Rule 403	BAAQMD Regulation 6	Equivalent Measure
29.	Addresses storage, handling, and transport of petroleum coke, coal, and sulfur.	SCAQMD Rule 1158	BAAQMD Regulation 6	Equivalent Measure
30.	Carryout and Track-out a) Requires track-out removal at the end of the workday, specifies a track-out control device must be installed at all access points to public roads. Requires maintaining sufficient length of paved interior roads to allow dirt/mud to drop off before leaving site and mud/dirt removal from interior paved roads with sufficient frequency to prevent track-out. b) Requires removing any track-out within one hour; or selecting a Table 3 track-out prevention option and removing track-out at the end of the workday.	a) SJVAPCD Rule 8041 b) SCAQMD Rule 403	BAAQMD Regulation 6	Equivalent Measure
31.	Carryout and Track-out Clean-Up Methods.	SJVAPCD Rule 8041	BAAQMD Regulation 6	Equivalent Measure
32.	Disturbed Open Areas a) Applies to non-agricultural areas of 3 acres or larger which have been unused for 7 days or more. b) Applies to non-agricultural areas of one-half acre or larger for residential use, and all non-residential areas.	a) SJVAPCD Rule 8051 b) SCAQMD Rule 403	BAAQMD Regulation 6	Equivalent Measure
33.	Paved Road Dust: New/Modified Public and Private Roads a) Requires paved shoulders for all roads with average daily vehicle trips (ADVT) of 500 or more. b) Establishes curbing or paved shoulder requirements in the event of a contingency notification.	a) SJVAPCD Rule 8061 b) SCAQMD Rule 1186	BAAQMD Regulation 6	Insignificant Potential Emissions Reductions

34.	Requires use of certified PM10 efficient street sweepers by governmental agencies or their street sweeping contractors where the contract date, purchase date, or lease date is after January 1, 2000.	SCAQMD Rule 1186	None	Insignificant Potential Emissions Reductions
35.	Requires vacuum-street sweeping on roads to remove sand and cinders that were placed on the road during winter storms as an anti-skid material.	GBUAPCD Town of Mammoth Lakes Rule 431	None	No Bay Area Sources
36.	Requirements for Unpaved Parking Lots/Staging Areas.	SJVAPCD Rule 8061	BAAQMD Regulation 6-301	Equivalent Measure
37.	Unpaved Roads: Control Requirements a) Sets requirements for days with 75 or more vehicle trips. Sets requirements for days with 100 or more vehicle trips. Sets as option to above, obtaining a Fugitive PM10 Management Plan. b) Sets applicability standard. Specifies all roads with ADT greater than the average ADT of all unpaved roads within its jurisdiction must be treated. Requires annual treatment of unpaved public roads beginning in 1998 and continuing for each of 8 years.	a) SJVAPCD Rule 8061 b)SCAQMD Rule 1186	None	Insignificant Potential Emissions Reductions
38.	Weed Abatement Activities a) Sets pre-activity requirements. Requires applying water to limit visible dust emissions. Sets stabilization requirements during periods of inactivity. b) Specifies weed abatement activities are subject to standards of Rule 403 with exemptions. Specifies that after discing, the requirement for taking action on disturbed surface areas applies.	a) SJVAPCD Rule 8021 b) SCAQMD Rule 403	None	Insignificant Potential Emissions Reductions
39.	Defines windblown dust as any visible emissions from any disturbed surface area which is generated by wind action alone. Specifies wind gusts as maximum instantaneous wind speed.	SCAQMD Rule 403	BAAQMD Regulation 6	Equivalent Measure
40.	Sets windblown dust construction/earth moving activity abatement requirements.	SCAQMD Rule 403	BAAQMD Regulation 6	Equivalent Measure
41.	Sets windblown dust abatement requirements for disturbed areas.	SCAQMD Rule 403	BAAQMD Regulation 6	Equivalent Measure

