HEALTHY PLANET, HEALTHY PEOPLE: GLOBAL WARMING AND PUBLIC HEALTH

HEARING

BEFORE THE

SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING HOUSE OF REPRESENTATIVES

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HEALTHY PLANETS, HEALTHY PEOPLE: GLOBAL WARMING AND PUBLIC HEALTH

WEDNESDAY, APRIL 9, 2008

HOUSE OF REPRESENTATIVES,
SELECT COMMITTEE ON ENERGY INDEPENDENCE
AND GLOBAL WARMING,
Washington, DC.

The committee met, pursuant to call, at 10:04 a.m., in Room B–318, Rayburn House Office Building, Hon. Hilda Solis presiding.

Present: Representatives Solis, Blumenauer, Inslee, Cleaver, McNerney, and Walden.

Staff present: Ana Unruh-Cohen and Stephanie Herring.

Ms. SOLIS [presiding]. Good morning. I would like to call the Select Committee on Energy Independence and Global Warming to order, and wanted to let our witnesses and everyone know that we are having some difficulty with timekeeping because these clocks are not working appropriately, but we will give you an indication when you begin to speak what the timing will be. I think most of you know what that procedure is like.

Unfortunately, this morning Chairman Markey is not able to be with us; he had a—wrinkle. He is getting it taken care of. And I don't mean it facially or figuratively speaking; he broke his wrist, so we hope that he will have a speedy recovery and come back to us very soon.

But I am very delighted that this particular hearing is going to focus on healthy planet, healthy people, global warming, and public health, something that some of us here on the committee have been talking about for some time. And it just happens that this week is both National Public Health Week and World Health Day, and so we are focusing on the impact of climate change that will have on our communities and the health and well-being of our communities. Today's hearing is an opportunity to address this important relationship.

The World Health Organization reported that the effects of climate change may have caused over 150,000 deaths in the year 2000, and predicts that these impacts are likely to increase in the future. According to the IPCC, the United States will be challenged by increased heat waves, air pollution, forest fires during the course of the century, with potential risks for adverse health impacts such as heat stress, increases in asthma, allergies, chronic and obstructive pulmonary disease.

Last October, the director of the United States Center for Disease Control and Prevention, Dr. Julie Gerberding, testified that climate change is anticipated to have a broad range of impacts on the health of Americans and the nation's public health infrastructure. The World Health Organization found that the negative public health impacts of climate change will disproportionately impact communities that are already vulnerable.

Children, the elderly, poor, and communities of color, as we know, are most vulnerable to the negative health impacts of climate change. More than 50 percent of 30 million people in the U.S. are impoverished and they currently live in urban areas; the majority of these communities are of color. And a recent report issued by the IPCC noted that these communities will have less capacity to deal with effects of climate change.

Many of those communities are already suffering cumulative exposure. For example, 5.5 million Latinos and 68 percent of all African-Americans live within the range where health impacts from power plants are the most severe, and more than 70 percent of African-Americans and Latinos live in counties that violate federal air pollution standards.

The EPA first recognized the possible impacts of climate change on public health over a decade ago, and in 1997, EPA's publication, titled "Climate Change and Public Health," the EPA wrote that, "as climate changes, natural systems will be destabilized, which could pose a number of risks to human health." And in 2001, the EPA sponsored a report for the Global Change Research Program entitled, "Climate Change and Human Health: The Potential Consequences of Climate Variability and Change." The report stated that the assessment makes clear that the potential health impacts are diverse and demand improved health infrastructure and enhanced targeted research.

As policymakers, we have a moral imperative to make sure that policy and regulations protect our most vulnerable population. Unfortunately, the health and welfare of minority and low-income communities continues to be put at risk by the administration's failure to develop and implement and enforce environmental regulations, including the regulation of greenhouse gases public health; it is unnecessarily risking public health. Hurricane Katrina demonstrated to the world the direct effect that climate change is having on the health of our most vulnerable populations. These outcomes, as we know, will worsen unless there is action taken.

Before we begin, I would also like to say that I am disappointed that we did not receive testimony from the administration prior to the start of this hearing. The failure of the administration to come to agreement on the CDC testimony is not only in violation of committee rules and courtesy, it is also a great disservice to my colleagues on this committee who deserve the opportunity to know in advance what a witness' position is, and in this case the administration's position.

Frankly, this is yet another indication of the role of politics that is playing in science, and I hope in this case that the testimony reflects the science and not the politics. The administration must recognize our role in preventing impacts of climate change on vulnerable communities, including the need to improve health status and health equity, the inclusion of health policy in the development of climate response, and the need to prevent injustices such as those that resulted in Hurricane Katrina.

I look forward to hearing from all of our witnesses today, and I really want to thank our chairman, Ed Markey, for agreeing to have this very important hearing. He has been a longtime advocate in this area, and finally we see the day now where these issues that we have been talking about have come to the forefront.

So I will yield back the balance of my time, and I will recognize Congressman Blumenauer, from Oregon, for 2 minutes.

Mr. BLUMENAUER. Thank you, Madam Chair. Well, actually I may—since it is a little more relaxed, I may take a couple more, in part because, as you, I am in three places at once right now, for which I apologize, but we have got some ways and means stuff going forward. We are missing a caucus and I don't even know where else I was supposed to be, but I wanted to be here to express my appreciation to the committee and staff for bringing us together and for the witnesses to join us.

Not everybody is here. We have had a chance, however, to review some of the testimony that did get to us, and we will—the record that is being built, I think, is very, very important to be able to shape and inform what we are going to be doing with climate change. And being able to focus on the human health aspect here, I think, is perhaps the most important and under-appreciated area.

Last week we had our state epidemiologist, Mel Kohn, give a presentation in Portland, where he outlined the public health issues that he is dealing with from climate change, from heat waves to vector-borne disease, asthma, allergy, air pollution, chronic—it was a pretty scary litany of items that they are considering with, from changes to physical activity to food insecurity, mental health. We need to be able to get the big picture together to be able to move forward on this.

One particular area that I am hopeful that the witnesses can help us focus on and supplement the record, dealing with the problem of waterborne disease in particular. And this is an area that is an international initiative; it is something we have been working on with my associate, Ms. Benner, since the Johannesburg World Sustainable Development in 2002. We have got the Water for the Poor legislation, but it is not being funded.

And candidly, the administration, as yet, has not even assembled the plan that was called for under that legislation. And this is only going to be compounded if global warming continues: an average global temperatures increase by just one degree, we are talking about a third of a billion cases of waterborne illness. Hundreds of thousands of people, potentially, that would be dying.

There are opportunities with our assessment of global warming to actually deal—to fight climate change, to actually improve human health. We have got some legislation, Dr. Frumkin, dealing with recycling, and land-use, and transportation, that actually not only addresses climate change, but actually has the potential of helping the human physical activity and condition. We will be moving forward with that.

One aspect I didn't see, at least as we were reviewing last night the testimony that had been submitted, dealt with climate change's impact on reduced biodiversity and missed opportunities for medical advancements, and I don't know if that is going to find its way into the record now or later. The testimony had that iconic picture of the polar bear. And some people are dismissing, you know, one more species, more or less, but just thinking about the amazing capacity of the polar bear to fast for 150 days, maintain a relatively normal body temperature, maintain bone mass, give birth, I mean, just basically stop the other processes—the impact that could have for long-term human health is something that I am hopeful we can get some help from you and others.

I am going to stick around for as long as I can; I hope to get back. I appreciate your leading us through this and look forward to hearing our witnesses.

[The prepared statement of Mr. Blumenauer follows:]

Rep. Earl Blumenauer
Statement for the Record
Hearing on Public Health and Global Warming
April 9, 2008

I deeply appreciate the Chairman holding this important hearing.

It's clear that global warming is not just about polar bears, but it impacts public health at home and abroad.

Earlier this week, Oregon's State Epidemiologist, Mel Kohn, gave a presentation in Portland in which he outlined a number of public health issues related to climate change, including heat waves, severe weather, vector-borne diseases, asthma and allergies, air pollution and chronic lung disease, changes in physical activity, food insecurity, mental health, and more. I look forward to further elaboration on these issues by the witnesses today.

I am especially interested in hearing more about water quality and quantity at home and abroad, as water will be where we feel the impacts of global warming most acutely.

For the past six years, I have been focused on helping the United States meet its commitment to the world made at the World Summit on Sustainable Development in Johannesburg, South Africa, in 2002 to cut in half the number of people around the world without access to safe drinking water and sanitation. Obviously global warming will make meeting this goal more difficult. The World Health Organization estimates that if global warming continues and average global temperatures increase by one degree, there could be an additional 320 million cases and 176,000 deaths from diarrheal illnesses, which is a water-related disease. This is an area where I think we should be focusing more of our resources.

One aspect I didn't see the witnesses focus on is that climate change means reduced biodiversity and missed opportunities for medical advancements. For example, cone snails, which have medicinal properties that biomedical researchers are just starting to understand, and which may contain one of the largest and most clinically important pharmacopoeias in nature, live in tropical coral reefs that are threatened by global warming. Another example is polar bears, which biomedical researchers have been studying because of their denning ability. They are the only animal that fasts for 150 days while maintaining a normal body temperature, maintaining bone mass, not defacating, and even giving birth to cubs – these are amazing physiological properties. Imagine the potential implications for human health – from osteoporosis to diabetes to kidney failure failure. But as we've learned through this Committee, polar bears are threatened by global warming. I hope we can look into these issues at a future hearing.

There are some positive connections between climate change and public health that I'd like to highlight. As both Mr. Patz and Mr. Benjamin point out in their written testimony, climate change solutions can create opportunities for improving public health.

Strategies to reduce greenhouse gas emissions from the transportation sector, such as encouraging people to walk or ride their bikes – burning calories instead of carbon – have substantial co-benefits to public health by increasing physical activity. Giving people transportation choices to reduce single occupancy vehicle trips will not only decrease greenhouse gas emissions but will improve quality of life.

For example, bicycle commuters annually save $1,825 in auto-related costs, reduce their carbon emissions by 128 pounds, conserve 145 gallons of gasoline, and avoid 50 hours of gridlock traffic. In 1969, approximately 50 percent of children in the United States got to school by walking or bicycling, but in 2001 only 15 percent of students were walking or bicycling to school. There are things we can do at the Federal level to turn this trend around.

Along these lines, next month I will be introducing legislation to help make communities more livable and reduce their carbon footprint by changing land use patterns and improving transportation systems to reduce the amount that people have to drive. My legislation will align transportation decisions with climate change goals and promote public transportation, bicycling, telecommuting, and walkable communities as a way of reducing greenhouse gas emissions. I hope the public health community will join me in this effort.

Ms. SOLIS. Great. Thank you very much, Mr. Blumenauer.

I also would like, at this time, to ask for unanimous consent to insert Ed Markey, our chairman, his statement into the record. If there is no objection, then we will do that.

[The statement of Chairman Markey follows:]

THE SELECT COMMITTEE ON
ENERGY INDEPENDENCE AND GLOBAL WARMING

Opening Statement for Edward J. Markey (D-MA)
"Healthy Planet, Healthy People: Global Warming and Public Health"
Select Committee on Energy Independence and Global Warming
April 9, 2008

Our planet is sick. As the planet's health deteriorates, our health will also be challenged in new ways. We have a choice: to take preventative medicine or to ignore the symptoms and suffer the consequences.

Today the Select Committee will examine the how the planet's aches and pains can influence our own health, and what we must do to save us both. The most direct effect of global warming in our country will be longer and hotter heatwaves. As we have seen in Chicago and other cities, the elderly suffer the most in heatwaves and are at greatest risk of dying.

But like any fever, the physical symptoms go beyond higher temperatures. Air quality also is affected by climate change. Hotter days will accelerate the reaction that creates ground level ozone. Ozone is a well established public health threat that can damage lung tissue and will increase the most in cities that already suffer from high pollution levels. Even modest exposure to ozone may encourage the development of asthma, especially in children

Warmer temperatures also mean plants will produce more ragweed and allergy-causing pollen. The allergy season will last longer as spring comes earlier and fall comes later, exposing already at risk populations to more and longer respiratory irritants.

Global warming will increase the United States vulnerability to infectious diseases. As the mercury rises in North America the warmer climate will encourage bacteria such as *E. coli* and *Salmonella* to multiply more rapidly, increasing our risk for water and food borne illness.

Higher temperatures also shift patterns of disease transmission. As North America warms, it will welcome a new range of illnesses. Already we have seen a lethal fungus once only found in the tropics take hold in the temperate rainforests of the Pacific North West.

The United Nations' IPCC predicts climate change to cause more extreme weather events, including flooding and drought. Floods and droughts both lead to additional human illness. Flooding can cause run-off and sewage overflow that contaminates drinking water with pollution and disease. Drought dehydrates the land, thus making it more difficult to quench our thirst with safe drinking water. Drought also increases the concentration of contaminates in water, thereby making it more difficult to purify.

Floods and droughts also promote the spread of infectious diseases by mice, rats and mosquitoes. The Hantavirus, a disease connected to large mice and rat populations which surge after droughts and flooding, was unknown before 1993 in the United States. It has now infected 465 people in the United States. An astounding 35% of these cases were lethal.

But warmer temperatures alone do not spread disease. Instead, climate change loads the dice by increasing the odds a disease will thrive in a new location once it is introduced. [SH: It is not obvious to me why that is so.] We are gambling with our health, and if we allow global warming to continue we are stacking the deck against ourselves.

The health impacts of global warming I just mentioned will not be shared equally. They will disproportionably affect the most vulnerable in our society – young children, the elderly, people in underserved communities and communities of color. While these citizens may suffer the most from the health consequences of climate change, they are historically the least responsible for the problem.

Within the United States there is a national consensus among public health professionals, academic researchers, and medical practitioners that climate change will negatively influence health. The consensus extends to our own Center for Disease Control whose Director, Dr. Julie Gerberding, testified in October 2007 that, "Climate change is anticipated to have a broad range of impacts on the health of Americans and the nation's public health infrastructure."

Thanks to an excellent public health care system, supported by the finest public health professionals in the world, the United States is better prepared to manage the health effects of climate change than many other nations. But even in the United States our ability to adapt is limited. If global warming continues unabated, we will constantly be reaching for our emergency kit of band-aids and pain killers that only relieve the symptoms without providing a lasting cure. This practice is not sustainable, and eventually the planet's fever will be out of our control.

But we are not paralyzed and unable to walk away from our current path. We must start the planet down the road to recovery by targeting the source of the problem, and reduce our levels of dangerous global warming pollution. This is the prescription that can heal the planet, and will be our best preventative medicine. We have one planet. We must work to save her as though our lives depend on it -- because they do.

Ms. SOLIS. Next I would like to recognize the distinguished member from California, Mr. McNerney, for an opening statement. Feel free to take more than 2 minutes if you would like, but keep it——

Mr. MCNERNEY. Great. Well, I typically am a brief speaker, so I will, probably. Thank you, Madam Chairwoman, and this is a really important part of the question on the issue of global warming, is the health effects. We know there is going to be flooding effects and so on, but the sort of secondary effects, I think, are going to be actually more important in terms of the effect on our people.

We have to adapt and mitigate; we all know that. But there is going to be things like problem plants growing that cause more allergies, more asthma, there will probably be an increase of ozone. The warmer temperatures—and I am sure we will hear about this from the experts—they will be increasing the rodent population, the insect population, which are vectors for diseases that we probably haven't seen in our society for a long, long time.

There will be droughts and floods, which have health impacts. There will be loss of habitat, which Mr. Blumenauer referred to a minute ago. We will lose tropical rainforests; we will lose costal areas.

So we have a whole range of impacts that are going to be coming down the pipe from global warming. It is important for us right now to understand what those impacts are so that we can begin to plan, we can begin to mitigate, and we can begin to use that as an issue to further the public's awareness and willingness to go along with steps that we are going to be needing to take to fight these coming issues.

And one thing I always like to say is that if we make the right decisions here, we are not only going to be adapting and mitigating, but we are going to be creating opportunities. We are going to be creating a cooperation worldwide, so I think of it as a great opportunity as well as a threat.

So what I want to do is listen to your testimony—hopefully I will be able to stay through most of it—and we will move forward with good legislation as a result.

So thank you, Madam Chairwoman.

Ms. SOLIS. Thank you. I thank the gentleman from California.

[The prepared statement of Ms. Blackburn follows:]

Opening Statement of Congresswoman Blackburn
US House Select Committee on Energy Independence and Global Warming
Hearing on "Healthy Planets, Healthy People: Global Warming and Public Health"

Mr. Chairman,

I want to thank you for holding this hearing and I want to thank the witnesses coming before us to testify on the relationship between global warming and public health.

Just for the purpose of debate, let's assume that global warming is happening and the public health dangers predicted by the IPCC, EPA, and CDC will happen.

Current climate change policies will **still** not prevent these dangers, and in many cases will actually make them worse.

For example, expensive CO2 emission cuts may slightly reduce public health hazards caused by heatwaves. But more deaths are caused by very cold climates than very hot ones, so in effect, and global warming would help more than hurt.

And in many cases, the cuts will reduce consumer income resources, decreasing citizens' ability to use resources to adapt to climate change. This will lead to even more deaths.

Even if CO2 causes global warming, cutting emissions through costly carbon reductions will make very little difference for the climate and society. Other less expensive policies exist and should be tried first.

For example, practical, common sense actions can bring basic access to clean drinking water and sanitation to more than 2 and ½ billion people at a cost of $40 billion.

If this money is mandated to mitigate CO2 emissions, the cost will be **much more** and results much **less effective**.

Mr. Chairman,

Climate change is not an imminent threat that will cause global catastrophes.

It is merely one problem among many that society will need to address over the next century.

There are no short term fixes to this problem, and approaches such as carbon taxes or a cap-n-trade program do not pass costs and benefits analysis and should be avoided, especially when more reasonable and fiscally responsible approaches are available.

Just for the sake of clarity here, each panelist will have a chance to give an opening statement for 5 minutes, and then from there we will go to question and answer. And I apologize if we don't have all of our members here; we do have a series of other committee meetings and caucuses that are going on.

So our first witness, I would like to thank Dr. Frumkin for coming here. Just a brief introduction: Dr. Howard Frumkin serves as the director of the National Center for Environmental Health and the Agency for Toxic Substances and Disease Registry. He received his M.D. from the University of Pennsylvania and his master's and doctorate in public health from Harvard.

Before joining the CDC in September 2005, he was professor and chair of the Department of Environmental and Occupational Health at Emory University, Rollins School of Public Health. He previously served as a member of EPA's Children's Health Protection Advisory Committee, where he chaired the Smart Growth and Climate Change workgroup.

He currently serves on the Institute of Medicine roundtable on environmental health services, research, and medicine. He is the lead author on "Climate Change: The Public Health Response," which was published in the American Journal of Public Health. This document outlines the CDC's strategy to address climate change impacts on public health in the United States.

Dr. Frumkin, welcome, and thank you, and you may begin.