42.	Windblown Dust: Bulk Materials/Storage Piles a) Requires application of if subject to large operation requirements or if seeking an exemption from property line or upwind/downwind standard. b) Additional bulk material control requirements for Coachella Valley sources.	a) SCAQMD Rule 403 b) SCAQMD Rule 403	BAAQMD Regulation 6	Insignificant Potential Emissions Reductions
43.	Wind Blown Dust abatement requirements for open areas.	GBUAPCD for Owens Lake Board Order #981116-01	BAAQMD Regulation 6	Insignificant Potential Emissions Reductions
44.	Agricultural Operations a) Limits fugitive dust from off-field agricultural sources such as unpaved roads. Requires producers to draft and implement a Fugitive Dust Management Plan. b) Exemption from the Rule 403 general requirements for producers that voluntarily implement district approved conservation practices and complete and maintain the self-monitoring plan. c) Cease tilling/mulching activities when wind speeds are greater than 25 mph (Coachella Valley). d) Limits fugitive dust from paved , unpaved roads and livestock operations. e) Reduces fugitive dust from livestock feed yards by requiring by limiting manure moisture and outlines manure management practices.	a) SJVAPCD Rule 8081 b) SCAQMD Rule 403 c) SCAQMD Rule 403.1 d) SCAQMD Rule 1186 e) ICAPCD Rule 420	BAAQMD Regulation 6	Insignificant Potential Emissions Reductions
45.	Boilers, Steam Generators, and Process Heaters (each rule has specific size and output thresholds) a) Limits NOx emissions from gaseous fuel or liquid fuel fired boilers, steam generators, or process heaters. b) Limits NOx emissions from any petroleum refinery boiler or process heater. Alternative Emission Control Plans allowed which result in equivalent emissions. All units subject to this rule are now under the SCAQMD's RECLAIM Program.	a) SJVAPCD Rule 4306 b) SCAQMD Rule 1109 c) SMAQMD	BAAQMD Regulation 9-7 Regulation 9-10 Regulation 9-11	Additional controls not included in existing BAAQMD regulations are being proposed as Control Measures in 2005 Ozone Strategy

	c) Limits NOx emissions from gaseous fuel or liquid fuel fired boilers, steam generators, or process heaters with a total rated heat input greater than 5 million Btu/hr to between 30-40 ppmv depending on fuel type. d) Limits NOx emissions from gaseous, liquid, or solid fossil fuel fired boilers, steam generators, or process heaters. e) Limits NOx emissions from any boilers, steam generators, or process heaters. f) Limits NOx emissions from new and existing natural gas-fired large (commercial) water heaters, small (industrial) boilers, and process heaters. Exempts residential and low use units. g) Limits NOx emissions from new natural gas-fired large (commercial) water heaters, small (industrial) boilers, and process heaters. Exempts residential and low use units.	Rule 411 and SCAQMD Rule 1146 d) SCAQMD Rule 1146.1 e) VCAPCD Rule 74.15.1 f) SCAQMD Rule 1146.2 g) SBAPCD Rule 360 and VCAPCD Rule 74.11.1		
46.	Turbines (NOx) - each rule has specific requirements depending on turbine operating capacity, yearly run time, and fuel type a) Limits NOx emissions from the operation of stationary gas turbines to between 9-65 ppmv. Exemptions include emergency standby and laboratory units. b) Limits NOx emissions to the atmosphere from the operation of stationary gas turbines to between 3-65 ppmv. Exemptions include emergency standby and laboratory units. c) Limits NOx emissions from the operation of gas turbines to 9-25 ppm for turbines in size range of 2.9 to 10 MW.	a) SMAQMD Rule 413 b) SJVAPCD Rule 4703 c) SCAQMD Rule 1134	BAAQMD Regulation 9-9	Additional controls not included in existing BAAQMD regulations are being proposed as Control Measures in 2005 Ozone Strategy
47.	IC Engines (NOx, VOC) a) Limits NOx emissions from gaseous- and liquid-fueled stationary and portable engines over 50 bhp depending on use category of engine.	a) SCAQMD Rule 1110.2	BAAQMD Regulation 9-8	Identified for New Rulemaking

	b) Limits NOx emissions from spark ignited internal combustion engines over 50 bhp 250 and CO emissions depending on engine type and size. c) Limits NOx emissions from spark ignited internal combustion engines over 50 bhp depending on engine type and size and NMHC depending on engine size.	b) SJVAPCD Rule 4702 c) SMAQMD Rule 412		
48.	Limits NOx emissions from lime kilns depending on fuel type.	SJVAPCD Rule 4313	None	No Bay Area Sources
49.	Cement Kilns (NOx, PM10, PM2.5) a) Limits NOx emissions from cement kilns during periods of operation other than start-up or shut-down. Additional limits are specified for start-up and shut-down periods. b) Limits NOx emissions from cement kilns. c) Limits PM emissions to 30 pounds per hour for kiln feed rates of 75 tons per hour or greater. Limits PM emissions.	a) MDAQMD Rule 1161 b) KCAPCD Rule 425-3 c) SCAQMD Rule 1112.1	1 Source in Bay Area currently complying with SIP-approved permit conditions	Equivalent Measure
50.	Does not allow operation of petroleum coke calcining equipment unless the uncontrolled emissions of oxides of sulfur from such basic equipment, expressed as sulfur dioxide (SO2), are reduced by at least 80 percent.	SCAQMD Rule 1119	BAAQMD Regulation 9-1-310.2 Additional permit requirements	Insignificant Potential Emissions Reductions
51.	Furnaces (NOx) a) Sets NOx emission limits of 4.0 pounds per ton of glass pulled for glass melting furnaces. Sets NOx emission limits of 5.5 pounds per ton of glass pulled for glass melting furnaces. b) Sets a NOx emission limit for gas fired residential units with rating less than 175,000 Btu/hr.	a) SCAQMD Rule 1117 BAAQMD Rule 9-12 b) SCAQMD Rule 1111 SDAPCD Rule 69.6	BAAQMD Rule 9-12	Equivalent Measure
52.	Residential Water Heaters (NOx) a) Limits NOx emissions from water heaters with heat input rates	a) SCAQMD	BAAQMD Regulation 9-6	Equivalent Measure

	equal to or less than 75,000 Btu per hour to 20 ng/joule of heat output and sets future limit to 10 ng/joule of heat output. b) Limits NOx emissions from water heaters with heat input rates equal to or less than 75,000 Btu per hour to 40 ng/joule of heat output.	Rule 1121 b) SJVAPCD Rule 4902		(SCAQMD standards have been found to be technically infeasible – replaced by mitigation fees)
53.	Requires new and existing chain driven charbroilers to be equipped with a catalytic oxidizer control device.	SJVAPCD Rule 4692 and SCAQMD Rule 1138	None	Identified for New Rulemaking
54.	General Administrative Requirements for composting and chipping and grinding facilities.	SCAQMD Rule 1133	BAAQMD Regulation 2-1	Equivalent Measure
55.	Prevents inadvertent decomposition associated with stockpiling of green and/or food wastes by establishing holding or processing time requirements for chipping and grinding activities.	SCAQMD Rule 1133.1	None	Identified as further study measure in 2005 Ozone Strategy
56.	Requires co-composting operations (biosolids and/or manure combined with bulking agents) to reduce VOC and ammonia emissions by 80%. Requires recordkeeping and source testing.	SCAQMD Rule 1133.2	None	Identified as further study measure in 2005 Ozone Strategy
57	Limits emissions of VOC from gasoline dispensing facilities through equipment and operational requirements.	BAAQMD Rule 8-7	BAAQMD Regulation 8-7	Equivalent Measure
58.	Organic Liquid Storage a) Limits VOC emissions from storage tanks with a capacity of 264 gallons and greater through operational and equipment requirements. b) Limits VOC emissions from any above-ground stationary tank with a capacity of 19,815 gallons or greater used for storage of organic liquids, and any above-ground tank with a capacity between 251 gallons and 19,815 gallons used for storage of gasoline by setting tank roof, other performance, and self-inspection requirements. Sets conditions for cleaning and degassing of aboveground and underground stationary tanks, reservoirs, or other containers storing or last used to store VOC.	a) BAAQMD Rule 8-5 b) SCAQMD Rule 463 in combination with SCAQMD Rule 1149	BAAQMD Regulation 8-5	Equivalent Measure