STATEMENTS OF DR. HOWARD FRUMKIN, DIRECTOR, NATIONAL CENTER, ENVIRONMENTAL HEALTH CENTER FOR DISEASE CONTROL; DR. JONATHAN PATZ, PROFESSOR AND DIRECTOR, GLOBAL ENVIRONMENTAL HEALTH, UNIVERSITY OF WISCONSIN AT MADISON; DR. GEORGES BENJAMIN, EXECUTIVE DIRECTOR, AMERICAN PUBLIC HEALTH ASSOCIATION; DR. DANA BEST, AMERICAN ACADEMY OF PEDIATRICS; MR. MARK JACOBSON, DIRECTOR ATMOSPHERE ENERGY PROGRAM, PROFESSOR ENVIRONMENTAL ENGINEERING, STANFORD UNIVERSITY

STATEMENT OF HOWARD FRUMKIN

Dr. FRUMKIN. Thank you very much, Madam Chair and other distinguished members of the committee. I am grateful to you for taking up this very important subject.

As you said, I am Howard Frumkin, director of the National Center for Environmental Health and the Agency for Toxic Substances and Disease Registry at the Centers for Disease Control and Prevention. I am here to speak on our emerging understanding of climate change and its potential impact on health, and to discuss steps we are taking, as public health officials, regarding these potential consequences.

I recognize that this topic remains controversial, and some of my testimony may not necessarily reflect broad consensus across the administration. In addition, CDC is not a regulatory agency and does not express any opinions on regulatory decisions pending before the Environmental Protection Agency.

I would like to make three simple points. First, climate change is very much a public health concern. Some of the components of that point were very well elucidated by members in their opening statements. Potential health impacts include heat waves, respiratory disease exacerbations, severe weather events, infectious disease risks, and others. For some of those, the science base is very well delineated; for others we have a lot to learn.

Collectively, that science base is very well described in documents of the intergovernmental panel on climate change, in the U.S. climate change science program, and I won't go into those in any more detail now. The bottom line is that climate change is a very serious public health concern.

As the chair has pointed out on many occasions, it is particularly a concern that affects some of us more than others. Public health is very committed to addressing health disparities, and that commitment very much has to be a part of our steps to address climate change as well.

The second point is that we need public health action to address the potential health consequences of climate change. Fortunately, the tools of public health—the tools in our toolbox—are very well-suited to addressing climate change.

Core functions of public health include surveillance and tracking; collecting data on environmental risk factors and on health outcomes; outbreak investigations, so that we better understand emerging or reemerging diseases that may be related to climate change; preparedness planning, such as heat wave preparedness plans, so that officials at the local level can better protect their populations from some of the consequences of climate change; research, because we need to understand much better the health implications of climate change.

Communication is a core function of public health that is especially important because this is a broad and complex topic that the public needs to understand well, including its health consequences; we in public health have considerable experience at communicating complex health-related topics to the public. All of these and others are core public health functions, and they can very, very readily be deployed as we address climate change.

With the permission of the chair, I would like to submit for the record an article entitled, "Climate Change: The Public Health Response," that makes these points in considerably more detail.

My third point is that CDC has a strong foundation for the work that we need to do going forward. We have ongoing activity, and have for a long time, in such functions as Vector-borne disease surveillance, heat wave epidemiology, strong working relationships with state and local health departments, preparedness planning, health communication. These are activities that are well-established at the CDC and form a strong foundation for moving forward as we address climate change.

In closing, let me offer a good news aspect of the challenge that we face. As has been mentioned in the opening statements, many of the steps we need to take to address climate change offer a range of co-benefits that will benefit public health as well as environmental and other areas in diverse ways. For example, if people walk and bicycle more, not only is that part of the climate change response, but it helps to promote physical activity, it helps us achieve clean air, it helps reduce the risk of car crashes, thereby offering a broad range of health benefits.

We think there are many opportunities to benefit health in diverse ways as we address climate change. Part of our job at the CDC, and in public health more generally, is to document the science base for those co-benefits to bring them to the attention of the public and policymakers, so that together we can protect health as well as we possibly can as we move forward in addressing climate change.

Thank you, again, for your interest in this subject and your commitment. I am pleased to answer any questions.

[The statement of Dr. Frumkin follows:]

Testimony
Select Committee on Energy Independence and Global Warming
United States House of Representatives

Climate Change and Public Health

Statement of
Howard Frumkin, MD, DrPH
Director, ***National Center for Environmental Health, Centers for Disease Control and Prevention and Agency for Toxic Substances and Disease Registry***
U.S. Department of Health and Human Services

SAFER • HEALTHIER • PEOPLE

For Release on Delivery
Expected at 10 am
April 9, 2008

Introduction

Good morning Chairman Markey, Representative Sensenbrenner, and other distinguished members of the Committee. I am Howard Frumkin, Director of the National Center for Environmental Health at the Centers for Disease Control and Prevention (CDC), and Assistant Administrator of the Agency for Toxic Substances and Disease Registry (ATSDR). I am here to speak on our emerging understanding of climate change and its potential impact on health, and to discuss steps we are taking as public health officials regarding these potential consequences. I recognize that this topic remains controversial and some my testimony may not necessarily reflect broad consensus across the Administration. In addition, CDC is not a regulatory agency and does not express any opinions on regulatory decisions pending before the Environmental Protection Agency.

Background

Scientific evidence supports the view that the earth's climate is changing. CDC considers climate change a serious public health concern, The programs and expertise used by CDC to address a broad range of public health challenges also are applicable to preparing for and responding to public health needs related to climate change. In this testimony, I will address the following dimensions of climate change and public health:

1) The likely public health threats of climate change,

2) The people most vulnerable to these threats, and

3) CDC activities to protect the public's health from these anticipated threats.

Climate change strategies are typically framed by two broad approaches. *Mitigation* encompasses efforts to reduce climate change itself, while *adaptation*, encompasses activities to manage those effects of climate change that are inevitable despite mitigation efforts. This framing aligns closely with the public health framework of prevention and preparedness. Like prevention, mitigation seeks to prevent negative outcomes. Like adaptation, preparedness acknowledges that, while not all negative outcomes can be prevented, they can be reduced and managed. For climate change, adaptation/preparedness is more broadly accepted as a public health activity. However, there is also a role for public health to play by articulating the health implications of climate change mitigation options, both by highlighting co-benefits to health of certain options and by identifying potential negative health outcomes of other possible mitigation strategies.

Climate Change is a Public Health Concern

Over the next few decades in the United States, climate change is likely to have a significant impact on health. The anticipated health impacts of climate change have been well-reviewed and articulated by the Intergovernmental Panel on Climate Change[1] and by the U.S. Climate Change Science Program through

[1] Intergovernmental Panel on Climate Change, 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, P.P. Palutikof, P.J. van

their Synthesis and Assessment Products[2]. While knowledge of the potential public health impacts of climate change will advance in the coming years and decades, the following are current best estimates of major anticipated health outcomes:

- Direct effects of heat,
- Health effects related to extreme weather events,
- Air pollution-related health effects,
- Water- and food-borne infectious diseases,
- Vector-borne and zoonotic diseases, and
- Other pathogens sensitive to weather conditions.

The United States is a developed country with a variety of climates. Because of its well-developed health infrastructure, and the greater involvement of government and nongovernmental agencies in disaster planning and response, the health effects from climate change are expected to be less significant than in the developing world. Nevertheless, Americans may experience difficult challenges, and different regions of the country may experience these challenges at varying degrees.

Heat Stress and Direct Thermal Injury

der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22. Available at: http://www.ipcc.ch/ipccreports/assessments-reports.htm.
[2] U.S. Climate Change Science Program. Public Review Draft of Synthesis and Assessment Product 4.6. Executive Summary. Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems. Available at: http://www.climatescience.gov/Library/sap/sap4-6/public-review-draft/default.htm

With climate change, the United States would expect to see an increase in the severity, duration, and frequency of extreme heat waves. Heat causes a range of health effects, from mild (heat cramps, heat exhaustion) to severe (such as heat stroke, which can be fatal). Certain populations are especially vulnerable to these health effects, including the elderly, those with certain underlying medical conditions, those who are socially isolated, and those without air conditioning. Midwestern and northeastern cities are at greatest risk, as heat-related illness and death appear to be related to exposure to temperatures much hotter than those to which the population is accustomed.[3]

Extreme Weather Events

Scientific evidence suggests climate change will likely modify extreme weather events, such as floods, droughts, and heavy precipitation. In addition, some evidence suggests hurricanes could become more intense. The health effects of extreme weather events range from loss of life and acute trauma to indirect effects such as loss of home, large-scale population displacement and subsequent mental health effects, damage to sanitation infrastructure (drinking water and sewage systems), interruption of food production, and damage to the health-care infrastructure. Displacement of individuals often results in disruption of health care, of particular concern for those with underlying chronic diseases. Future climate projections also show likely increases in the frequency of heavy rainfall events, posing an increased risk of flooding. Climate change models

[3] McGeehin MA, Mirabelli M. The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. Environ Health Perspect 109 (suppl 2), 185-189 (2001)

also suggest some areas of the United States may have less rainfall leading to severe drought, reducing availability and quality of water.

Air Pollution-Related Health Effects

Climate changes will likely affect air quality by modifying local weather patterns and pollutant concentrations, affecting natural sources of air pollution, and promoting the formation of secondary pollutants. Studies show that higher surface temperatures, especially in urban areas, encourage the formation of ground-level ozone. Ozone can irritate the respiratory system, reduce lung function, aggravate asthma, and inflame and damage cells that line the lungs. In addition, it may cause permanent lung damage and aggravate chronic lung diseases.

Water- and Food-borne Infectious Diseases

Altered weather patterns resulting from climate change could affect the distribution and incidence of food- and water-borne diseases. Changes in precipitation, temperature, humidity, and water salinity have been shown to affect the quality of water used for drinking, recreation, and commercial use. For example, outbreaks of *Vibrio* bacteria infections following the consumption of seafood and shellfish have been associated with increases in temperatures. Heavy rainfall has also been implicated as a contributing factor in the overloading and contamination of drinking water treatment systems, leading to illness from organisms such as *Cryptosporidium* and *Giardia.* Storm water runoff from heavy precipitation events can also increase fecal bacterial counts in coastal waters as well as nutrient load, which, coupled with increased sea-surface temperature, can lead to increases in the frequency and range of harmful algal blooms (red tides) and potent marine biotoxins such as ciguatera fish poisoning.

Vector-borne and Zoonotic Diseases

Vector-borne and zoonotic diseases, such as, Lyme disease, West Nile virus, malaria, plague, hantavirus pulmonary syndrome, and dengue fever have been shown to have a distinct seasonal pattern, and in some instances their frequency has been shown to be weather sensitive. Because of the sensitivities of the vectors and animal hosts of these diseases to climactic factors, climate change-driven ecological changes, such as variations in rainfall and temperature, could significantly alter the range, seasonality, and human incidence of many zoonotic and vector-borne diseases. More study is required to fully understand all the implications of ecological variables necessary to predict climate change effects on vector-borne and zoonotic diseases. Moderating factors such as housing quality, land-use patterns, and vector control programs make it unlikely that climate change will have a major impact on tropical diseases such as malaria and dengue fever in the United States. However, climate change could facilitate the establishment of new vector-borne diseases imported into the United States, or alter the geographic ranges of some of these diseases that already exist in the country.

Climate Change Vulnerability

The effects of climate change will likely vary by geographic area and demographic group. With respect to geographic vulnerability, urban centers in the west, southwest, mid-Atlantic, and northeast regions of the United States are expected to experience the largest increases in average temperatures; these areas also may bear the brunt of increases in ground-level ozone and associated airborne pollutants.[4] Populations in midwestern and northeastern cities are expected to experience more heat-related illnesses as heat waves increase in frequency, severity, and duration. Different rates of coastal erosion, wetlands destruction, and topography are expected to result in dramatically different regional effects of sea level rise. Distribution of animal hosts and vectors may change; in many cases, ranges could extend northward and increase in elevation. The West coast of the United States is expected to experience significant strains on water supplies as regional precipitation declines and mountain snow packs are depleted.

Some demographic groups are more vulnerable to the health effects of climate change than others. Children are at greater risk of worsening asthma, allergies, and certain infectious diseases. Those with underlying diseases and the elderly are at higher risk for health effects due to heat waves, extreme weather events, and exacerbations of chronic disease. In addition, people of lower socioeconomic status are particularly vulnerable to extreme weather events. The health effects of climate change on a given community will depend not only on a

[4] Bernard SM, et al. The potential impacts of climate variability and change on air pollution-related health effects in the United States. Environ Health Perspect. 2001 May; 109 Suppl 2:100-209.

community's exposures and demographics, but also on how these characteristics intersect. For example, heat waves are both more likely to occur in urban areas and more likely to affect certain populations: the home-bound, elderly, poor, minority and migrant populations, and populations that live in areas with less green space and with fewer centrally air-conditioned buildings.

Given the differential burden of climate change health effects on certain populations, public health preparedness must include assessments to identify the most vulnerable populations and anticipate their risks. At the same time, health communication targeting these vulnerable populations must be devised and tested, and early warning systems focused on vulnerable communities should be developed. With adequate notice and a vigorous response, adverse health effects from climate change may be reduced.

<u>CDC's Current Public Health Preparedness for Climate Change</u>

Climate change is anticipated to have a broad range of impacts on the health of Americans and the nation's public health infrastructure. As the nation's public health agency, CDC is uniquely poised to lead efforts to anticipate and respond to the health effects of climate change. In preparing for climate change, CDC works closely with a broad array of partners including other Federal Agencies (such as the Environmental Protection Agency, National Aeronautics and Space Administration, National Academy of Sciences, United States Department of Agriculture, Food and Drug Administration, National Institutes of Health) through the U.S. Climate Change Science Program; state and local organizations (such as the National Association of County and City Health Officials, Association of State and Territorial Health Officials, and state and local veterinary officials); faith-based organizations; and many other organizations and agencies. Preparedness for the health consequences of climate change aligns with traditional public health contributions, and – like preparedness for terrorism and pandemic influenza – reinforces the importance of a strong public health infrastructure. CDC's expertise and programs in the following areas provide a strong platform:

- *Surveillance of Water-borne, Food-borne, Vector-borne, and Zoonotic Diseases:* CDC has a long history of surveillance of infectious, zoonotic, and vector-borne diseases. Preparing for climate change will involve working closely with state and local partners to document whether potential changes in climate have an impact on infectious and other diseases and to use this information to help protect Americans from the potential change in a variety of water-borne, food-borne, vector-borne, and zoonotic diseases. Among the tracking systems CDC has developed for these diseases is ArboNet, the national arthropod-borne viral disease tracking system. Currently, this system supports nationwide West Nile virus surveillance that links all 50 states and four large metropolitan areas to a central database that records and maps cases in humans and animals and would detect real-time changes in distribution and prevalence of arthropod-borne viral diseases. CDC also supports the major foodborne surveillance and investigative networks of FoodNet PulseNet, and OutbreakNet that rapidly identify and provide detailed data on cases of foodborne illnesses, the organisms that cause them, and the foods that are the sources of infection. Altered weather patterns resulting from climate change may affect the distribution and incidence of food- and water-borne diseases, and these changes can be identified and tracked through PulseNet, the Electronic Foodborne Disease Outbreak Reporting System (eFORS) and the Waterborne Disease Outbreak Surveillance System (WBDOSS)

- *Environmental Public Health Tracking:* CDC is pioneering new ways to understand the impacts of environmental hazards on people's health. CDC's Environmental Public Health Tracking Program has funded several states to build a health surveillance system that integrates environmental exposures and human health outcomes. The Tracking Network will contain critical data on environmental trends and on the incidence, trends, and potential outbreaks of diseases, including those affected by climate change.
- *Geographic Information Systems (GIS):* CDC has applied GIS technology in unique ways to a variety of public health issues. It has been used in data collection, mapping, and communication to respond to issues as wide-ranging and varied as the World Trade Center collapse, avian flu, SARS, Rift Valley fever, and plague. GIS allows CDC to overlay public health disease data with enviro-climatic datasets such as temperature and precipitation information to determine if associations exist. In addition, GIS technology was used to map issues of importance during the CDC response to Hurricane Katrina. This technology represents an additional tool for the public health response to climate change.

- *Modeling:* Projections of future climate change can be used as inputs into models that assess the impact of climate change on public health. For example, CDC has conducted heat wave modeling for the city of Philadelphia to predict the most vulnerable populations at risk for hyperthermia. CDC has also worked with others to model the potential impacts of climate change on the distribution of plague and tularemia in the United States.
- *Preparedness Planning:* The principles that guide us to prepare for terrorism and pandemic influenza also apply to preparedness for the health impacts of climate change. For example, CDC scientists have developed tools for local emergency planners and decision-makers to use in preparing for and responding to the threats posed by heat waves in urban areas. With other Federal partners, CDC helped develop an Excessive Heat Events Guidebook, which provides a comprehensive set of guiding principles and a menu of options for cities and localities to use in developing Heat Response Plans. These plans clearly define specific roles and responsibilities of government and non-governmental organizations during heat waves. They identify local populations at increased high risk for heat-related illness and death and define which strategies will be used to reach them during heat emergencies.
- *Training and Education of Public Health Professionals*: Preparing for the health consequences of climate change requires that professionals have the skills required to conceptualize the impending threats, integrate a wide variety of public health and other data in surveillance activities, work closely with other agencies and sectors, and provide effective health communication for vulnerable populations. CDC is holding a series of workshops to explore key

dimensions of climate change and public health, including drinking water, heat waves, health communication, and vulnerable populations. In addition, CDC recently published an article outlining the public health approach to climate change to guide public health professionals in prevention and preparedness.

- *Health Protection Research:* CDC can also promote research to further public health preparedness for climate change. This includes predictive research to model potential impacts of climate change on health outcomes, epidemiologic research to identify modifiable risk factors, and intervention research to determine the most effective public health practices. For example, CDC has conducted research to model the impact of the urban environment on temperature-related morbidity and mortality. The Agency has also conducted epidemiologic research on the relationship between rainfall and other climactic factors on Hantavirus pulmonary syndrome and plague. Finally, intervention research will help us focus public health action on the most appropriate target audiences.
- *Communication*: CDC has expertise in communicating health and risk information to the general public, and has deployed this expertise in areas as diverse as smoking, HIV infection, and cancer screening. Effective communication can alert the public to health risks associated with climate change and encourage constructive protective behaviors.

While CDC can conduct targeted research or offer technical support and expertise in these and other activities to states, local governments, tribes, and territories be carried out at the state and local level and through other public health partners. For example, CDC can support climate change preparedness activities conducted by state and local public health agencies and climate change and health research in universities, approaches currently used by CDC to address a variety of other health challenges.

Advancing Public Health Prevention and Preparedness for Climate Change

In addition to leveraging existing programs across the agency, CDC has identified the following opportunities for advancing public health prevention and preparedness for climate change:

1) Improve surveillance systems for food-borne, water-borne, vector-borne, zoonotic, and other diseases in cooperation with state and local partners to have a better understanding of the impact of climate change on public health, and to potentially develop models and early warning systems to improve health outcomes.

2) Building research capacity within the Agency: CDC could convene staff experienced in epidemiology, infectious disease ecology, disaster preparedness, modeling and forecasting, climatology/earth science, and communication. This group could support internal research on the links between climate change and public health outcomes. Enhanced capacity within the agency would position CDC to serve as a trusted resource for decision makers and the public, a role we currently provide for public health issues such as vaccinations for foreign travel.

3) Supporting academic capacity to research linkages between climate change and public health: This capacity would include research in such areas as forecasting and modeling anticipated health effects, vector-borne and zoonotic diseases, food-and water-borne diseases, vulnerable populations, and heat waves.

4) Providing research-based communication and technical assistance on the health effects of climate change and best approaches to preparedness: Important audiences for outreach include health professionals, state and local health departments, university environmental studies departments, science teachers, federal, state and local officials, community groups, faith-based organizations, industry, and the public.

<u>Conclusion</u>

An effective public health response to climate change can prevent injuries, illnesses, and death while enhancing overall public health preparedness. Protecting Americans from adverse health effects of climate change directly correlates to CDC's four overarching Health Protection Goals of Healthy People in Every Stage of Life, Healthy People in Healthy Places, People Prepared for Emerging Health Threats, and Healthy People in a Healthy World.

While we still need more emphasis on public health preparedness for climate change, many of our existing programs and scientific expertise provide a solid foundation to move forward. The activities needed to protect overall public health and to protect Americans from adverse health effects of climate change are mutually beneficial. CDC also has a role in examining the health implications of various mitigation efforts aimed at slowing, stabilizing, or reversing climate change by reducing greenhouse gas emissions. While these solutions will occur mainly in sectors other than health, such as energy, transportation, and architecture, the health sciences can contribute useful information regarding the choice of safe, healthful technologies.

Thank you again for the opportunity to provide this testimony on the potential health effects of global climate change and for your continued support of CDC's essential public health work.

Ms. SOLIS. Thank you very much.

Our next speaker is Dr. Jonathan Patz. Dr. Jonathan Patz is a professor and director of global environmental health at the University of Wisconsin in Madison. He co-chaired the health expert panel of the United States National Assessment on Climate Change, and was a convening lead author of the United Nations and World Bank Millennium Ecosystem Assessment. For the past 14 years, he has been a lead author for the United Nations intergovernmental panel on climate change and shared the 2007 Nobel Peace Prize.

Dr. Patz is president of the International Association for Ecology and Health, and has written over 75 peer-reviewed papers and a textbook addressing the health effects of global environmental change. He has served on several scientific committees of the National Academy of Sciences, and currently serves on the science advisory board of both the CDC and EPA. At the EPA he also serves on a committee investigating the health impacts of climate change on children.

Welcome, Dr. Patz, and congratulations.

STATEMENT OF JONATHAN PATZ

Dr. PATZ. Thank you. And it is really an honor. I want to thank you for allowing me to present to this committee, and for a topic that I have worked on for about 15 years. As you mentioned, I did serve as co-chair for the U.S. National Assessment on Climate Change health expert panel and on the IPCC, and from your introductory comments it is quite clear that you understand that public health really is a core impact area of climate change, and that, in my view as a public health scientist, the health effects of climate change could be really one of the greatest challenges that we face in this century.

The reason is that climate change is a unique and different type of health risk compared to others that we have dealt with in the past. We are used to dealing with single agents of disease, and trying to find a cure or a vaccine to toxic chemicals and trying to figure out ways to reduce exposure. But climate change can potentially affect our health through multiple pathways.

Certainly we know about direct effects from heat waves, when more than 700 people died in the 1995 Chicago heat wave. And a new paper out just this year puts the number, as far as the European heat wave of 2003, up at approximately 70,000 people dying in less than a 2-week period. So we know that heat waves kill people. And the projections from the climatologists are that we are going to be having more frequent and more extreme heat waves.

We have, in our sense, or our preliminary findings, at least for Wisconsin, showing that there will be a disproportionate increase in extreme heat waves compared to a decline in cold snaps. So we are worried about this.

Dr. Jacobson will go further into detail looking at air pollution effects of climate change. I will just point out that accompanying heat waves are often stagnant air masses that exacerbate air pollutions, and according to the IPCC citing climate studies, there may be an increase in stagnant air masses, at least for the eastern United States.

One study that I want to point out that took a look at the relationship between climate and ozone air pollution—that is the ground-level photochemical smog pollution—finds that in the eastern United States, red ozone alert days, which are dangerous for asthmatics and other people with respiratory problems, that could increase by 68 percent. So warmer temperatures drive that chemical reaction that forms ground-level ozone smog pollution, and Dr. Jacobson will cover that further.

Another air pollution issue is pollen. And ragweed pollen, according to one study, will increase by 50 percent under conditions of doubled CO_2. So the issue of both ozone and allergens could be a problem as far as air quality.

And Representative Blumenauer brought up the concern about water. Our group actually studied the—all waterborne disease outbreaks reported in the United States between the years 1948 and 1994, and we found that the majority—actually, about 60—well, two-thirds, two-thirds—67 percent of reported waterborne disease outbreaks were preceded by extremely heavy rainfall months.

So we see this issue of extremes of the hydrologic cycle—the water cycle—that climatologists tell us it is not just global warming, it is climate change. It is extremes, you know, more droughts and more flooding, that actually could present a challenge to our already challenged water quality. And in municipalities with rusting pipes and water systems, this could be an added pressure.

So, can we adapt to these challenges? As Dr. Frumkin said, we do have many—we have means to adapt to many of these issues.

However, I would argue that we need a multi-pronged approach that includes both preparedness and more upstream greenhouse gas mitigation. We do need to address specific issues of heat waves, air quality, water quality problems, but not lose sight of the root problem that is driving this, and that is climate change caused by greenhouse gas emissions.

In approaching climate change, we must also look at this not in isolation of other environmental problems that could act in synergy with climate change. For example, a heat wave over a sprawling urban environment with lots of heat-retaining surfaces, the urban heat island effect. Or when a hurricane hits a city like New Orleans, and the fact that the coastal wetlands have been degraded makes that area much more vulnerable to a climate event. So we need to look at climate change with other issues.

Finally, as Dr. Frumkin mentioned, there are great opportunities—co-benefits—if we reduce fossil fuel burning, and change our transportation system, and promote exercise, that is a great thing. And in this regard, I feel that energy policy becomes one and the same as public health policy.

And currently there is very little funding to look at these issues of health, especially the CDC and NIH. There is no funding to protect the American public, and that needs to change.

[The statement of Dr. Patz follows:]

Testimony before the

SELECT COMMITTEE ON ENERGY INDEPENDENCE

AND GLOBAL WARMING

U.S. HOUSE OF REPRESENTATIVES

April 9, 2008

Jonathan Patz, MD, MPH, Professor

Center for Sustainability and the Global Environment (SAGE)

Gaylord Nelson Institute for Environmental Studies &

The Department of Population Health Sciences

University of Wisconsin – Madison

Good morning Mr. Chairman, Representative Markey, and other distinguished members of the Committee. Thank you for the opportunity to appear before your committee for this hearing, "Healthy Planet, Healthy People: Global Warming and Public Health," a topic that I have studied for over 14 years. I served as Co-chair for the Health Expert Panel of the US National Assessment on Climate Variability and Change and have been a Principle Lead Author on five reports of the UN Intergovernmental Panel on Climate Change (IPCC) since 1995. I am a Full Professor at the University of Wisconsin at Madison, and have active research and teaching in the field of environmental public health, specifically addressing global climate change.

I will now address the five specific questions contained in your invitation letter.

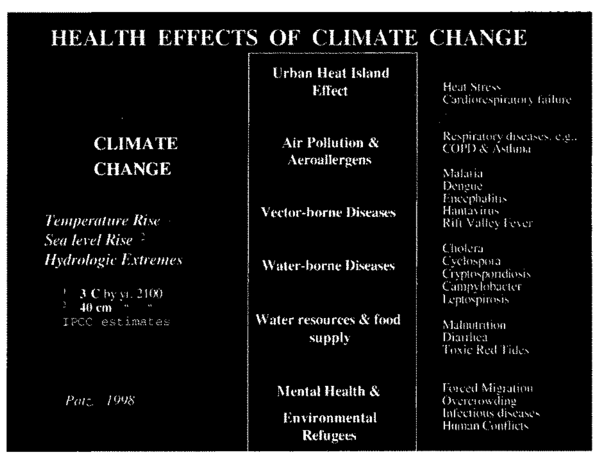
1) Is there scientific consensus that climate change poses a threat to public health?

From direct involvement with the IPCC and the US National Assessment, I can say with confidence that the conclusions across assessments have been consistent finding that, on balance, the health risks of climate change outweigh the benefits. Global warming is unlike many other health threats with which we have confronted because unlike 'single agent' toxins or microbes, climate change affects multiple pathways of harmful exposures to our health. Climate change can affect human health either from direct heatwaves and severe storms to ground level smog /ozone pollution and airborne allergens, as well as many climate-sensitive infectious diseases.

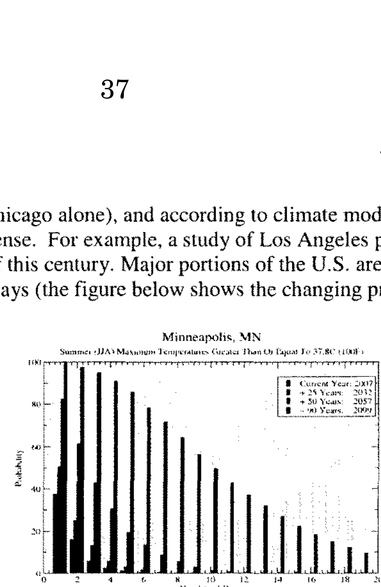
Disease risks originating outside the US must also be considered because we live in a very globalized world. Many poor nations of the world are expected to suffer even more health consequences due to climate change compared to the U.S. With global trade and transport, however, disease flare-ups in any part of the world can potentially reach the U.S. Additionally, climate extremes, e.g. droughts and storms, can further stress environmental resources by destabilizing economies and potentially creating security risks both internally and to other nations.

Finally, while climate change is a long term environmental threat, health ramifications are already occurring. The World Health Organization finds that warming in just the past 30 years may already be adversely affecting the global burden of disease. And while single climate events can not be attributed to climate change, 70,000 deaths in the 2003 European heatwave remind us of the risk of extreme weather events (a study in Nature concluded that global warming over the recent decades doubled the 'probability' of the occurrence of such an extreme heat wave).

1) *What are some of the potential impacts of climate change on health in the United States? Will any of these impacts disproportionately affect the poor or other vulnerable communities?*



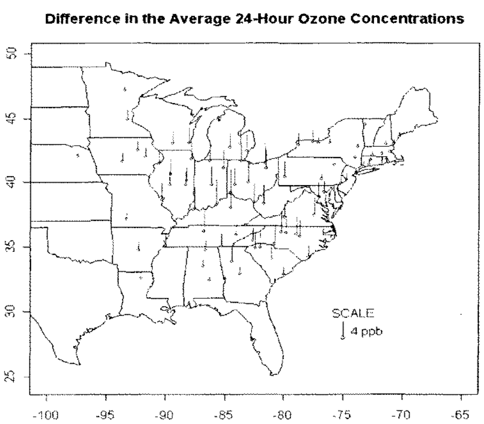
Climate-related disease risks occur throughout the US, and many are expected to be exacerbated by climate change. Some health benefits could result, including reduced cold-related mortality and Rocky Mountain Spotted Fever in the Southeastern U.S. However, the net health effects have been assessed to be adverse. Our country has experienced deadly heatwaves (e.g, the 1995 heatwave killed >700 persons in Chicago alone), and according to climate models, heatwaves will become more frequent and intense. For example, a study of Los Angeles projected a 3-fold increase in heatwaves by the end of this century. Major portions of the U.S. are expected to have a higher number of extremely hot days (the figure below shows the changing probability for days >100°F in Minneapolis).



Peterson *et al.*, 2007a

Preliminary analysis from our own research finds that the frequency of extreme heatwaves in Wisconsin will increase disproportionately compared to a smaller decline in the frequency of extremely cold temperatures. Poor and elderly populations are especially at risk of dying in heatwaves.

Air pollution accompanies heat waves, due in part to the temperature sensitivity of the chemical reaction that forms ozone smog pollution. A recent study of the 50 largest cities in the Eastern US finds that by mid-century, 'Red Ozone Alert Days' could increase by 68% due to projected regional warming alone. But the projected increase in stagnant air masses for the Midwest and Northeast, according to the IPCC, may exacerbate this problem further. Ozone is especially dangerous to children with asthma. Recall the findings during the 1996 Atlanta Olympics when traffic restrictions resulted in a 28% decrease in ground-level ozone, and subsequent 42% decline in asthma admissions to emergency rooms.



Pollen, another air contaminant, may increase with elevated temperature and CO_2. For instance, a doubling of the atmospheric CO_2 concentration stimulated ragweed-pollen production by over 50%.

Many infectious diseases are sensitive to climate fluctuations. For example, 67% of reported water-borne disease outbreaks in the U.S. (between 1948-1994) were preceded by very heavy rainfall; projections are for increases in extreme rainfall and runoff, placing more risk on already deteriorating water systems in many cities. Combined sewage overflows (CSOs) will likely become a more frequent problem. West Nile virus (WNV) emerged for the first time in North America during the record hot July, 1999. While international transport likely explained its entry, this particular strain of WNV requires warmer temperatures than other strains around the globe. The greatest WNV transmissions during the epidemic summers of 2002-2004 in the U.S. were linked to above-average temperatures.

3) If climate change continues unabated, will the United States reach the limits of our adaptive capacity to manage the impacts of climate change on health?

Relying on adaptation alone is a dangerous strategy. Building adaptive capacity takes time and it is unlikely to be reliable for climatic changes that might be more rapid or more extreme than expected. In addition, according to an energy policy expert at SAGE (Dr. Greg Nemet) a majority of greenhouse gas emissions in the future will come from developing countries. Therefore, by relying on adaptation to deal with climate change, the U.S. provides no basis for leadership or persuasion to enlist developing countries in reducing their emissions – in the end, we may have to adapt even more. Dr. Nemet further notes that global greenhouse gas emissions have been accelerating over the past decade and outside the upper end of scenarios predicted a decade ago.

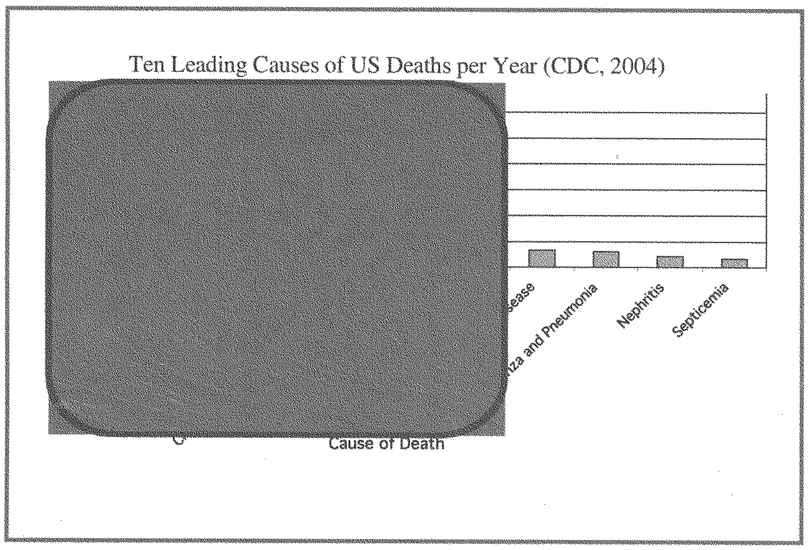
4) Is reducing our nation's greenhouse gas emissions and preventing global warming important for protecting the health of the United States citizens from climate change? Are there co-benefits to reducing greenhouse gas emissions that also improve public health simultaneously?

Considering the multiple health outcomes and potential for adverse synergies between global warming, urban sprawl, and land degradation, climate change poses a major threat to the health of the US population. The policy changes needed to address this problem are going to be very large if we are serious about protecting the public from the adverse health effects of climate change. Adopting a modest emissions reductions policy, which may be riddled with loopholes, in the interest of pushing the US to finally adopt a climate policy seems a like a risky approach. With such large ramifications at stake and so many potential health co-benefits to be gained by reducing greenhouse gas emissions, major policy measures to mitigate climate change seem like an obvious component to protecting our health.

Scientific assessments caution that climate change will have dangerous synergies with other environmental public health risks and so must not be viewed as an isolated health risk. Dangerous synergies will include, for example: the 'urban heat island' effect over sprawling cities with asphalt highways; destruction of storm-buffering coastal wetland, e.g, near New Orleans; and increased allergens in the air along with a lengthening ozone pollution season.

Yet, these dangerous synergies also point to potential co-benefits of mitigating greenhouse warming. There are potentially large opportunities and co-benefits in addressing the health risks of global warming. Certainly, our public health infrastructure must be strengthened, e.g. fortify water supply systems, heat and storm early warning and response programs, and enhance disease modeling and surveillance. However, energy policy now becomes one and the same as public health policy. Reducing fossil fuel burning will: (a) further reduce air pollution – all reductions of fossil fuel burning will reduce NOx and CO emissions, as well as SO2, PM2.5, Hg, VOC and/or air toxic emissions as well (depending on the sectors, fuels, and technologies affected); (b) improve our fitness – only 40% of the US population meets the minimum daily recommended level of exercise (60% of Americans are overweight), and if urban transportation planning allows for more Americans to travel by foot or bike and public transportation rather than by car, these percentages would inevitably improve); and (c) lessen potential greenhouse gas emissions and subsequent global warming. Note from the figure below that most of the ten leading causes of death in the US are linked either to sedentary lifestyles, air pollution, or motor vehicle crashes.

In short, the challenges posed by climate change urgently demand improving public health infrastructure AND energy conservation / urban planning policies – as such, climate change can present both enormous health risks and opportunities quite directly via improved fitness, reduced obesity (with its multitude of associated diseases), and improved air quality.



5) *What actions are the EPA taking to protect children's health from climate change? Although EPA has refused to legally conclude that greenhouse gases are a threat to public health, are EPA's actions in line with such a conclusion?*

According to the World Health Organization, children represent 88% of the vulnerable population most at risk to climate change. Here in the U.S., the EPA's Office of Children's Health Protection has established a special Climate Change Task Force to address this children's health threat. The initiative is a recent development and I have been asked to co-chair the task force. The group will be meeting in Washington in two weeks from today (April 23-24).

The scientific rationale for regulating CO_2 is absolutely clear when considering the health risks described above. The legal nuances, however, are beyond my expertise. My colleague and energy policy expert, Dr. Greg Nemet, shared with me his concern that if CO_2 is regulated by the EPA, then CO_2 regulation will be subject to a cost/benefit risk assessment analysis – he is skeptical that the EPA would justify strong regulatory action on that basis alone. The dilemma is that since many of the impacts of climate change will be only weakly captured in that type of analysis: (1) most impacts of US emissions will be outside the US; (2) impact assessments are focused on likely ranges, and ignore tails (or extremes) of distributions; and (3) impacts will be mostly in the future, so will be discounted heavily. Thus, a worrisome outcome is that EPA could end up regulating CO_2, but set only modest reduction targets which do not adequately protect the health of Americans. From my standpoint as a public health scientist, I view the health threats of climate change as extremely large in magnitude, and therefore requiring equivalently significant policy change –both in areas of public health preparedness and in greenhouse gas mitigation to avert this threat by whatever the best policy interventions are required.