59.	Equipment Leaks (Valves and Flanges) a) Limits VOC and methane emissions from leaking equipment at petroleum refineries, chemical plants, bulk plants, and bulk terminals depending on equipment type. b) Limits VOC emissions from leaking equipment at petroleum facilities and chemical plants by setting forth leak standards and requirements for component identification, operator inspection, maintenance, and atmospheric pressure relief devices.	a) BAAQMD Rule 8-18 b) SCAQMD Rule 1173	BAAQMD Regulation 8-18	Equivalent Measure
60.	Sets forth operational and "housekeeping" requirements for coatings and ink manufacturing.	SCAQMD Rule 1141.1	BAAQMD Regulation 8-35	Equivalent Measure
61.	Limits VOC emissions from fiberboard manufacturing by requiring use of capture and control systems with specified efficiencies	PCAPCD Rule 229	None	No Bay Area Sources
62.	Limits VOC emissions from solvents used in food product manufacturing and processing operations by limiting the VOC content of products depending on product, or by the use of a control device.	SCAQMD Rule 1131	BAAQMD Regulation 8-2 Regulation 8-4	Identified as further study measure in 2005 Ozone Strategy
63.	Sets forth equipment and operational requirements for pharmaceuticals and cosmetic manufacturing.	SCAQMD Rule 1103	BAAQMD Regulation 8-24	Equivalent Measure
64.	Limits VOC emissions from all polyester resin operations that fabricate, rework, repair, or touch-up products through operational controls and by limiting the monomer content of products depending on product type.	SCAQMD Rule 1162	BAAQMD Regulation 8-50	Additional controls not included in existing BAAQMD regulations are being proposed as Control Measures in 2005 Ozone Strategy
65.	Polymeric Cellular Products (Foam) a) Sets forth emission limits for polymeric cellular products manufacturing operations. b) Limits VOC emissions from the manufacture of foam products composed of polystyrene, polyethylene or polypropylene. A control device with at least 98% efficiency may be used.	a) SCAQMD Rule 1175 b) BAAQMD Rule 8-52	BAAQMD Regulation 8-52	Equivalent Measure

66.	Requires the total emissions of VOC from the surfactant manufacturing equipment, before being vented to the atmosphere, be reduced; and all ports used for inspection, taking samples, or adding ingredients must be closed when not in use.	SCAQMD Rule 1141.2	None	No Bay Area Sources
67.	Adhesives and Sealants a) Reduces VOC emissions from the application of adhesives, adhesive primers, sealants, sealant primers, or any other primers through operational controls and by limiting the VOC content of products. Emission control equipment can be used in lieu of meeting VOC limits. b) Reduces VOC emissions from the application of adhesives, adhesive primers, sealants, sealant primers, or any other primers through operational controls and by limiting the VOC content of products. Emission control equipment can be used in lieu of meeting VOC limits. This rule has more stringent standards for a few categories than the rule above.	a) VCAPCD Rule 74.20 b) SCAQMD Rule 1168	BAAQMD Regulation 8-51	Identified as further study measure in Ozone Strategy
68.	Several districts have adopted regulations consistent with ARB's Suggested Control Measure (SCM) which limits the content of VOC in architectural coatings	SJVAPCD, SDAPCD, SMAQMD, SBAPCD, TeCAPCD, MDAQMD, and AVAQMD.	BAAQMD Regulation 8-3	Equivalent Measure
69.	Limits VOC emissions from the coating of glass products by limiting the VOC content of coating products or installing control equipment.	SJVAPCD Rule 4610	BAAQMD Regulation 8-4 1 Source in Bay Area currently complying with SIP-Approved permit conditions	Insignificant Potential Emissions Reductions
70.	Limits VOC emissions from graphic arts operations by limiting the VOC content of products or by installing a control device.	SCAQMD Rule 1130	BAAQMD Regulation 8-20	Additional controls not included in existing BAAQMD regulations are being proposed as Control Measure in

				2005 Ozone Strategy
71.	Applies to all coating operations on magnet wire, where the wire is continuously drawn through a coating applicator. Prohibits use or application of any magnet wire coating which contains more than 200 grams VOC per liter (1.67 lb/gal) of coating, less water and exempt compounds. The rule also provides for use of approved emission control systems.	SCAQMD Rule 1126	BAAQMD Regulation 8-26	Equivalent Measure
72.	Applies to coating operations of marine and fresh water vessels, oil drilling platforms, navigational aids and component parts; and structures intended for exposure to a marine environment. Limits VOC emissions. Allows use of specified air pollution control equipment which captures VOC emissions associated with coating, cleaning, and surface preparation, in lieu of use of low-VOC coatings and non-VOC materials used in cleaning and surface preparation.	SDAPCD Rule 67.18	BAAQMD Regulation 8-43	Insignificant Potential Emissions Reductions
73.	Limits VOC emissions from metal container, metal closure and metal coil coating operations through operational controls and by limiting the VOC content of products.	SCAQMD Rule 1125	BAAQMD Regulation 8-11	Equivalent Measure
74.	Limits VOC emissions from the coating of metal parts and products not regulated by other specific regulations by limiting coating VOC content.	SCAQMD Rule 1107	BAAQMD Regulation 8-19	Equivalent Measure
75.	Sets forth VOC emission limits and VOC content of motor vehicle coatings. This rule applies to all assembly line coating operations conducted during the manufacturing of new motor vehicles.	SCAQMD Rule 1115	BAAQMD Regulation 8-13	Equivalent Measure
76.	Applies to coatings or wash primers for paper, fabric, or film substrates. Includes drying and curing processes such as heated, forced-air dried, and non-heated processes. The rule specifies VOC content of applicable coatings and sets forth application method and cleaning requirements.	SCAQMD Rule 1128	BAAQMD Regulation 8-12	Equivalent Measure
77	Specifies VOC content of coatings used on plastic, rubber, and glass and sets forth transfer efficiency requirements. The rule allows for use of an approved emission control system in lieu of VOC content limits.	SCAQMD Rule 1145	BAAQMD Regulation 8-31 (plastics coatings) No Bay Area sources for coatings of rubber. 1 glass coating facility	Equivalent Measure