Dr. Tracey Holloway, a climate-air pollution expert at SAGE, pointed out to me that policy analyses for Europe have quantified the economic and physical interactions between climate change and air quality, and they find that integrated policies to address both issues simultaneously could reduce total costs by well over 1 billion Euro/yr by 2020 (vs. the cost of considering air quality and climate separately). http://www.iiasa.ac.at/rains/gains-presentations.html?sb=12

Conclusions and Recommendations

The broad and interconnected exposures stemming from climate change will require a well-coordinated, cross-sector and comprehensive disease prevention strategy. In addition to enhancing disease preparedness, this would include proactive energy conservation and transportation policies, and in so doing, will provide substantial health co-benefits.

The Department of Health and Human Services, that includes CDC and NIH, are responsible for protecting the health of the American public. To the extent that extremes of climate can have broad population-wide impacts, neither the CDC nor NIH have directed adequate resources to address climate change, and to date, funding has been minimal compared to the size of the health threat. Coordinated efforts on climate change & health also will need to cut across agencies – EPA, NASA, NSF, and NOAA have already been engaged on the issue, though funding historically has been insufficient in the health impacts area.

Strategic planning should take place across federal, state, and local government, academia, and the private sector to look for co-benefits of solutions in combating climate change.
The multimodal transportation scenario (reducing obesity and associated diseases while also reducing greenhouse gas emissions and improving local air quality) is a clear example. Such cases of co-benefits bring me to the conclusion that policies towards sustained mitigation of the threat of global warming could, in the end, represent one of the largest public health opportunities that we've had in over a century.

Ms. SOLIS. Thank you very much. Sorry our time is short, but we will get back with you when we ask our questions.

Our next speaker is Dr. Georges Benjamin. Dr. Georges Benjamin has been the executive director for the American Public Health Association, the nation's oldest and largest organization of public health professionals, since 2002. This year, the APHA has dedicated National Public Health Week to climate change impacts on health in America.

I am proud to have worked with APHA and Chairman Markey to introduce a resolution recognizing this week. We currently have 104 cosponsors on the resolution. As an established administrator and author and orator, Dr. Benjamin started his medical career serving our military at the Madigan Army Medical Center.

Later he moved to Washington, D.C., where he served as chief of emergency medicine at the Water Reed Army Medical Center. After leaving the Army, he directed one of the busiest ambulance services in the nation here in the District of Columbia Fire Department. Prior to joining APHA, he was chief executive of the State of Maryland's Department of Health and Mental Hygiene, a cabinet-level agency.

And we would like to welcome you, Dr. Benjamin. Thank you, and you have 5 minutes.

STATEMENT OF GEORGES BENJAMIN

Dr. BENJAMIN. Good morning, Madam Chair and members of the committee. Let me first of all thank you very much for that resolution. We think that is a very, very important statement of the engagement of Congress in this issue of climate change.

You know, each year the American Public Health Association creates policies—public policy statements—that we think are important for the public's health, and we actually put out our first public policy on climate change back in 1995. This past November we reaffirmed that policy, and many of the things in that policy are very consistent with both your statement, Madam Chair, as well as my colleagues—things my colleagues here at the table have said.

Let me just point out four things, just in the interest of time. Number one, the fact that climate change is real and does affect our health, and most importantly, that there are certain populations that are more at risk—vulnerable populations. Number two, that we certainly support policies that are co-beneficial, meaning that public health has an opportunity here to get twofers and threefers and really leverage public health action to try to improve the climate as well as our own human health.

Number three, that we don't know a lot, or as much as we need to know, about the interrelationship between climate change and our health, and more importantly what we can do about it. And so there is really a need for an extraordinary research effort to find some of those things out. And then four, this requires enhancing the public health system with the skills, tools, and capacity to really address this very, very important role.

Now, this week during National Public Health Week, what we are trying to do, of course, is to raise consciousness around this issue. We are asking all Americans to do five things.

Number one, be prepared, particularly for these extreme weather events. This is consistent with all of the other preparedness activity that is occurring for a variety of threats to human health. Secondly, to think about traveling differently, which means folks like me need to drive less and walk more, bicycle more, do what we can.

Thirdly, eat differently; find ways in which we can certainly eat more locally, do things so that both it improves our health as well as address the issue of climate change. That means eating more fruits and vegetables and less meat, and that is always a challenge for a guy like me.

Greening your work, recycling. Even at the American Public Health Association we had an event. We brought someone in yesterday to talk to our staff about things that we can do to green our work; we actually have a Green Team at our office, which is trying to lead by example.

And green your home: all the things that we talk about in terms of insulating your home, changing the bulbs to the compact fluorescent bulbs, reducing your use of wasteful products, recycling, et cetera, and conserving water.

These are things that we think all Americans can do, and we are trying to encourage, this week, for all Americans to focus on this effort. I think the communication that we are trying to put out is trying to tell the American people that there are things that they can certainly do to address this problem.

We also think there are some things, certainly, that Congress can do. Number one, continue to play a leading role in this area. We think that Congress and the administration both have an opportunity to play a very important role here. That includes authorizing a program at the Center for Disease Control and Prevention—a very specific program to address this issue, including the funding to support that.

Funding the National Institutes of Health, particularly NIEHS, to begin doing some of the basic science research that they do. Better funding and support for the EPA as well. Using some of the vehicles that you already have, such as the to-be-debated transportation bill, when it comes before you, the Farm bill, which is in front of you, and others.

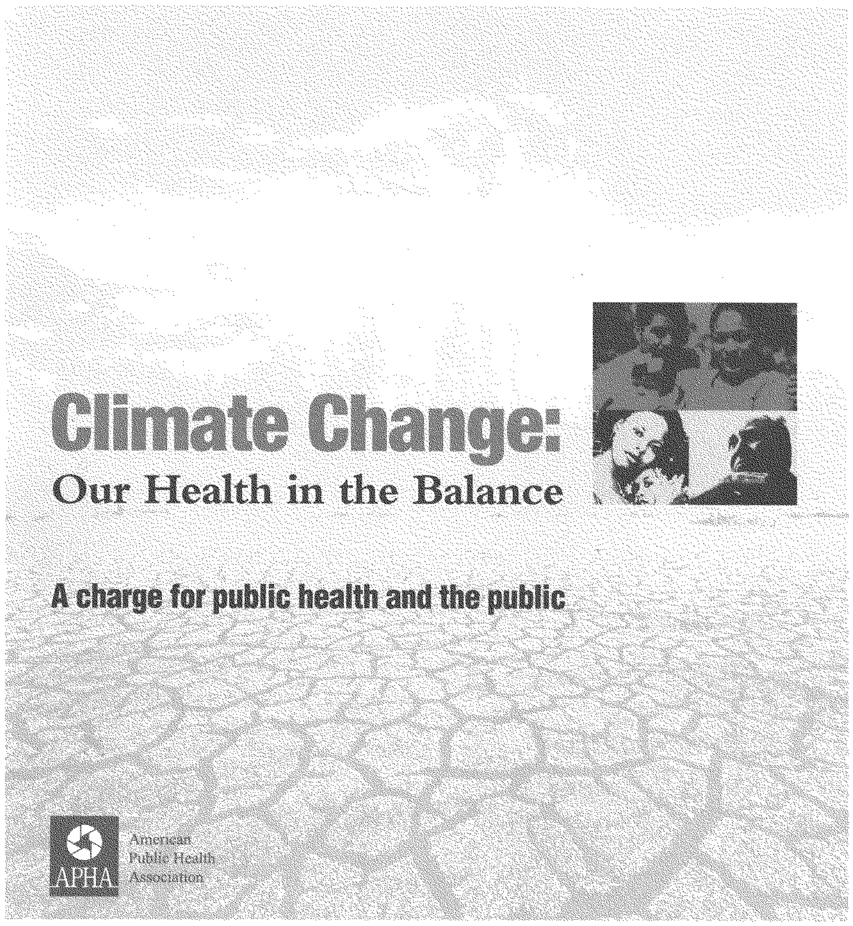
These are opportunities for you to leverage health into the discussion, and that way build capacity to do some of the things you heard Dr. Patz talk about to make this more of a holistic approach to improving our environment. And also provide funding for health impact assessments so that people are continually asking about, what is the health impact of the actions that we are going to do as a way of trying to both do adaptation and mitigation as we go forward?

We think, in conclusion, that we certainly can't wait. This is a very, very important time in our nation's history. We think we ought to start now.

I also, with your permission, would like to introduce a couple things for the record: both our white paper on climate change as well as a blueprint document that we have here. If we could possibly introduce those in the record. With that I will——

Ms. SOLIS. Thank you. Without objection, we will include that in your testimony.

[The information follows:]



National Public Health Week
April 7-13, 2008
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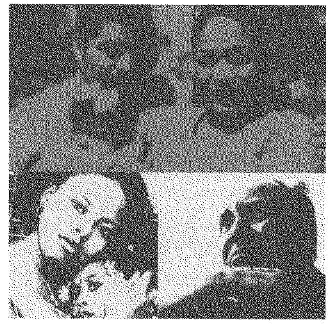
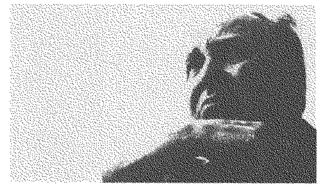


I. INTRODUCTION: Climate Change Is a Public Health Issue

Addressing public health challenges from global warming and climate change is already an everyday reality for rural sanitation coordinators in Alaska. They help rural communities properly dispose of and manage their solid and hazardous waste. More frequent and dramatic storm events, and changes in permafrost (due to warmer winter temperatures) are producing challenges such as floods and erosion. Many communities lack adequate systems to deal with waste. In some cases, solid waste disposal sites turn into uncontrolled dumps due to warmer temperatures and overstressed infrastructures. Tribal, state and federal service providers as well as organizations such as the Rural Alaska Sanitation Coalition are working with villages to deal with the immediate and significant public health challenges associated with climate change.

In Philadelphia, a rise in heat-related deaths caused the public health department to develop a series of Hot Weather-Health Watch/Warning System response actions. Media announcements on how to minimize exposure, buddy system advocacy for sick and older individuals, cooling shelters, agreements with water and electrical companies to maintain services for late-paying customers during heat warnings and a "heatline" residents can call with questions are just some of the activities involved.



The Human Face of Climate Change

Throughout the United States, communities are addressing the impacts of climate change. And growing scientific consensus shows that the climate is changing in ways that increasingly will affect the health of people around the world. Because climate influences how people live, breathe and eat as well as the availability of drinking water, populations everywhere may experience the health impacts of these changes. The most vulnerable people in terms of health and socioeconomic status, both in the United States and globally, will be most affected.

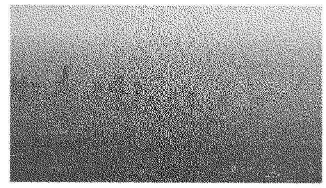
Yet, as a whole, the U.S. population and the public health work force do not see climate change as a pressing human health issue. Many view it as a web of debates over scientific abstractions. People think of faraway melting icecaps and polar bears, and possible events in the distant future; they don't fathom the direct and indirect health impacts on families, local communities and people around the world. Making the health impacts of climate change real in the public's eyes means putting a human face on the issue. This can be done first by making sure the very real effects that climate change has on human life are understood, and then, by empowering individuals, communities and public health professionals to take charge and action to help change the situation.

Not only is the climate changing, but it is predicted to change at an increasingly rapid rate over the next few decades.[1] The United Nations Intergovernmental Panel on Climate Change (IPCC) brings together hundreds of the world's leading scientists to study the impact of human activities on the Earth's climate. Its latest consensus report notes:

- increases in global average air and ocean temperatures;
- widespread melting of snow and ice, and rising sea levels;[2]
- changes in land precipitation over broadening areas;
- dry areas becoming more arid and their soils drying out;[3]
- changing circulation patterns, including wind and temperature patterns;[4] and
- evidence suggesting that severe storms are becoming more common, although this point is still being explored.[5,6]

These changes will strain the ability of public health systems worldwide to cope unless proactive policy actions are taken.[7] While humans are extremely adaptable to changes in climate, severe conditions can have many effects on health. For example:

- In eastern U.S. cities, climate change could cause increases in air pollution, which is harmful to respiratory health, leading to increases in asthma, allergies and chronic obstructive pulmonary disease.[8]
- In any community, especially with inadequate infrastructure and when unprepared, severe weather can lead to a plethora of harmful health outcomes and risks: injury, mental anguish and despair; polluted water from sewage overflow; lack of safe shelter; spoiled food; and, in general, conditions that are especially harmful to the young, the sick and the elderly.
- In the developing world, the harmful effects of climate change are already happening. Regions of the world where disease is linked to warm temperatures are experiencing an increased disease burden. A good example is the rising incidence of malaria (a vector-borne disease) in sub-Saharan Africa, especially in young children, due to increases in temperature from climate change.[9]

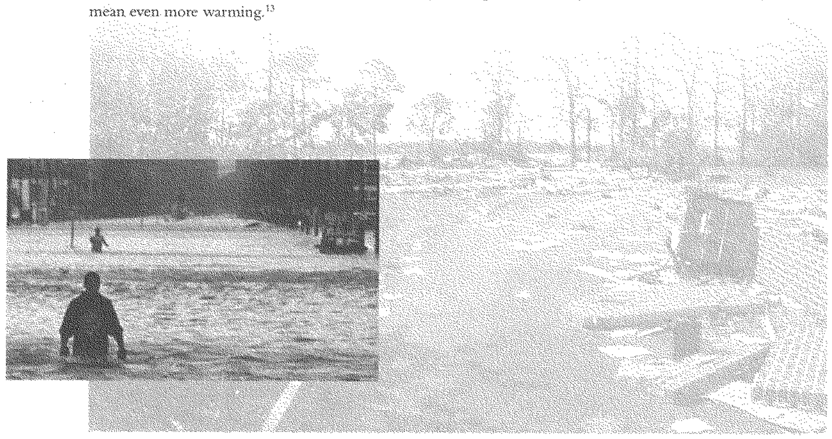


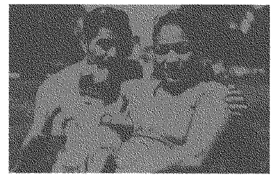
The Causes of Climate Change

Growing global atmospheric concentrations of carbon dioxide, methane and nitrous oxide — known as "greenhouse gases" — are causing temperatures on Earth to increase. And strong evidence suggests the global warming that scientists have observed since the mid-20th century stems from human sources — mainly from the fossil fuel we burn in our cars and trucks, the power plants that bring us electricity, the industries that manufacture our goods as well as modern agricultural methods. Increasingly, scientists are finding that these human-induced causes are the root of the problem rather than natural variations in climate.[10]

While there is debate over if and how occurrences like Hurricane Katrina are linked to climate change, overwhelming events such as these are expected to increase in the future. How can the primary approach that the public health community takes to climate change be one of environmental awareness and preparedness rather than emergency response? How can the public health system prepare in uncertain circumstances to properly treat those affected and promote prevention? How can this issue be made real to Americans in human terms? In the coming decades, these questions will be some of the most challenging the public health community will face.

For prevention to be effective, a link between the choices we make and their impact on the global "big picture" of climate change must be made. The United States is the largest source of greenhouse gas emissions. Though the U.S. population makes up just 4 percent of the world's population, it produces 25 percent of the carbon dioxide pollution from fossil-fuel burning — by far the largest share of any country. In fact, the United States emits more carbon dioxide than China, India and Japan combined.[11] Some of the carbon dioxide emitted from all sources around the Earth remains in the atmosphere for hundreds of years.[12] Even if greenhouse gases are kept at current levels, global temperatures are still expected to rise by 0.6 degrees Celsius by 2100. If emissions increase, it will mean even more warming.[13]





Making the Connection Between the Global, the Local and the Personal

In an already deeply divided world, global warming is magnifying disparities between rich and poor, denying people an opportunity to improve their lives. Ironically, those living in developing countries, which have historically contributed the least to warming the Earth, are the most vulnerable to the premature death and increased disease risk that higher temperatures and associated climate change effects can bring.[9]

In the United States, the overwhelming loss of life and property by the poor and the suffering of the chronically ill residents of the Gulf Coast region during Hurricane Katrina provide a striking example of how severe weather events devastate communities who are least able to rebuild their lives. Although not in the news, residents in other parts of the country, in particular Alaska, are also facing real dangers and threats to their economic and health viability because of climate change.

These real stories and pictures should make the need to reduce greenhouse gas emissions clear. It's about helping not just the United States, but also the world — in the short-term and for generations to come. The good news is that climate change provides an unprecedented opportunity for public health leadership. Encouraging behavior change — a familiar territory for public health experts — is part of the solution. The shift away from fossil fuels and a movement toward general environmental awareness aligns with existing public health priorities. Transportation, for example, is one of the largest sources of greenhouse gases and one that individuals can take charge of in daily life. Encouraging the public to walk, bike, use public transportation or carpool are co-beneficial, helping to improve air quality by decreasing vehicle emissions and increasing physical activity. At the broadest level, policies that steer away from fossil fuel consumption will help increase national security and reduce the risk of war, which is also important to public health.

Climate change challenges the public health system in ways that are still being understood.[14] To be prepared, action must be taken now. The public health system will be a first-line responder to emergency conditions caused by these potential changes. It will also play a key role in informing, educating and empowering the nation to make the changes needed to mitigate the problem.

This document provides an overview of the current state of the science on climate change, the role of the public health system in responding and examples of what currently is being done to address the problem. Based on this supporting evidence, recommendations — developed and selected by a group of public health leaders — are offered as a charge to the public health community and to the public to help mitigate and address the health impacts of climate change.

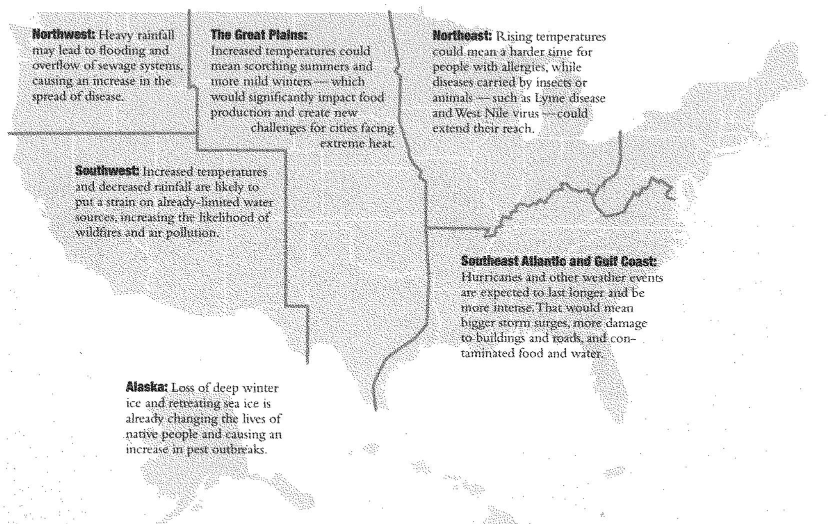
II. The Health Impacts of Climate Change

A Global Problem with Varying Regional Impacts

The World Health Organization reported that the climate change which occurred from 1961 to 1990 may have already caused over 150,000 deaths or the loss of over 5.5 million disability adjusted life years annually starting in 2000. The growing health impacts of climate change affect different regions in markedly different ways.[15] In the United States, because of the great deal of climate diversity, more research is needed to fully know the exact impact of climate change. However, it is known that the burden will vary by region:

- The largest increases in average temperatures are expected to occur in the nation's northern latitudes; they will also bear the brunt of increases in ground-level ozone and other airborne pollutants.
- Populations in midwestern and northeastern cities are likely to be disproportionately affected by heat-related illnesses as heat waves increase in frequency, severity and duration.
- Changing precipitation levels are also expected to widen the distributions of disease vectors. The range of many vectors more common in the South is likely to extend northward and to higher elevations.
- The West Coast is likely to experience even greater demands on water supplies as regional precipitation declines and average snow packs decrease.
- Forest fires with their associated decrements to air quality are likely to increase in frequency, severity, distribution and duration in the Southeast, the Intermountain West and the West.

Examples of Regional Effects of Climate Change



Health Impacts in the United States

A comprehensive assessment of the potential impacts of climate variability and change on human health in the United States was published in 2000, as part of the First National Assessment of the Potential Impacts of Climate Variability and Change undertaken by the U.S. Global Change Research Program. The U.S. Climate Change Science Program (CCSP) is in the process of finalizing its *Analyses of the effects of global change on human health and welfare and human systems in the US* (section 4.6 of the synthesis and assessment reports). This report will further define and establish the potential impact of climate change on human health.

The potential effects of climate change on human health include the following:

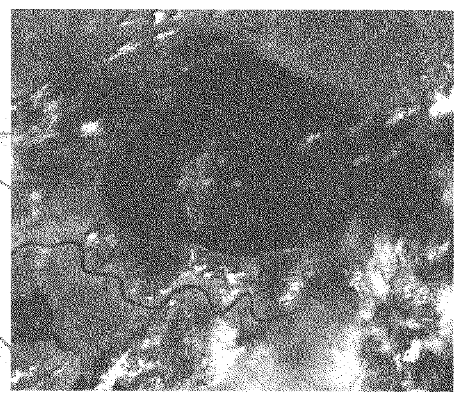
- It is very likely that the burden of heat-related morbidity and mortality will increase during the coming decades. The U.S. population is aging; the percent of the population older than 65 is projected to be 13 percent by 2010 and 20 percent by 2030, or more than 50 million people. Older adults are vulnerable to temperature extremes, suggesting that temperature-related illness and death are likely to increase. Heat-related mortality affects low-income populations and communities of color disproportionately, in part due to lack of air conditioning or even the inability to open windows due to poor housing. In fact, the concentration of poverty in inner-city neighborhoods leads to disproportionate adverse effects related to urban heat islands.

- Higher urban temperatures and increased ozone concentrations are likely to cause or exacerbate cardiovascular and pulmonary illness. Stagnant air masses related to climate change are likely to increase air pollution in some local areas. U.S. residents' vulnerability to temperature extremes is shaped by many factors in their communities. These include housing quality and green space; access to health care; population composition, including level of education, racial/ethnic composition, and social and cultural factors.

- Hurricanes, wildfires and extreme precipitation resulting in floods also have the potential to affect public health through direct and indirect health risks. Health risks associated with extreme events are likely to increase with the size of the population and the degree to which it is physically, mentally or financially constrained in its ability to prepare for and respond to these occurrences.

- Food and water-borne pathogens are likely transmitted among susceptible populations depending on the pathogens' survival, persistence, habitat range and transmission under changing climate and environmental conditions. The primary climate-related factors that may affect these pathogens include temperature, precipitation, extreme weather events and ecological shifts.

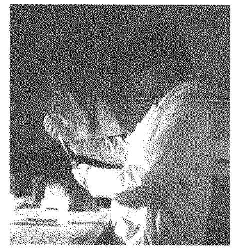
In the United States, there have been shifts of population from Frost Belt to Sun Belt, the movement of households from urban centers to far-flung suburbs, an overall loss of population in some urban centers in the Midwest and Northeast, and rapid growth in the metropolitan areas of the South and West. These trends dramatically alter anticipated impacts from climate change because they fundamentally shape the nature and scope of human vulnerability. Understanding the impacts of climate change and variability on U.S. communities will require more knowledge on how these dynamics vary by location, time and socioeconomic group.



Why Should I Care?
The Health Impacts of Climate Change

The facts on the health impacts of climate change can be overwhelming. Yet, these very real impacts are what help keep the human perspective on the issue. They show why everyone should care about climate change and do what they can to help mitigate climate change.

The Public Health Community	The Public
Climate change is a public health issue.	Climate change is expected to affect the health of all residents of the United States.
Climate change places new demands on the public health system.	
Public health professionals have a key role to play in responding to the problem as well as in prevention efforts and as educators and role models.	
The most vulnerable members of our population, those who depend on the public health system for their care, including the poor, the chronically ill, the elderly, the disabled and the uninsured, are most affected by the health impacts of climate change.	The most vulnerable members of our population are most affected by the health impacts of climate change. In our society, all people's health is linked.
Climate change stresses social and political structures by increasing management and budget requirements for public services such as public health care, disaster risk reduction and even public safety.	Beyond the direct health impacts, climate change may also cause social upheaval, mass migrations, violence as well as food and water shortages.
There is something each member of the public health work force can do personally to help improve the situation by being aware of the environmental choices one makes and how they contribute to global warming, and acting to minimize that impact. Small efforts have large results. They help us as individuals, our friends and family, our immediate neighbors, and people around the world — now and for generations to come.	Each American is personally empowered to help lessen the impacts of climate change. This means being aware of the environmental choices one makes, how they contribute to global warming and acting to minimize that impact. These small efforts have a large payoff. They help you as an individual, your friends and family, your neighbors, and people around the world — now and for generations to come.



III. The Role of Public Health in Addressing Climate Change

Public health professionals are well positioned to lead the way in addressing the health impacts of climate change through preparedness, prevention, research, partnerships and policy. The first step is making sure public health practitioners are knowledgeable and understand the connection between climate change and health. They must also understand the role of public health and the programs and interventions that may be needed in preparing for and responding to potential threats of climate change. The essential services that public health already provides are also appropriate for addressing climate change. Activities to protect the environment by reducing greenhouse gas emissions fit well into already established public health objectives.

The 10 Essential Public Health Services Respond to Climate Change

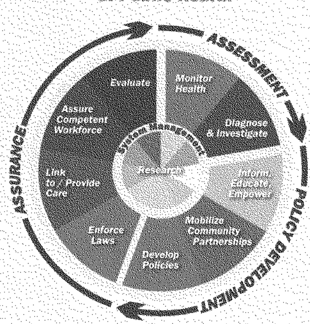
Existing public health fundamentals provide a framework to help us address the health impacts of climate change. These **10 Essential Services of Public Health** have been adopted by a group of federal, state and local government agencies concerned with public health and the American Public Health Association.

The Essential Services are:

1. Monitor health status to identify and solve community health problems
2. Diagnose and investigate health problems and health hazards in the community
3. Inform, educate and empower people about health issues
4. Mobilize community partnerships and action to identify and solve health problems
5. Develop policies and plans that support individual and community health efforts
6. Enforce laws and regulations that protect health and ensure safety
7. Link people to needed personal health services and assure the provision of health care when otherwise unavailable
8. Assure a competent public and personal health care workforce
9. Evaluate the effectiveness, accessibility, and quality of personal and population-based health services
10. Research for new insights and innovative solutions to health problems

Source: Centers for Disease Control and Prevention, http://www.cdc.gov/od/ocphp/nphpsp/EssentialPHServices.htm

The Ten Essential Services of Public Health



Source: Centers for Disease Control and Prevention. Office of the Director. National Public Health Performance Standards Program. The essential public health services. [Internet] Accessed online at http://www.cdc.gov/od/ocphp/nphpsp/EssentialPHServices.htm January 2008.

Preparedness

The Centers for Disease Control and Prevention (CDC) has started addressing some of the critical questions related to climate change and health such as:

- What are the highest priority threats to public health that are climate-change driven?
- What is the proper balance of mitigation and adaptation in public health policy related to climate change?
- What are the most important unresolved methodological issues in monitoring climate-health relationships?
- What are the most important educational messages to put out and whom should the messages target?
- With what agencies should the public health community partner to respond to health-climate problems?
- What past experience and models should guide the public health community's response?
- What is the ideal portfolio of climate-health activities in the short- and medium terms?

In answering these questions, it is important to consider that as the activities of the public health system take place at the local level, local approaches are best suited to address the varying health impacts of climate change. Planning efforts will draw on local data, and involve local and regional authorities and health care providers.[16]

Prevention

Effective prevention involves making recommendations today to prevent future health risks. The health risks associated with climate change are both immediate and long term. Much progress has been made in informing the public about how diet, physical activity and smoking affect their health. And compelling analogies such as the well-documented effects of secondhand smoke may be useful in addressing climate change. As an environmental hazard on a global scale, climate change poses a unique and "involuntary exposure" to many populations.

It may seem hard to arouse Americans to be concerned about a problem that cannot be seen. Making the climate change issue real means helping people understand how the way they live — their transportation choices, the water and electricity used, and the goods purchased and consumed — affects others. Messages must be adapted to individual audiences as there are broad differences in individual and household fossil fuel consumption patterns depending on socioeconomic status. It is important to make the connection between fossil fuel emissions and consequences far beyond those in our immediate environment — and that the greatest impact will be on vulnerable populations, both at home and around the world.

Vulnerable populations have more immediate concerns that compete for this message. Helping communities understand the direct health impacts they face from climate change can "bring the issue home." People with modest economic means may find it useful to know that efforts they make to help the environment can help to save money as well as improve air quality, for example. Individual efforts can help city-dwelling children with asthma, the elderly and all people with cardiovascular and respiratory problems. The empowering part of this message is that an individual's small personal efforts can have a big impact.

Incorporating the issue of environmental justice may also be helpful as some Americans suffer disproportionately from the emissions we produce as a society. Exposure to air pollution is often divided along racial lines in the United States. More than 70 percent of African Americans live in regions in violation of federal air pollution standards.[17] And some studies show that African Americans as a group contribute significantly less to greenhouse gas emissions than others both in terms of direct emissions and emissions generated during production or delivery of consumed products.[18] Increasing awareness of these forces may help African Americans become more directly involved in environmental issues. Other vulnerable and uninsured populations include migrant workers and recent immigrants. However, more research is needed to understand the impact of climate change on these populations.

For the public to take their messages seriously, public health professionals must lead by example. This means making their own lives and the facilities from where they serve the public environmentally friendly. This encompasses being conscious of energy efficiency; recycling paper, bottles, cans and non-medical supplies; and making good choices when procuring the materials they use for their facilities. More recommendations for individuals as well as for the "greening" of public health facilities are found in Part 5 of this report.

Research

More research is needed to understand the health impacts of climate change and how they vary by geography and community, in particular to identify and assess the needs of vulnerable populations. Research is also needed to assess the potential health impacts of any new policies or technologies associated with climate change. Currently, there is limited funding available for research and a robust research agenda has not been developed.

The Climate Change Science Program (CCSP) was established in 2002 "to empower the nation and the global community with the science-based knowledge to manage risks and opportunities of change in the climate and related systems." CCSP incorporates and integrates the U.S. Global Research Program and integrates the 13 federal entities that participate in CCSP. CCSP is currently finalizing the section of their report on the human health impacts of climate change (S&A 4.6).

The public health community recognizes that the research area is lacking. To this end, several efforts are underway to develop a climate change and public health research agenda. In particular, the Center for Disease Control's (CDC) National Center for Environmental Health is convening a series of workshops with experts from across the country on various topics related to climate change and health such as extreme weather, water, communications and impacts on communities of color. These workshops are intended to help CDC chart its future work in this area, including developing a research agenda.

In addition, several states are conducting their own research and developing research agendas. For example, the California Climate Change Center published an analysis of the health impacts of climate change and identified needs for future research in its report, *Public Health-Related Impacts of Climate Change in California*.

Partnerships

Climate change provides a unique opportunity for the public health community to deepen existing partnerships and create new ones. Synergies can be found with the faith community, for example. Religious congregations, a long-term force in delivering public health messages, especially within the African American community, emphasize care for creation and stewardship of the Earth's resources as well as a concern for the most vulnerable among us. It will also involve new partnerships with organizations responsible for large amounts of fossil fuel emissions such as electric utilities. Other potential partners include architects and city planners whose design work can reduce energy demand and limit vulnerability to heat, flooding and other risks. Transportation planners can design our travel systems in a way that reduces greenhouse gas emissions and promotes safe, healthy travel.[19] These partnerships may be expanded to create climate change coalitions for the public's health at the state, regional or other levels. Some states are already moving forward with actions in this area. Learn more in Section 4 of this report.

Policy

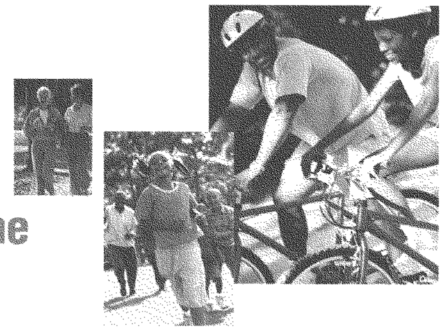
Preventing the health impacts of climate change means creating national and international policies to mitigate further harm to the environment — not just eliminating greenhouse gases. Climate change-related policy addresses virtually every area of life, including the economic, political and social. Since public health practitioners often work closely with society's most vulnerable populations, they are uniquely positioned to communicate and reinforce to policy-makers first-hand knowledge on climate change's impacts on these groups. As the issue is global in nature, advocacy efforts may take place at the international, federal, state and local levels. They will broaden beyond the health arena to touch on energy, industrial and environmental policy.

The national approach to climate change is still emerging. As with the approaches taken to serving the local populations most affected, efforts to prevent climate change will vary by region. Because of their large population, many U.S. states are major sources of greenhouse gas emissions. Texas, for example, emits more greenhouse gases than France. California's are comparable to those of Australia. In the absence of federal leadership on this issue, many states and regions have begun taking action on their own. California, for example, is adopting proactive and far-reaching targets to reduce greenhouse gas emissions. These include new vehicle standards to reduce new vehicle fleet emissions 30 percent by 2016.[20]

In addition to emerging efforts among states, policy initiatives at the national level are addressing climate change's disproportionate impact on low-income, underserved and minority communities. The Congressional Black Caucus has conducted a great deal of analysis on climate change and the African American community. The Congressional Hispanic Caucus has stated that creating environmentally healthy communities is one of its priorities. In addition, the National Religious Partnership for the Environment developed *"A Religious Agenda on Poverty and Global Climate Change."* It proposes setting aside 40 percent of all new revenues generated by national climate change legislation for programs aimed at shielding vulnerable populations from environmental dangers and limiting the economic burdens of new policies on low-income and working families at home and abroad.

Find out about more state policy efforts in Section 4.

IV. What Is Being Done



Across the nation, health departments are making key contributions to larger state efforts by emphasizing the health impacts of climate change and identifying the role of public health in addressing these issues. It is this work that adds the human dimension to the issue and takes it beyond the economic and purely environmental.

The National Association of City and County Health Officials (NACCHO) is currently surveying their constituents about issues associated with climate change and public health at the local level. The results of this survey will be used to help determine what is happening within public health departments at the local level and to identify best practices.

Most state efforts in these areas are relatively new and many are yet to be uncovered. Here are a few state level efforts that can serve as good models and resources.

California. The Public Policy Institute of California (PPIC) is creating a climate change report to include a public health component. As part of this effort, PPIC surveyed local health officers' attitudes and resource needs in relation to climate change impacts. They asked critical questions on whether these institutions had adequate resources and authority to adjust to a changing climate. They found that some programs are already in place that can aid in adaptation to climate change such as disease tracking and heat emergency plans. However, almost 70 percent indicated that their agency *lacks* adequate resources to respond specifically to climate change. Officers surveyed noted the following would be needed to help their efforts: health impact assessments, funding, staff with expertise in climate science, vulnerability assessments, and state and local coordination.[21] Preliminary recommendations from the PPIC work, presented to the California Conference of Local Health Officers, include better integrating public health into climate change-related policy efforts.

Florida. The Florida Department of Health (DOH) is working as part of the state's comprehensive "Lean to Green" Initiative.[22] This effort gives the DOH and other Florida state agencies the opportunity to lead by example by establishing more sustainable choices in public service operations. The initiative stems from three executive orders signed in July 2007 by Gov. Charlie Crist to reduce Florida's greenhouse gases and increase energy efficiency. Some areas addressed include:

- **Flexible Work Schedules/Telework/Telecommuting** — supporting more employees working at least one day from home or an alternate location and studying arrival and exit times to support staggering work hours.
- **Alternative Transportation** — including allowing a 30-minute work credit time per day for bus, bike or carpool

commuters and establishing a variety of incentives such as free bus passes and reinstituting the employee transportation coordinator position.

- **Purchasing** — encouraging purchasers to adopt practices such as purchasing laptops instead of desktops when they refresh their computers in the future; purchasing only from vendors with the highest standards of recycling and offset initiatives; and considering travel options and the purchase of carbon offsets with all air travel.
- **Energy Use in Buildings** — conducting energy audits of each building; using desktop power strips at each workstation to encourage turn-offs and diminish "phantom" loss of energy; decreasing the number of printers and increase the reuse of paper and double-sided printing; supporting the transition to solar roofing for certain DOH buildings; supporting the use of green roofs on all facilities; transitioning to use of rechargeable batteries; and ensuring that vending machines in buildings are using energy-saving features.
- **Recycling** — establishing recycling within each building for paper, cans, bottles and electronics.
- **Environmental Protection** — promoting alternatives to the use and disposal of plastic-bottled water and ensuring that the landscape plan for the complex is environmentally sustainable.
- **Education** — adding a green focus to meetings, conferences and calls throughout 2008; establishing green work groups in each division; including green objectives in all strategic plans; establishing an assessment process for this initiative; and working toward offering assistance for staff interested in green alternatives and to conduct individual assessments of their carbon footprints.

"I believe there should be national action and a national energy policy that addresses these issues, but I also do not believe that New Hampshire can afford to wait for national actions — and we are not waiting. We are taking the lead in securing our energy independence and protecting our environment because not only is it the right thing to do for our environment, but also it is the smart thing to do for our future."

— John Lynch, New Hampshire State Governor

The state has developed the *Governor's Taskforce on Climate Change*, which includes representatives from multiple state agencies, organizations and businesses, including the commissioner from the Department of Health and Human Services to develop a Climate Change Action Plan for the state by September 2008.

Maryland. The state has established the Maryland Commission on Climate Change to develop a plan of action to address the drivers of climate change, prepare for its likely impacts in Maryland and establish goals and timetables for implementation. A specific work group within the commission is tasked with addressing the health implications of climate change to Marylanders. The commission emphasizes Maryland's particular vulnerability as a coastal state to climate change impacts of sea level rise and increased storm intensity. The state has also experienced extreme droughts. The commission will recommend legislation and mitigation initiatives in areas, including greenhouse gas reduction, green building incentives and encouraging federal and international action.[23]

Developing partnerships to raise public awareness of climate change will be one major initiative. Behavior change will be encouraged through education and outreach to consumers, the commercial and industrial sectors and students. The commission will develop its final climate action plan for presentation to the governor and General Assembly in April 2008.