			controlled by permit requirements	
78.	Specifies VOC content of screen printing materials and applies to persons performing screen printing operations or who sell, distribute, or require the use of screen printing materials.	SCAQMD Rule 1130.1	BAAQMD Regulation 8-20	Equivalent Measure
79.	Further reduces VOC emissions from spray coating or laminating operations in high VOC-emitting facilities.	SCAQMD Rule 1132	None	Proposed as Control Measure in 2005 Ozone Strategy
80.	Limits VOC emissions from coatings applied on Group I vehicles and equipment and Group II vehicles through operating requirements and by limiting VOC content.	SCAQMD Rule 1151	BAAQMD Regulation 8-45	Additional controls not included in existing BAAQMD regulations are being proposed as Control Measure in 2005 Ozone Strategy
81.	Limits VOC content of coatings, inks, and adhesives applied to wood flat stock for the purpose of manufacturing a finished wood panel intended for attachment to the inside walls of buildings, including, but not limited to, homes and office buildings, mobile homes, trailers, prefabricated buildings and similar structures, boats and ships, or a finished exterior wood siding.	SCAQMD Rule 1104	BAAQMD Regulation 8-23	Equivalent Measure
82.	Specifies VOC content of wood products coatings. Requires wood strippers to have a maximum VOC content. The rule allows for use of an approved emission control system in lieu of VOC content limits and also includes an averaging provision.	SCAQMD Rule 1136	BAAQMD Regulation 8-32	Additional controls not included in existing BAAQMD regulations are being proposed as Control Measure in 2005 Ozone Strategy
83	Cleaning operations – Limits on VOC emissions a) Reducing VOC content of cleaning products to between 25 g/l-900 g/l depending on process. b) Reducing VOC content of cleaning products to between 50 g/l-900 g/l depending on process	a) SCAQMD Rule 1171 b) SMAQMD Rule 466	BAAQMD Regulation 8	Identified as further study measure in 2005 Ozone Strategy

84.	Degreasing Operations – Limits on VOC emissions a) Applies to cold cleaners and vapor degreasers by limiting product VOC content to 25 g/l. Air-tight and airless cleaning systems can be used in lieu of meeting the VOC limit. b) Applies to cold cleaners by limiting product VOC content to 25 g/l for (900g/l for exempted categories.) c) Applies to batch-loaded vapor degreasers by setting equipment and operating requirements. d) Applies to cold cleaners limit to 50 g/l. Limits VOC emissions from vapor degreasers by setting equipment requirements. Air-tight and airless cleaning systems can be used in lieu of meeting the VOC limit.	a) SCAQMD Rule 1122 b) VCAPCD Rule 74.6 c) VCAPCD Rule 74.6.1 d) SMAQMD Rule 454	BAAQMD Regulation 8-16	Additional controls not included in existing BAAQMD regulations are being proposed as a further study measure in 2005 Ozone Strategy
85.	Limits VOC emissions from VOC containing materials or equipment not subject to VOC limits in any other, specific district regulation to no more than 833 lbs/month. A control device may be used in lieu of the monthly throughput limit.	SCAQMD Rule 442	BAAQMD Regulation 8-4	Equivalent Measure
86.	Soil Decontamination (VOC) a) Limits the emissions of organic compounds from soil that has been contaminated by organic chemical or petroleum chemical leaks or spills, and requires description of an acceptable procedure for controlling emissions from underground storage tanks during removal or replacement through the use of operational requirements and by limiting the amount of soil to be processed daily. b) Limits VOC emissions from excavating, grading, handling and treating VOC contaminated soil as a result of leakage from storage or transfer operations, accidental spillage, or other deposition by requiring that soil with VOC concentrations above 1000 ppm be containerized, sealed, and shipped away for disposal.	a) BAAQMD Rule 8-40 b) SCAQMD Rule 1166	BAAQMD Regulation 8-40	Equivalent Measure
87.	Solid Waste Landfills (VOC) a) Limits VOC emissions from municipal solid waste landfills through installation of gas collection and control systems. b) Limits VOC emissions from the waste decomposition process at solid waste disposal sites through requirements for gas collection and	a) SCAQMD Rule 1150.1 b) BAAQMD Rule 8-34	BAAQMD Regulation 8-34	Equivalent Measure