Washington State. In response to many factors, including expectations that the frequency and duration of heat waves will increase in this state — temperatures in some Washington towns already reach 118 degrees Fahrenheit and will most certainly exceed 120 degrees Fahrenheit in the coming decades — the Washington Department of Health has developed a series of recommendations in its report, "Preparing for the Impacts of Climate Change in Washington."[24] Their work is in collaboration with other state agencies, community groups and organizations. The report's high-priority, short-term recommendations are as follows:

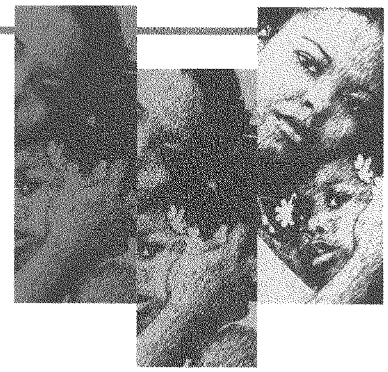
- **Public health surveillance enhancement strategy**
  - The departments of health and agriculture should collaborate on zoonotic disease surveillance improvements.
  - The departments of health and ecology should collaborate on air quality surveillance and outreach improvements.
  - The Department of Health should increase the overall efficiency and sensitivity of the current surveillance systems to monitor and respond to disease events.

- **Emergency preparedness and response efforts enhancement strategy**
  - A Heat Emergency Task Force should be convened to review emergency management planning requirements and guidelines for heat emergencies and emergency preparedness exercises.
  - The Emergency Management Division should coordinate improvements to the state's ability to respond to heat wave emergencies.

- **Built environment policies enhancement strategy**
  - Adapt the built environment to make communities more walkable and pedestrian-friendly, and ensure consideration of climate change in planning.
  - Adapt the built environment to mitigate the impacts of climate change on human health.

The above examples by no means comprehensively cover the actions taking place throughout the country. In light of these important activities, APHA offers the following list of recommendations for both the public health community as well as the public to help lessen the health impacts of climate change.

V. Recommendations



Climate change is about us, all of us — public health professionals, communities and individuals around the globe.

Efforts to make the health impacts of climate change broadly understood and addressed, and our personal efforts to protect the environment will go a long way to help mitigate the impact of climate change on health.

The following recommendations are a charge for public health professionals and the public to help mediate these impacts.

Recommendations for the public health community

1) Educate yourself about the connection between climate change and health.
2) Educate your community about the connection between climate change and health.
3) Educate decision-makers (policy-makers, opinion leaders) about the connection between climate change and health.
4) Communicate how climate change affects the health of all US residents, including those who are most vulnerable, those in your own community as well as the health of people around the world.
5) Conduct vulnerability and needs assessment(s) and determine the potential impacts of climate change within your community.
6) Identify and build upon existing public health programs that can also help to address the health impacts of climate change.
7) Develop and promote best practices especially for local public health response to climate change.
8) Integrate climate change into current preparedness and response plans.
9) Support and promote federal funding of research on the health impacts of climate change and how the impact varies by geography, climate and community, in particular among vulnerable populations.
10) Assess the health impacts of new technology and policy related to climate change.
11) Support and promote science-based policies that drastically reduce greenhouse gas emissions by the United States.
12) Support and promote policies that generate green-collar jobs.

13) Support and promote policies to develop and design communities that benefit both health and the environment.

14) Support and promote policies that strengthen the public health leadership, work force capacity and infrastructure.

15) Lead by example and serve as a good role model by doing what you can both personally and professionally to mitigate the health impacts of climate change.

16) Step out and speak out. Take every opportunity to speak out about the connection between climate change and health and what you are doing to help.

17) Help the public health system go green and initiate programs to green your work environment.

18) Build partnerships with stakeholders to ensure inclusion of public health concerns on policies and programs related to climate change mitigation and adaptation.

19) Assess and communicate the potential short-term public health benefits, as well as the potential adverse public health impacts, of climate change mitigation strategies.

Guiding Principles

During a meeting of health communications experts, 4 simple guiding principles were suggested by a prominent public health leader as ways to frame messages and behavior changes to counter global warming and reduce carbon emissions (that are also beneficial to health):

1.) Travel differently 2.) Green your work and home 3.) Eat differently 4.) Be prepared

Recommendations for the public

Recent public opinion surveys show that climate change is an issue for many US residents — and one that many feel they can personally help change. The time is ripe for leveraging the concern over this topic to help lessen the health impacts of climate change. The following recommendations are a charge for the public to do their part.

This same poll expressed a degree in terms of uncertainty given that roughly a third of the people surveyed are still undecided on climate change issues, suggesting that attitudes are still being formed and are in flux. For public health professionals, this represents a significant opportunity to shape attitudes based on sound science before they are formed and resistant to change.

Public Opinion on Climate Change

A recent assessment of perceptions of global warming and environmental behaviors shows that:

Almost half of Americans believe they are personally at risk from global warming, but significantly more believe it is a threat to future generations (60 percent) or to all life (57 percent). A quarter to a third are undecided on the level of threat.

More than forty percent feel "afraid of what might happen" when they think about global warming.

Most had a sense of optimism that we can limit global warming. Specifically, close to 6 in 10 people believed that "the actions we take can prevent global warming from becoming more severe" and that the actions of a single person can make a difference; nearly half (44 percent) believed that they themselves "can take actions that will help reduce global warming."[1]

1) Educate yourself and those around you about the link between climate change and health.

2) Educate yourself about the potential health threats to you and your community — the US as a whole — as well as to the health of people around the world from climate change.

3) Prepare for climate change-related emergencies.

4) Adopt as many good practices as possible to reduce your contribution to global warming and help mitigate the health impacts of climate change.

5) Give your car a break. If possible, use public transportation, carpool, walk, bike or telecommute.

6) Reduce, Reuse and Recycle.

7) Heat and cool smartly. Clean air filters regularly and have your heating and cooling equipment tuned annually by a licensed contractor. Buy Energy Star approved appliances.

8) Seal and insulate your home.

9) Use water efficiently.

10) Use and purchase green power.

11) Eat less meat and buy local green products.

12) Spread the word and educate family and friends.

13) Support and promote policies that are environmentally and health friendly.

14) Support policy-makers that endorse and support positive environmental-health issues and policies.

15) Get involved in one of the many efforts going on across the country to address the climate crisis.

16) Initiate programs, not only at home, but at work and play to help green your community.

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Climate Change Is a Public Health Issue

There is a direct connection between climate change and the health of our nation today. Few Americans, however, are aware of the very real consequences for our communities, our families and our children. It is time for the public health community to take a seat at the table for this critical discussion.

The Issue and the Challenge

Over the past year, scientists from around the globe have stated in the strongest possible terms that the climate is changing, and human activity is to blame. Greenhouse gases — mainly from the fossil fuels we burn in our cars and trucks, the power plants that bring us electricity and the industries that manufacture our goods and produce our food — are causing temperatures on Earth to increase.

These changes are already dramatically affecting human health around the world. The World Health Organization reported that the climate change which occurred from 1961 to 1990 may already be causing over 150,000 deaths or the loss of over 5.5 million disability adjusted life years annually starting in 2000.

These numbers are staggering, but they should not be surprising: climate change influences our living environment on the most fundamental level, which means it affects the basic biological functions critical to life. It impacts the air we breathe and the food available for us to eat. It impacts the availability of our drinking water and the spread of diseases that can make us sick.

These impacts are different in different parts of the world — and equally troubling, they are disproportionately burdensome for the world's more vulnerable populations. Children, the elderly, the poor and those with chronic and other health conditions are considered the most vulnerable to the negative health impacts of climate change because they are most susceptible to extreme weather events like heat waves, drought, intense storms and floods. They are also least likely to have the resources to prepare or respond. This unequal burden seems especially unjust given that these populations are the least likely to contribute to climate change. Any strategies for managing climate change impacts must take their unique challenges and needs into account.

Why the Public Health Community Is Uniquely Qualified to Respond

There is growing recognition that we must act and we must act now. As public health professionals, we are in the unique position of playing an important role in both keeping people healthy and addressing the impacts of climate change. Thankfully, these twin goals are not incompatible. In fact, many of the choices individuals should make for the sake of their health — and the health of their communities — are the same choices that benefit the health of the planet. Making the climate change issue real means helping people understand how the way they live affects themselves and others, whether through transportation choices, the use of water and electricity or the types of goods purchased and consumed.

Encouraging behavior change is familiar territory for public health experts, and it is a key part of the solution. The shift away from fossil fuels and a movement toward general environmental awareness aligns with existing public health priorities:

- The transportation sector is one of the largest sources of greenhouse gases. Encouraging people to walk, bike, use public transportation or carpool is co-beneficial, as it helps reduce vehicle greenhouse gas emissions and helps improve an individual's health by increasing physical activity.
- Similarly, improving community design to reduce reliance on cars means less greenhouse gases and also less obesity, diabetes and even asthma exacerbation because of cleaner air.
- Eating less meat reduces the need to convert land from rainforest or grassland to grazing fields; requires less corn to be grown for feed (meaning less pesticides and other fossil fuel-based products needed in the growing process); and reduces the output of methane gases from manure.

There are public health professionals around the country already implementing groundbreaking strategies to respond to and prevent the potentially devastating impacts of climate change. Others are in the trenches, tackling public health problems day in and day out without recognizing that many of them are directly related to climate change.

The public health system will be a frontline responder to potential emergency conditions caused by climate change. It will also play a key role in informing, educating and empowering the nation to make the changes needed to mitigate the problem.

Moving Forward

As representatives of the public health community, we acknowledge that it is our responsibility to make the connection between the way Americans lead their lives, their impact on the planet and the planet's impact on their health. By highlighting these links, we can help Americans make choices and lead lifestyles that are healthy for them, their families, their communities and the climate. Doing so will help communities prepare to manage and lessen the impacts of climate change.

We recognize that climate change requires serious actions and we have no time to waste. We support the development of a detailed blueprint around which the public health community can continue to build consensus about how to prevent further damage and respond to existing problems. We believe the following recommendations are the starting point and reflect the unique contribution of the public health community.

Recommendations

Education and outreach

- Educate yourself, your family and your community about the connection between climate change and health.
- Build partnerships with stakeholders to ensure inclusion of public health concerns on policies and programs related to climate change mitigation and adaptation. Reach out to colleagues in other programs and departments at the local, state and federal levels, such as emergency management agencies, departments of agriculture and water resources, and others to form a cross-agencies committee to collaborate on climate change-related risks.

Research

- Conduct vulnerability and needs assessment(s) and determine the potential impacts of climate change within your community. Evaluate how a future climate could affect the ability of programs to achieve their goals, and identify where and when modifications are likely to be needed, and what additional human, financial and technical resources will be required.
- Support and promote federal funding of research on the health impacts of climate change and how the impact varies by geography, climate and community, in particular among vulnerable populations.

Advocacy

- Educate decision-makers (policy-makers, opinion leaders) about the connections between climate change and health with a particular focus on its impact on vulnerable populations.
- Support and promote policies that strengthen public health leadership and work force capacity to ensure the infrastructure is in place to be ready.

Support Best Practices

- Identify and build upon existing public health programs that can also help to address the health impacts of climate change. Ensure that surveillance and data monitoring programs capture information needed to improve public health programs and effectively identify and address the health risks of climate change.
- Support and promote policies to develop and design communities that benefit both health and the environment.

Healthy Behavior

- Help the public health system go green and initiate programs to green your work environment.
- Adopt as many good practices as possible to reduce your contribution to climate change. For example, reduce, reuse and recycle, and give your car a break. If possible and you are not already taking advantage of available opportunities, use public transportation, carpool, walk, bike or telecommute.

Climate Change: The Public Health Response

Howard Frumkin, MD, DrPH, Jeremy Hess, MD, MPH, George Luber, PhD, Josephine Malilay, PhD, MPH, and Michael McGeehin, PhD, MSPH

There is scientific consensus that the global climate is changing, with rising surface temperatures, melting ice and snow, rising sea levels, and increasing climate variability. These changes are expected to have substantial impacts on human health. There are known, effective public health responses for many of these impacts, but the scope, timeline, and complexity of climate change are unprecedented. We propose a public health approach to climate change, based on the essential public health services, that extends to both clinical and population health services and emphasizes the coordination of government agencies (federal, state, and local), academia, the private sector, and nongovernmental organizations. (*Am J Public Health.* 2008;98:435–445. doi:10.2105/AJPH.2007.119362)

Weather and climate have been known to affect human health since the time of Hippocrates.[1] Heat causes hyperthermia,[2,3] cold causes hypothermia,[4] and droughts cause famine.[5] Injuries, displacement, and death result from floods,[6,7] hurricanes,[8] tornadoes,[9] and forest fires.[10] An entire category of diseases—the tropical diseases—is named for a particular climate; climate and weather affect the distribution and risk of many vectorborne diseases, such as malaria,[11] Rift Valley fever,[12] plague,[13] and dengue fever.[14] Weather also affects the risk of foodborne[15] and waterborne[16,17] diseases and of emerging infectious diseases such as hantavirus,[18] Ebola hemorrhagic fever,[19] and West Nile virus.[20] There is a well-established if less intuitive association between weather and mortality from cardiovascular and respiratory disease.[21,22]

The world's climate has been relatively stable for thousands of years, with a strong temperate central tendency and a nearly constant atmospheric level of carbon dioxide (CO_2).[23] For more than a century, however, levels of CO_2, methane, and other greenhouse gases have been rising, a trend associated with changes in climate and other earth systems. For example, global mean temperature has increased approximately 0.6°C since 1860,[23] rainfall patterns have changed in many regions,[23] and sea levels have risen.[24] There is evidence that severe storms have become more common,[25,26] although the science on this point is not settled.[27,28] Global emissions of CO_2 continue to increase, and CO_2 persists in the atmosphere for approximately 100 years, so the climate will continue to change into the foreseeable future.[29] Models predict that by the year 2100, the world's mean temperature will rise an additional 1.8 to 4.0°C, sea levels will rise 0.18 to 0.59 m, and weather variability will increase significantly.[23]

The potential health effects of climate change have been extensively reviewed.[30–35] Principal concerns include injuries and fatalities related to severe weather events and heat waves; infectious diseases related to changes in vector biology, water, and food contamination; allergic symptoms related to increased allergen production; respiratory and cardiovascular disease related to worsening air pollution; and nutritional shortages related to changes in food production. Indirect concerns, for which data to support projections are less available and uncertainties are greater, include mental health consequences, population dislocation, and civil conflict. In addition, changes in the patterns of pests, parasites, and pathogens affecting wildlife, livestock, agriculture, forests, and coastal marine organisms can alter ecosystem composition and functions, and changes in these life-support systems carry implications for human health.[36] These health effects, summarized in Table 1, are not discussed in detail here. In the United States, the burden of these conditions is expected to increase as climate change advances.

There is evidence that climate change has already affected human health. The World Health Organization (WHO) estimates that by 2000, the global burden of disease from climate change had exceeded 150000 excess deaths per year.[31,39] Although individual weather events cannot be attributed to climate change, the rising burden of storms such as Hurricane Katrina suggests that climate change has already affected public health in the United States. Public health planners and professionals at the state and local level, policymakers, and members of the public all need to consider health a central dimension of climate change and to plan and act accordingly. We propose a public health approach to climate change.

PUBLIC HEALTH PERSPECTIVES ON CLIMATE CHANGE

Scientists, clinicians, and public health professionals have called for attention to climate change on both practical and ethical grounds.[34,40–45] Several well-established principles point to a vigorous, proactive public health approach to climate change.

One such principle is *prevention*. Primary prevention aims to prevent the onset of injury or illness; clinical examples include immunization, smoking cessation efforts, and the use of bicycle helmets. Secondary prevention aims to diagnose disease early to control its advance and reduce the resulting health burden; clinical examples include screening for hypertension, hyperlipidemia, and breast cancer. Tertiary prevention occurs once disease is diagnosed; it aims to reduce morbidity, avoid complications, and restore function.

There are clear analogies in the approach to climate change. Primary prevention corresponds to *mitigation*—efforts to slow, stabilize, or reverse climate change by reducing greenhouse gas emissions. Secondary and tertiary prevention corresponds to *adaptation*—efforts to anticipate and prepare for the effects of climate change, and thereby to reduce the associated health burden.[46,47] Mitigation efforts will occur mainly in sectors other than health, such as energy, transportation, and architecture (although the health sciences can contribute useful information regarding the choice of safe, healthful technologies). Adaptation efforts, on the other hand, correspond closely to conventional medical and public health practices.

TABLE 1—Anticipated Health Effects of Climate Change in the United States

Weather Event	Health Effects	Populations Most Affected	Additional US Health Burden	Nonclimate Determinants	Adaptation Measures	Health Data Sources for Surveillance	Meteorological and Other Data for Surveillance
Heat waves	Heat stress	The very old; athletes; the socially isolated; the poor; those with respiratory disease	Low to moderate	Acclimation; built environment	Architecture; air conditioning; warning systems; distributed, resilient, "smart power grid"; community response	ED and ambulatory visits; hospital admissions; mortality	Daily minimum and maximum temperatures; humidity; soil moisture
Extreme weather events	Injuries; drowning	Coastal, low-lying land dwellers; the poor	Uncertain: likely moderate	Engineering; zoning and land-use policies	Architecture; engineering; planning; early warning systems	Attributed risk; ED visits; hospital admissions; FEMA records; mortality	Meteorological event data: extent, timing, severity, return time for rare events
Winter weather anomalies (e.g., rain, ice)	Slips and falls; motor vehicle crashes	Dwellers in northern climates; elderly people; drivers			Public education; mass transit	ED visits	Meteorological event data
Sea-level rise	Injuries; drowning; water and soil salinization; ecosystem and economic disruption	Coastal dwellers; those with low SES	Low	Water pollution; storms; coastal development; land-use policies	Sea walls and levees; abandonment	Attributed risk; ED and ambulatory visits; mental health measures (indirect effects)	Satellite mapping of coastal areas; sea level and tidal surge records
Increased ozone and pollen formation	Respiratory disease exacerbation (e.g., COPD, asthma, allergic rhinitis, bronchitis)	The elderly; children; those with respiratory disease	Low to moderate	Smoking; air quality; respiratory infections; industrial activity; electric demand and production mode; access to health care	Pollution controls; air conditioning; education; medical therapy	ED and ambulatory visits; hospital admissions	Daily and weekly temperature; rainfall; pollen counts; ozone levels; particulate measures
Drought, ecosystem migration	Food and water shortages; malnutrition	Those with low SES; elderly; children	Low	Population growth; food distribution systems; economic and trade issues; biotechnology; petroleum cost	Technological advances; enhanced delivery systems; trade negotiations	Growth monitoring; food insecurity data	Crop yields; rainfall patterns; data on food sources and marketing
Droughts, floods, increased mean temperature	Food- and waterborne diseases	Swimmers; multiple populations at risk depending on outcome of interest	Low to moderate	Travel; land use; water treatment and quality; housing quality; food-handling practices	Public education; water treatment; medical treatment; watershed management	Disease surveillance; ED and ambulatory visits; seasonal patterns in incidence; focused observations at geographic margins	Temperature and rainfall data; vector population and habitat/range monitoring
Droughts, floods, increased mean temperature	Vector-borne disease	Outdoor workers; people pursuing outdoor recreation; the poor (without air conditioning/window screens)	Low to moderate	Travel; vector and animal host distribution; habitat change; land use	Public education; vector control; medical prophylaxis and treatment; vaccination	Disease surveillance; ED and ambulatory visits; focused observations at geographic margins	Temperature and rainfall data; vector population and habitat/range monitoring
Extreme weather events; drought	Mass population movement; international conflict	General population	Uncertain: potentially moderate to high	Sociopolitical factors; resource use and conflicts; economic development	Negotiation and conflict mediation; postdisaster response	Event and population movement monitoring; mental health outcomes surveillance	Meteorological event data; regional economic and resource use data

Continued

TABLE 1—*Continued*

Climate change generally; extreme events	Mental health	The young; the displaced; those with depression or anxiety	Uncertain: potentially moderate	Baseline mental health disease burden	Health communication; postdisaster mental health outreach; various therapeutic and medical management options	Mental health outcomes surveillance	Correlation of mental health outcomes with regional variable responses to extreme events; climate change as a whole

Source. Adapted from Patz et al.[37] and Balbus and Wilson.[38]
Note. ED = emergency department; FEMA = Federal Emergency Management Agency; SES = socioeconomic status; COPD = chronic obstructive pulmonary disease.

This set of practices is collectively known as *public health preparedness*. Preparedness efforts have assumed a central role in public health in recent years. The threat of terrorist attacks, especially since September 11, 2001; the emergence of new infectious diseases and the reemergence of old ones (including the possibility of pandemics such as avian influenza); and the occurrence of natural disasters such as earthquakes and hurricanes have all compelled health professionals to study, anticipate, and prepare for such eventualities. Public health preparedness for the predicted effects of climate change is consistent with this approach.

Preparedness often occurs in the face of scientific uncertainty. Events such as an influenza pandemic, a terrorist attack, or a hurricane cannot be predicted with precision, but protecting public health remains essential. The precautionary principle, as articulated at the 1998 Wingspread Conference, holds that "When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically."[48] Specific climate change outcomes are uncertain, especially indirect and derivative outcomes such as population displacement. However, the notion that steps to protect the public from the threats of climate change cannot await full scientific certainty, and the use of "margins of safety" to ensure safer conditions, are consistent with prevailing public health practice.[49,50]

Risk management—systematic ongoing efforts to identify and reduce risks to health—is another relevant framework Industries that manufacture, use, or store dangerous chemicals are required by the US Environmental Protection Agency to analyze their processes (including assessing worst-case scenarios), identify vulnerable steps, develop strategies to reduce the risk of chemical releases or other mishaps, and implement those strategies.[51] Similarly, the hazard analysis and critical control point paradigm for food safety assesses the entire "life cycle" of food, from production to consumption, analyzes potential hazards, identifies critical control points, corrects, and verifies.[52] By analogy, health scientists can analyze relevant activities such as energy production and transportation. Using techniques such as health impact assessment,[53,54] they can provide data to support decisionmaking and in some cases recommend specific actions to protect public health.

Cobenefits provide another important framework for public health action on climate change. Steps that address climate change frequently yield other health benefits, both direct and indirect. For example, reducing emissions of greenhouse gases from power plants can also improve regional air quality, with direct benefits for respiratory and cardiovascular health.[55–57] Reducing vehicle miles traveled by encouraging walking, bicycling, and transit use not only lowers motor vehicle contributions to climate change, it also promotes physical activity, an important solution to the obesity epidemic.[58,59] Steps that reduce social isolation not only improve overall health[60] but also reduce vulnerability to heat waves.[61,62] A broad public health approach that fully accounts for health benefits may provide important evidence-based support for climate change strategies.

Economic considerations are critical in public health planning. The mandate to maximize health protection at the lowest short-term and long-term cost is highly relevant to climate change. In 2006, the United Kingdom Government Economic Service released *The Stern Review* on the economics of climate change,[63] which predicted that climate change would bring enormous costs, including health care costs, and that mitigation and adaptation efforts would be far less costly if undertaken soon. Indeed, the costs of procrastinating may far exceed the costs of timely action, in both economic terms and health terms.[43] Timely action to address the health impacts of climate change makes good economic sense.

Finally, ethical considerations guide public health attention to climate change.[64] Medical ethics are usually based on 4 principles: autonomy, beneficence, nonmaleficence, and justice.[65,66] Addressing climate change embodies beneficence, because it protects people now and in the future, and nonmaleficence, because it avoids harms (including distant "downstream" harms) that flow from climate change. Justice considerations arise in the inequities that characterize the impacts of climate change and the ability to cope with them.[67,68]

Public health ethics reflect 3 traditions—utilitarianism, liberalism, and communitarianism[69]—that also offer a rationale for addressing climate change. Utilitarians would note that the net sum of human well-being—especially when future generations are taken into account—will likely increase if the health impacts of climate change are controlled. Liberal analysts, following Kant, would posit a right to a healthy environment and would therefore support policies and practices that prevent environmental degradation. Communitarians would argue that climate change undermines the requisite conditions for an intact social order. The principles of the ethical practice of public health, as presented by Thomas et al., begin with a statement that prima facie directs attention to climate change: "Public health should address principally the fundamental causes of disease and requirements for health, aiming to prevent adverse health outcomes."[70(p1058)] Thus, attention to climate change is dictated by the traditions of both medical and public health ethics.

PUBLIC HEALTH ACTIONS TO ADDRESS CLIMATE CHANGE

As climate change has become a certainty, so has the need for public health action to anticipate, manage, and ameliorate the health burdens it will impose. The standard framework for public health action is the 10 Essential Services of Public Health, developed in 1994 by the American Public Health Association and a group of federal, state, and local agencies and partners.[71] These services, with examples pertinent to climate change, appear in Table 2 and are discussed in detail in this section.

In developing and implementing services to address climate change, public health professionals will need to confront several practical realities. First, the effects of climate change will vary considerably by region. Second, they will vary by population group; not all people are equally susceptible. Third, these effects are highly complex, and planning and action will need to be multidimensional.

Regional variation will play a critical role in public health responses to climate change.[72] Although CO_2 and other greenhouse gases are relatively uniformly distributed in the atmosphere, the human health effects of climate change will vary by region, topography, and capacity for response.[31] For example, far northern locations will see relatively dramatic changes in temperature, hydrology, and ecosystem conditions, with effects ranging from infectious disease risk to inadequate health services.[73,74] Low-lying coastal regions may face flooding, salt infiltration of fresh water tables, harmful algal blooms, and in some cases severe storms.[75–77] The western United States may experience significant strains on water supplies as regional precipitation declines and mountain snowpacks are depleted,[78] in turn raising the risk of forest fires.[10] As a result, planning for and managing the health impacts of climate change will need to draw on local data and will involve local and regional authorities and health care providers.

Health disparities are well recognized in public health and clinical practice, and a central tenet of public health is that such disparities need to be eliminated. One contributor to health disparities is environmental risks that disproportionately threaten certain populations, especially poor people and members of ethnic and racial minority groups—the basis of environmental justice advocacy.[79,80] Climate change is expected to perpetuate health disparities in this way.[81] Events such as Hurricane Katrina highlighted the vulnerability of the poor in New Orleans, La,[82–84] and on a global scale, people in poor countries will face greater health risks, with fewer resources and less resiliency than will those in wealthy nations.[67,68,85–88] Public health action on climate change must include vulnerability assessments, identification of the most vulnerable populations, and a focus on eliminating health disparities.

Complexity is a cardinal feature of climate change. Vast numbers of factors influence meteorological systems, many feedback loops operate, and sufficient data needed for a full evaluation are rarely available. The same is true of the health impacts of climate change. These effects will unfold over coming decades against a backdrop of other changes: demographic shifts including population growth and an aging population, increasing scarcity of fossil fuels, continuing migration to Southern and Southwestern states, and urbanization. To grapple successfully with this complexity, public health scientists will need to engage in systems thinking[89] and learn and apply techniques such as system dynamics modeling.[90]

The recognition of these 3 realities—geographic variability, population variability, and complexity—set the stage for considering public health actions to address climate change based on the following 10 essential services of public health.

Monitor Health Status to Identify and Solve Community Health Problems

Information is key to a responsive and functioning public health system. Data from public health surveillance or tracking systems are used to determine disease burdens and trends, identify vulnerable or affected people

TABLE 2—The 10 Essential Services of Public Health, With Climate Change Examples

Service	Climate Change Example
1. Monitor health status to identify and solve community health problems.	Tracking of diseases and trends related to climate change
2. Diagnose and investigate health problems and health hazards in the community.	Investigation of infectious water-, food-, and vector-borne disease outbreaks
3. Inform, educate, and empower people about health issues.	Informing the public and policymakers about health impacts of climate change
4. Mobilize community partnerships and action to identify and solve health problems.	Public health partnerships with industry, other professional groups, faith community, and others, to craft and implement solutions
5. Develop policies and plans that support individual and community health efforts.	Municipal heat-wave preparedness plans
6. Enforce laws and regulations that protect health and ensure safety.	(Little role for public health)
7. Link people to needed personal health services and ensure the provision of health care when otherwise unavailable.	Health care service provision following disasters
8. Ensure competent public and personal health care workforce.	Training of health care providers on health aspects of climate change
9. Evaluate effectiveness, accessibility, and quality of personal and population-based health services.	Program assessment of preparedness efforts such as heat-wave plans
10. Research for new insights and innovative solutions to health problems.	Research on health effects of climate change, including innovative techniques such as modeling, and research on optimal adaptation strategies

Source. Public Health Functions Steering Committee.[71]

and places, recognize disease clusters, and plan, implement, and evaluate public health interventions.[91] When these data are systematically collected, analyzed, interpreted, and disseminated, they guide the design of effective public health interventions and the judicious use of public health resources.

To respond to climate change, several categories of data—on environmental risks, vulnerability, and disease—are needed. Examples of risk data include meteorological data (such as temperature trends) and ecological data (such as mosquito density). Indicators of vulnerability include not only physical factors such as elevation, urban infrastructure, loss of forest cover, and prevalence of household air conditioning,[92-95] but also social factors such as isolation and poverty.[96] One example, the Climate Vulnerability Index, focuses on susceptibility to floods using a combination of factors measured at the local level.[94] Disease surveillance is a traditional public health function; data systems for infectious diseases known to be linked to climate variability, including foodborne[15] and waterborne[97,98] diseases, need to be strengthened.

These data—on risk, vulnerability, and disease—are often collected at different spatial scales and through different methods. It is essential that they be harmonized and integrated. Epidemic early warning systems combine clinical data such as emergency department and outpatient clinic syndromic surveillance with climate data, vector biology data, clinical laboratory data, veterinary data, telephone hotline call tracking, pharmaceutical use data, and other data.[99-103] Such systems exist in many parts of the world for vector-borne,[104-107] foodborne,[108,109] waterborne,[110] and respiratory[111] diseases and for acts of terrorism.[112] Such early warning systems need to be evaluated and strengthened.[113-115] In the United States, the National Environmental Public Health Tracking Program is a comprehensive approach to collecting and integrating data on environmental exposures, human body burdens, and diseases.[116,117] This program needs to expand in terms of the number of participating jurisdictions, data elements collected, integration of diverse data sources, and greater spatial resolution of the data. This will enable health authorities to understand more clearly the associations among long-term climate changes, weather events, ecological changes, and direct and indirect health outcomes.

Diagnose and Investigate Health Problems and Hazards in the Community

Identifying, investigating, and explaining health problems at the population level remain classic public health responsibilities—the community equivalent of a physician's diagnostic workups of patients. These functions, which flow directly from the previous task (monitoring health status), are well established in public health. However, climate change will require enhanced diagnostic and investigative capacity throughout the health system. For example, ecological changes may alter traditional vector-borne disease dynamics, possibly redefining animal hosts, vectors, and disease outcomes at the local and regional scales. Techniques that help assess health vulnerability to climate change have been proposed and offer a proactive approach to diagnosis.[47] The capacity of public health laboratories must be enhanced to allow rapid diagnosis and reporting of diseases that are reintroduced or alter their distribution.

An example of such investigation comes from British Columbia, where an outbreak of *Cryptococcus gattii*, formerly considered a tropical organism, was observed in 2001.[118,119] Investigation of the outbreak, a collaborative effort of a university and a provincial center for disease control, included such innovative sampling techniques as testing of air, soil, trees, garden waste, vehicle wheel wells, and the shoes of personnel participating in sampling, and it required laboratory capacity to culture the organism and identify it using the methods of restriction fragment length polymorphism.[120]

A component of diagnosis and investigation is attribution—determining the extent to which health problems can be attributed to climate change. Understanding attribution will help in developing the most effective and cost-effective strategies for health system response. Methods for estimating the health burden of climate change use techniques analogous to risk assessment.[39,121] These methods need further development and application.

Inform, Educate, and Empower People About Health Issues

Most Americans believe that climate change is already having effects, and a large and increasing plurality report that they worry about it "a great deal." However, only 1 in 5 reports understanding climate change very well. Moreover, Americans are equally divided among those who believe that media coverage of climate change is exaggerated, correct, and underestimated.[122] There is a high and growing level of concern, but clearly public understanding of climate change is incomplete, and a majority lacks confidence in information presented in the media.

This situation, which is familiar to health professionals, in many ways reflects public views of health and illness. The need to inform, educate, and empower people about health is critical, and experience with smoking cessation, HIV prevention, physical activity promotion, and other health issues has yielded rich insights into effective health communication.[123,124] However, little of this insight has been applied to climate change.[125-128]

Effective health communication on climate change will inform the public and policymakers about potential health effects and about steps that can be taken to reduce risk. The communication needs to be targeted to specific groups, accounting for varying levels of understanding, cultural and ethnic differences, vulnerability to the health effects of climate change, and other factors. Messages should empower people to access and use necessary health resources. Since frightening scenarios may elicit despair and helplessness, it is important to design messages that minimize these responses and that lead instead to constructive behaviors. For example, the Environmental Protection Agency offers a "What You Can Do" Web page[129] that provides tips for use at home, at the office, on the road, and at school, together with user-friendly tools such as a personal greenhouse gas emissions calculator. Other nations may provide useful models. For example, Health Canada offers the Canadian public a regular publication called *Your Health and a Changing Climate*, a user-friendly Web site,[130] and other information channels. Research on the most effective means of communication is needed, and once implemented, communication strategies should be evaluated for efficacy.

Mobilize Community Partnerships to Identify and Solve Health Problems

Responding to the health challenges posed by climate change requires a multilevel, interdisciplinary, and integrated response, so efforts should focus on developing partnerships among federal, state, and local government agencies, academia, nongovernmental organizations, and the private sector. Many of these partnerships must evolve at the local and state levels, because identifying health threats and vulnerable populations, designing and implementing adaptive measures, and responding to emergencies occur largely at those scales.

Although existing relationships with traditional public health partners should be strengthened, new collaborations must be developed. Leading examples include collaborations with architects and city planners (whose design work can reduce energy demand and limit vulnerability to heat, flooding, and other risks), transportation planners (who can design transportation systems that reduce greenhouse gas emissions and promote safe, healthy travel), and the faith community (which shares an emphasis on long-term stewardship and can help disseminate public health information). For example, the National Religious Partnership for the Environment[131] identifies human health as a central issue in climate change, offering a firm basis for collaboration with public health agencies.

Develop Policies and Plans That Support Individual and Community Health Efforts

National policy on the mitigation of climate change will likely evolve in coming years. Although responsibility for reducing greenhouse gas emissions lies outside the health arena, health input is appropriate in at least 2 ways. First, health professionals can explain the health rationale for climate change mitigation in terms of reduced morbidity and mortality. Second, health scientists can provide evidence on the health impacts of various approaches to climate change mitigation (including cobenefits and disbenefits),[132] using such techniques as health impact assessment.[53,54] Such input will help produce decisions that best protect public health.

The health sector should play a major role in developing plans that address health threats related to climate change. For example, cities at risk of heat waves need preparedness plans[133,134] that provide early warnings, educate the public and health care providers, identify vulnerable people and places,[135] implement health surveillance,[136] create buddy systems and other rescue plans, identify shelter facilities, ensure that backup generators are available and supplied with fuel, prepare transport and evacuation plans, and prepare clinical facilities to deliver appropriate care, including surge capacity.[137] Similar plans are needed for severe weather events,[138] infectious disease outbreaks, and other health threats. A good example is the Hospital Safety Index proposed by the Pan-American Health Organization, to help plan and achieve "hospitals safe from disasters."[139] Health data can inform the design of "climate-proof" housing, enhanced infectious disease control programs, early warning systems, and other plans. Public health authorities need to collaborate with other agencies, such as those responsible for law enforcement and emergency response, in planning and exercising. Initiatives in Portland, Ore,[140] and Seattle, Wash,[141] exemplify local health department engagement in such planning.

Other policies and plans are internal to the health system, relating to the operation of health facilities. The health sector, like many other industries, can examine its own contributions to climate change and work to reduce them. Hospitals and clinics can be designed, built, and operated in ways that lower energy demand, reduce their waste streams, and link with local transit systems to cut driving by staff, patients, and visitors. "Green purchasing" refers to preferential purchasing of environmentally friendly supplies and equipment, another set of strategies to reduce health sector contribution to climate change. The British National Health Service has adopted these approaches as policy,[142] and technical advice is available to US health organizations in the peer-reviewed literature[143] in sources such as the *Green Guide for Health Care*,[144] from organizations such as Hospitals for a Healthy Environment[145] and from private architects and consultants.

Enforce Laws and Regulations That Protect Health and Ensure Safety

Few public health laws and regulations have a direct bearing on climate change. However, public health can provide science-based input regarding laws and regulations in the environmental, transportation, and energy arenas. As policies are codified, there may be roles for state and local public health agencies in enforcing such policies as building codes, water quality regulations, and air quality laws.

Link People to Needed Health Services and Ensure Provision of Care

A strong infrastructure for delivering health care services must be part of the health response to climate change. To prepare for disasters such as hurricanes, floods, and heat waves, support is needed for developing local, regional, and national emergency medical systems and enhancing their disaster response capacity, including specialized services and surge capacity. These requirements are included as part of the National Response Plan under Emergency Support Function No. 8, called Public Health and Medical Services.[146] Although disaster medical planning often focuses on trauma care, disasters may interrupt ongoing care for diseases such as HIV infection and renal failure, routine laboratory testing such as newborn screening, and other services, all of which must be restored. System failures during and after Hurricane Katrina made clear the need for effective, coordinated approaches for delivering clinical services.[147–150]

In the context of climate change, mental health services may be an important component of health service delivery. The mental health burden following acute disasters is considerable,[151–155] especially for high-risk groups such as children.[156,157] In addition, the long-term stresses of climate change—living with uncertainty, environmental threats, and alterations in familiar habitats and habits—may impose a chronic mental health burden.[158–163] The health system needs the capacity for rapid needs assessment, mental health service delivery, and long-term follow-up.[164]

Ensure a Competent Public and Personal Health Care Workforce

A trained and competent workforce is central to the success of the health system.[165] Preparing the health workforce for the potential impacts of climate change and for a host of other challenges over the coming decades will require a concerted effort at the local, state, and federal levels. It will involve ensuring a basic set of competencies throughout the system and developing a cadre of scientists with multidisciplinary, specialized skills in nontraditional fields.