	control systems.			
88.	Requires any woodworking facility that uses a pneumatic conveyance system connected to woodworking equipment to vent sawdust emissions to a PM10 emissions control device, such that there are no visible emissions; to cover sawdust storage bins at all times; and to take measures to prevent visible emissions from waste disposal activities from crossing any property line.	SCAQMD Rule 1137	BAAQMD Regulation 6	Equivalent Measure
89.	Applies Visible Emission Limits (PM10, PM2.5) by prohibiting discharges into the atmosphere from any single source of emission of any air contaminant for specified periods of time. Provides the option of exempting permitted outdoor residential burns.	MaCAPCD Rule 202 SMAQMD BAAQMD SCAQMD SDAPCD	BAAQMD Regulation 6	Equivalent Measure
90.	Prohibits discharges into the atmosphere from the burning of fuel of combustion contaminants.	MDAQMD Rule 409	BAAQMD Regulation 6	Equivalent Measure
91.	Grain Loading (PM10) Prohibits release or discharge into the atmosphere from any source or single processing unit, exclusive of sources emitting combustion contaminants only.	MaCAPCD Rule 207	BAAQMD Regulation 6	Equivalent Measure
92.	DMV Funds (AB 2766 Funds): Motor Vehicle Registration Fee Program (Many districts implement this program) State law authorizes air districts to assess motor vehicle registration fees of between $2-$4 (MV Fees) to reduce air pollution from motor vehicles and for related planning, monitoring, enforcement, and technical studies necessary for the implementation of the California Clean Air Act.	SCAQMD BAAQMD SJVAPCD Programs	BAAQMD Transportation Fund for Clean Air	Equivalent Measure
93.	Heavy-Duty Engine Incentive Program a) Helps fleets pay for new lower emission heavy-duty engines, lower emission retrofits, and engine replacements. Applies to public and private fleets. The program is funded by the air district and by the Carl Moyer Incentive Program sponsored by ARB. b) Provides incentive funds for the differential cost associated with the reduced emission technology as compared with the cost of	a) SMAQMD Program b) SJVAPCD Program	BAAQMD Transportation Fund for Clean Air Carl Moyer Program Low Emissions School Bus Program Solid Waste Collection Vehicle Program	Equivalent Measure

	conventional technology. Eligible funding categories include heavy-duty on-road vehicles, off-road vehicles, locomotives, marine vessels, electric forklifts, electric airport ground support equipment and stationary agricultural irrigation pump engines. The SJVAPCD received $25 million in State transportation funds from special legislation for the Valley Emergency Clean Air Program (VECAP). The air district added the VECAP funds to the Heavy Duty Engine Incentive Program.			
94.	Lower Emission School Bus Program Provides financial incentives to school districts to replace older school buses using both air district and ARB grant funding.	BAAQMD VCAPCD SCAQMD Programs	BAAQMD Lower Emission School Bus Program	Equivalent Measure
95.	Moyer Program Provides funds on an incentive-basis for the incremental cost of cleaner than required engines and equipment. Eligible projects include cleaner on-road, off-road, marine, locomotive and stationary agricultural pump engines, as well as forklifts, airport ground support equipment, and auxiliary power units. The program achieves near-term NOx and PM reductions.	Most Districts	BAAQMD Carl Moyer Program	Equivalent Measure
96.	Sacramento Emergency Clean Air Transportation (SECAT) Program Encourages cleanup of the existing HDD truck fleet by providing funds to pay for the cost of retrofitting existing engines with newer, cleaner engines or paying a significant amount of the cost of a newer vehicle. The goal is to reduce NOx emissions from HDD trucks by 3 tons per day by 2005 by upgrading 3,000 to 6,000 trucks. Uses State transportation funds under special legislation plus funds from the federal Congestion Mitigation and Air Quality Improvement (CMAQ) Program.	SMAQMD Program	BAAQMD Carl Moyer Program	Equivalent Measure
97.	Provides incentives for certain new on-road original equipment manufacturer (OEM) alternative fuel vehicles with a Gross Vehicle Weight Rating (GVWR) up to 14,000 pounds, including passenger cars, pick-up trucks, small buses, and vans. With the exception of hybrid electric vehicles, no vehicles with the ability to operate on gasoline or diesel fuel are funded.	SJVAPCD Program	BAAQMD Vehicle Incentive Program and Transportation Fund for Clean Air	Equivalent Measure

98.	Encourages trading of gasoline-powered lawn mowers, by providing funds to offset the purchase cost of electric mowers	BAAQMD SJVAPCD SMAQMD SCAQMD Programs	BAAQMD Lawn Mower Replacement Program	Equivalent Measure
99.	On-Road Motor Vehicle Mitigation Options Requires employers who employ 250 or more employees to implement a program to reduce mobile source emissions generated from employee commutes and meet an annual emission reduction target (ERT) for their worksite.	SCAQMD Rule 2202	BAAQMD Transportation Fund for Clean Air funds Regional Rideshare Program, county-level and school and university ridesharing programs. Spare the Air and BayCAP Programs include employer outreach.	Additional measures not included in existing BAAQMD programs are proposed as Further Study Measures in 2005 Ozone Strategy
100.	Transportation Outreach Program Requires employers with 100 or more employees to register with the air district annually and collect survey data on their employee's commute distances and ridesharing participation every two years. This rule allows the air district to devote resources and efforts in assisting employers with their voluntary trip reduction efforts.	VCAPCD Rule 211	BAAQMD Transportation Fund for Clean Air funds Regional Rideshare Program, county-level and school and university ridesharing programs. Spare the Air and BayCAP Programs employer outreach	Equivalent Measure
101.	Spare the Air Program Spare the Air is a voluntary, summertime effort aimed at reducing air pollution (specifically, ground-level ozone) through public outreach programs to encourage the general public and employers to take actions to reduce transportation related emissions.	SMAQMD, SJVAPCD, BAAQMD Programs	BAAQMD Spare the Air Program	Equivalent Measure
102.	Public Awareness Programs Some air districts have implemented public awareness programs that: 1) support voluntary employer based trip reduction programs, 2) encourage alternative modes of transportation, 3) encourage cities	BAAQMD SCAQMD SMAQMD SJVAPCD	BAAQMD Spare the Air Program, CEQA Commenting, Smart Growth Program,	Equivalent Measure

	and counties to incorporate air quality beneficial policies into local planning and development activities, 4) promote demonstrations of low emission vehicles and refueling infrastructure, and/or 5) continue public education by informing residents about air quality status, air pollutant health effects, sources of pollution, and actions individuals and communities can take to help improve air quality.	Programs	and 2005 Ozone Strategy Transportation Control Measures	
103.	Leveraging Other Sources for Transportation Funding Some air districts apply for and receive money for transportation-related projects from federal, state, and local funding sources, the most notable being the federal Congestion Mitigation and Air Quality Improvement (CMAQ) program. The projects funded are usually small scale and include incentives, facilities, support services, and public awareness for carpools, vanpools, telecommuting, public transit, biking and walking.	BAAQMD SCAQMD	BAAQMD Spare the Air Program and Grant Programs	Equivalent Measure

More in-depth information about *District rules and regulations can be obtained at* ***http://www.arb.ca.gov/drdb/drdb.htm***

1.0 Introduction

2.0 Executive Summary

3.0 Comments and Responses to Comments on the Draft EIR

4.0 Minor Revisions to the Draft EIR

APPENDIX

APPENDIX A- BAAQMD PM IMPLEMENTATION SCHEDULE

1.0 INTRODUCTION

2.0 EXECUTIVE SUMMARY

3.0 COMMENTS AND RESPONSES TO COMMENTS ON THE DRAFT EIR

4.0 MINOR REVISIONS TO THE DRAFT EIR

APPENDIX

LIST OF TABLES