Medical care providers should be trained to recognize and manage emerging health threats that may be associated with climate change. For public health professionals, training networks need to provide a systematic approach to training, linked directly to essential services and needs as identified by local and state health officials. Partnerships should be developed between health science schools and other academic institutions to provide cutting-edge education for health professionals in nontraditional subjects such as economics, health impact assessments, ecology, urban health, and vulnerability modeling. It is critical that the health system develop a wider range of expertise at every level to respond adequately to the challenges of climate change. Health professional training in climate change can be found at several universities; examples include Harvard's course on human health and global environmental change[166] and the University of Wisconsin's graduate certificate on humans and the global environment.[167]

TABLE 3—Research Topics on Global Environmental Change and Human Health

Research Domain	Examples
Understanding the health effects of global environmental change	Identification of key health indicators to monitor
	Empirical studies of current health effects, taking advantage of circumstances (extreme weather events) and localities (environmental hotspots) where these effects already manifest themselves
	Scenario analyses of future health effects, combining theoretical insights, empirical data, and quantitative and qualitative modeling exercises[169]
	Integrated assessment analyses of current and future health effects, comparing different environmental changes to facilitate priority setting
Adaptation to reduce the health effects of global environmental change	Development of more-effective methods for the health management of heat waves, floods, and other extreme weather events
	Development of more-effective methods to control emerging infectious diseases, such as vector control, vaccination, and pharmacological treatment
	Development of diets that are nutritious, palatable, and affordable and do not require unsustainable food production and transportation methods
	Economic analyses of various adaptation strategies, including health costs and benefits
Understanding the contribution of the health sector to global environmental change	Assessment of the environmental effect ("footprinting") of health sector resource use and waste generation
	Development of health sector practices that are sustainable in terms of resource use and waste generation
Communication research	Assessment of public and policymaker knowledge, attitudes, and behaviors with respect to climate change and identifying audience segments
	Testing of various communication strategies regarding climate change

Source. Adapted from Mackenbach.[170]

Evaluate Effectiveness, Accessibility, and Quality of Health Services

As they work to reduce the health impacts of climate change, health professionals must demonstrate accountability for the effectiveness, accessibility, and quality of programs and interventions. The evaluation of preparedness plans, health communication strategies, and other initiatives not only helps improve public health efforts, but it can also facilitate communication with key community stakeholders.

Evaluation requires robust surveillance capacity, a well-trained public health workforce, and established, efficient, reliable systems for sharing information among different levels of government and parts of the health sector. It also requires a periodic inventory of available services and assessment of the degree to which those services are accessible to the most vulnerable populations they are designed to serve. As with many other essential public health services, evaluation activities related to climate change and health will have cobenefits with other important public health activities and will likely exhibit synergistic effects in strengthening the nation's public health system.

Search for New Insights and Innovative Solutions to Health Problems

Several lines of health research are needed to provide data-based support for public health action on climate change.[168,169] These include empirical research on the association between climate change and health, scenario development to forecast health impacts and vulnerabilities, and development and testing of strategies to reduce risk. For each intervention, research is needed on the level of public health protection produced and on attendant costs. Examples are shown in Table 3.

CONCLUSIONS

There is widespread scientific consensus that the world's climate is changing. Mounting evidence suggests current and future effects on human health, including injuries and illnesses from severe weather events, floods, and heat exposure; increases in allergic, respiratory, vector-borne, and waterborne diseases; and threats to food and water supplies. Indirect effects may include anxiety and depression and the consequences of mass migration and regional conflicts.

Addressing these occurrences is a pressing challenge for public health. Although the scope and complexity of the challenge are unprecedented, the conceptual framework for responding draws on long-standing public health thinking. An effective public health response to climate change is essential to preventing injuries and illnesses, enhancing public health preparedness, and reducing risk. Science-based decisionmaking, informed by public health ethics, will help manage uncertainty and optimize health, environmental, and economic outcomes. The Essential Services of Public Health serve as a useful framework for planning and implementing a public health response. ■

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Dr. BENJAMIN. Thank you very much. Madam Chair, I will pass the rest of my time.

[The statement of Dr. Benjamin follows:]

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Protect, Prevent, Live Well

Testimony of Georges C. Benjamin, MD, FACP, FACEP (Emeritus)
Executive Director, American Public Health Association
House Select Committee on Energy Independence and Global Warming
"Healthy Planet, Healthy People: Global Warming and Public Health"
April 9, 2008

Chairman Markey and members of the Committee, my name is Dr. Georges Benjamin and I serve as the Executive Director of the American Public Health Association. The American Public Health Association (APHA) is the nation's oldest and most diverse organization of public health professionals in the world, dedicated to protecting all Americans and their communities from preventable, serious health threats and assuring community-based health promotion and disease prevention activities and preventive health services are universally accessible in the United States. I thank the Committee for the opportunity to present APHA's views on the health impacts of climate change. We are especially pleased this hearing is being held during National Public Health Week.

Each year since 1996, the American Public Health Association has organized National Public Health Week and developed campaigns to educate the public, policy-makers, and public health professionals about issues important to improving the public's health. This year the theme of National Public Health Week is "Climate Change: Our Health in the Balance." By making climate change the theme for 2008, the public health community is changing how society addresses this unprecedented challenge. While we are pleased that the issue of climate change has received much attention over the past year, we are also aware that the health effects of climate change continue to be overshadowed by the concerns of climate change on the environment. APHA believes it is critical that Congress act now to address the growing threat that climate change poses not just to the environment but also to the health of the American public and the entire global community.

Climate Change and Health

Climate change is a public health issue. Scientists from across the globe have stated in the strongest possible terms that the climate is changing and that human activity is to blame. The recent Intergovernmental Panel on Climate Change (IPCC) report has unequivocally concluded that greenhouse gas is causing global warming and the United States is a leading contributor of greenhouse gases globally. Greenhouse gases – produced mainly from the fossil fuels used to power cars and trucks, from power plants used to create electricity and from the industries that manufacture goods and produce food –are causing the Earth's temperature to increase. This increase in the Earth's temperature (referred to as global warming) is causing regional weather changes such as more extreme weather events and increases and decreases in temperature and rainfall. These regional weather changes may create environmental conditions (floods, heat waves, drought, poor air quality) that lead to poor health outcomes such as heat stroke, injury, malnutrition, respiratory illness and asthma, and infectious (vector- and rodent- borne) diseases.

Climate change is already dramatically affecting the health of people around the world especially in the developing world. The World Health Organization reported that climate change, which occurred from 1961 to 1990, may already be causing over 150,000 deaths or the loss of over 5.5 million disability adjusted life years annually starting in 2000, in developing countries.

These numbers are staggering, but they should not be surprising: climate change influences the living environment on the most fundamental level, which means it affects the basic biological functions critical to life. It impacts the quality of air breathed, availability of food and drinking water, and the potential for disease to spread.

These impacts are different in different parts of the world — and equally troubling, they are disproportionately burdensome for the world's more vulnerable populations. Children, the elderly, the poor and those with chronic and other health conditions are considered the most vulnerable to the negative health impacts of climate change because they are most susceptible to extreme weather events like heat waves, drought, intense storms and floods. They are also least likely to have the resources to prepare or respond. This unequal burden seems especially unjust given that these populations are the least likely to contribute substantially to climate change. Any strategies for managing climate change impacts must take the unique challenges and needs of vulnerable populations into account.

Many studies predict that climate change will cause adverse health outcomes due to regional changes in weather causing poor environmental conditions in communities around the country. For example:

- In the Midwest and Northeast, major cities such as New York and Chicago could see temperatures that would mean more heat stress and heatstroke. The poor and the elderly would be hit especially hard.
- In the Northwest, heavy rainfall may lead to flooding and overflow of sewage systems, causing an increase in the spread of disease.
- In the southwest, higher temperatures and decreased rain are likely to strain already limited water sources, increasing the likelihood of wildfires and air pollution.
- In the Great Plains, increased temperatures could mean scorching summers and more mild winters - which would significantly hurt food production.
- In the southeast Atlantic and Gulf Coast, hurricanes and other weather events are expected to last longer and be more intense. That would mean bigger storm surges, more damage to buildings and roads, and contaminated food and water.

Extreme weather events that have occurred in the US such as the Chicago heat wave in 1995, Hurricane Katrina, and the recent wild fires in southern California offer good examples of how extreme weather have led to poor environmental conditions and death and disease. Several Alaskan communities are facing real consequences of climate change – mostly associated with increased temperatures - that is resulting in shorter winters and melting ice, which is negatively impacting many aspects of life. In addition as concluded by a recent study, climate change could detrimentally affect air quality (therefore respiratory health) in major urban cities in the US.

APHA Policy on Climate Change and Health

APHA has been concerned about the potential effects of global climate change and health for more than a decade and has had a policy on this issue since 1995. In 2007, APHA updated its policy to include new information from the fourth IPCC report, which concluded that the warming of the earth is unequivocal and that warming can be attributed to human behavior. APHA's current policy and position on addressing the health impacts of climate change is:

- Based on scientific evidence, the long- term threat of global climate change to health is serious and that greenhouse gas emissions are primarily responsible.
- Policies (such as policies that will reduce greenhouse gas emissions) and actions (choosing alternative modes of transportation) to mitigate and avoid further increases in climate change are critical and a priority.
- Adaptation strategies are necessary to protect health from poor environmental conditions caused by climate change.
- Research is needed to better understand the health impacts of climate change and to develop effective adaptation strategies.
- It is the right of all individuals to be free of serious adverse effects from global climate change - vulnerable populations including individuals living in extreme poverty must be protected.
- As a front line protector and communicator to communities, the public health community plays a key role in helping to mitigate and adapt to climate change. As such the public health community must have the tools, skills, training and education and resources to fulfill this role.

The Problem of Greenhouse Gases

As the United States is the leader in contributing to greenhouse gas globally, the U.S. should also be a leader in solving the problem by reducing our greenhouse gas emissions. To achieve that goal, we must focus on carbon dioxide which is the major component of greenhouse gases. Carbon dioxide emissions come primarily from coal-burning power plants and vehicle exhaust.

While individuals can help to reduce their contribution to global warming by making healthier choices such as walking or biking rather than driving or eating less meat, this alone will not solve the problem. The solution must include:

- Energy policies that will significantly reduce greenhouse gases in particular reductions in carbon dioxide.
- Using new and existing technologies for producing cleaner cars and cleaner plants, and more efficient appliances.
- Exploring and using renewable energy sources such as wind, sun, and geothermal.

The Role of Public Health

Even though there is a direct connection between climate change and the health of our nation today, few Americans are aware of the very real consequences for our communities, our families and our children. It is time for the public health community to take a seat at the table for this critical discussion.

There is growing recognition that we must act and we must act now. As public health professionals, we are in the unique position of playing an important role in both keeping people healthy and addressing the impacts of climate change. Thankfully, these twin goals are compatible. In fact, many of the choices individuals should make for the sake of their health — and the health of their communities — are the same choices that benefit the health of the planet. Making the climate change issue real means helping people understand how the way they live affects themselves and others, whether through transportation choices, the use of water and electricity or the types and amounts of goods purchased and consumed.

Encouraging behavior change is familiar territory for public health experts, and it is a key part of the solution. The shift away from fossil fuels and a movement toward general environmental awareness aligns with existing public health priorities:

- The transportation sector is one of the largest sources of greenhouse gases. Encouraging people to walk, bike, use public transportation or carpool is co-beneficial, as it helps reduce vehicle greenhouse gas emissions and helps improve an individual's health by increasing physical activity.
- Similarly, improving community design to reduce reliance on cars means less greenhouse gases and also less obesity, diabetes and even asthma exacerbation because of cleaner air.
- Eating less meat reduces the need to convert land from rainforest or grassland to grazing fields; requires less corn to be grown for feed (meaning less pesticides and other fossil fuel-based products needed in the growing process); and reduces the output of methane gases from manure.

There are public health professionals around the country already implementing groundbreaking strategies to respond to and prevent the potentially devastating impacts of climate change. Others are in the trenches, tackling public health problems day in and day out without recognizing that many of them are directly related to climate change.

The public health system will be a frontline responder to potential emergency conditions caused by climate change. It will also play a key role in informing, educating and empowering the nation to make the changes needed to mitigate the problem.

The public health community is well positioned to lead the way in addressing the health impacts of climate change in a number of areas including preparedness, prevention, research, partnerships and policy. While APHA and its partners at the national level play a leading role in advocating for policies to lessen the impact of climate change on health, the public health community at the local level may play the most important role of all.

As many public health activities occur at the local level, it is critical that state and local health departments have the resources they need to educate public health workers, the public and their partners about the health impacts of climate change. Additionally, our state and local health departments need adequate resources to plan and implement efforts to lessen the impact of climate change on the health of our communities.

We must also ensure that our public health workers have the tools and resources they need to educate themselves and their communities about the connection between climate change and health. We encourage those in the public health community to build partnerships with other key stakeholders to ensure the inclusion of public health concerns in programs and policies related to climate change mitigation and adaptation.

We encourage the public health community to take the following steps:

- Conduct vulnerability and needs assessment(s) and determine the potential impacts of climate change.
- Identify and build upon existing public health programs that can also help to address the health impacts of climate change.
- Ensure that surveillance and data monitoring programs capture information needed to improve public health programs and effectively identify and address the health risks of climate change.

Making Progress at the State and Local Level

Across the nation, health departments are making key contributions to larger state efforts by emphasizing the health impacts of climate change and identifying the role of public health in addressing these issues. It is this work that adds the human dimension to the issue and takes it beyond the economic and purely environmental.

The National Association of City and County Health Officials (NACCHO) is currently surveying their constituents about issues associated with climate change and public health at the local level. The results of this survey will be used to help determine what is happening within public health departments at the local level and to identify best practices. Most state efforts in these areas are relatively new and many are yet to be uncovered. Here are a few state level efforts that can serve as good models and resources:

California

The Public Policy Institute of California (PPIC) is creating a climate change report to include a public health component. As part of this effort, PPIC surveyed local health officers' attitudes and resource needs in relation to climate change impacts. They asked critical questions on whether these institutions had adequate resources and authority to adjust to a changing climate. They found that some programs are already in place that can aid in adaptation to climate change such as disease tracking and heat emergency plans. However, almost 70 percent indicated that their agency *lacks* adequate resources to respond specifically to climate change. Officers surveyed noted the following would be needed to help their efforts: health impact assessments, funding, staff with expertise in climate science, vulnerability assessments, and state and local coordination. Preliminary recommendations from the PPIC work, presented to the California Conference of Local Health Officers, include better integrating public health into climate change-related policy efforts.

Florida

The Florida Department of Health (DOH) is working as part of the state's comprehensive "Lean to Green" Initiative. This effort gives the DOH and other Florida state agencies the opportunity to lead by example by establishing more sustainable choices in public service operations. The initiative stems from three executive orders signed in July 2007 by Gov. Charlie Crist to reduce Florida's greenhouse gases and increase energy efficiency. Some areas addressed include:

- **Flexible Work Schedules/Telework/Telecommuting** — supporting more employees working at least one day from home or an alternate location and studying arrival and exit times to support staggering work hours.
- **Alternative Transportation** — including allowing a 30-minute work credit time per day for bus, bike or carpool commuters and establishing a variety of incentives such as free bus passes and reinstituting the employee transportation coordinator position.
- **Purchasing** — encouraging purchasers to adopt practices such as purchasing laptops instead of desktops when they refresh their computers in the future; purchasing only from vendors with the highest standards of recycling and offset initiatives; and considering travel options and the purchase of carbon offsets with all air travel.
- **Energy Use in Buildings** — conducting energy audits of each building; using desktop power strips at each workstation to encourage turn-offs and diminish "phantom" loss of energy; decreasing the number of printers and increase the reuse of paper and double-sided printing; supporting the transition to solar roofing for certain DOH buildings; supporting the use of green roofs on all facilities; transitioning to use of rechargeable batteries; and ensuring that vending machines in buildings are using energy-saving features.

- **Education** — adding a green focus to meetings, conferences and calls throughout 2008; establishing green work groups in each division; including green objectives in all strategic plans; establishing an assessment process for this initiative; and working toward offering assistance for staff interested in green alternatives and to conduct individual assessments of their carbon footprints.

Maryland

The state has established the Maryland Commission on Climate Change to develop a plan of action to address the drivers of climate change, prepare for its likely impacts in Maryland and establish goals and timetables for implementation. A specific work group within the commission is tasked with addressing the health implications of climate change to Marylanders. The commission emphasizes Maryland's particular vulnerability as a coastal state to climate change impacts of sea level rise and increased storm intensity. The state has also experienced extreme droughts. The commission will recommend legislation and mitigation initiatives in areas, including greenhouse gas reduction, green building incentives and encouraging federal and international action. Developing partnerships to raise public awareness of climate change will be one major initiative. Behavior change will be encouraged through education and outreach to consumers, the commercial and industrial sectors and students. The commission will develop its final climate action plan for presentation to the governor and General Assembly in this April.

The above examples by no means comprehensively cover the actions taking place throughout the country. APHA is committed to working with our local, state and national partners to continue to build and strengthen efforts to help lessen the health impacts of climate change.

What Congress Can Do

Congress must play a leading role in addressing the health effects of climate change. APHA has been working with this Committee and others in Congress in an effort to ensure that agencies including the Department of Health and Human Services (HHS), the Centers for Disease Control and Prevention (CDC), the National Institutes of Health (NIH), the Environmental Protection Agency (EPA) and others are involved in the planning and implementation of measures to mitigate and adapt to the health effects of climate change. Specifically, APHA supports the following:

1. Funding for the Centers of Disease Control and Prevention to formally establish a climate change program at the agency. As the nation's public health agency, CDC needs to be involved in helping us prepare for and adapt to the potential health effects of global climate change. CDC has several programs that support global climate change preparedness strategies e.g., the National Center for Environmental Health routinely responds to natural disasters and heat waves, and monitors respiratory disease, the National Center for Zoonotic, Vector-borne, and Enteric Diseases works on surveillance and response to vector-, water- and food-borne diseases. However, much more program development and support is needed. APHA recommends funding the following activities at CDC to strengthen their efforts to address climate change:

- Establish a "Climate Change" program within CDC to develop expertise among CDC staff in the areas of epidemiology, disaster preparedness, climatology, communications, infectious disease ecology and others.
- Fund up to six academic "Centers of Excellence" at universities. Research would focus on forecasting and modeling; vector-borne diseases; climate change communication and behavioral change science; food and water-borne diseases; vulnerable populations; heat waves; healthy urban design and transportation to minimize the climate change impacts.
- Strengthen CDC's Global Disease Detection Centers around the world to monitor new infectious disease trends related to changed climates by improving outbreak response, global surveillance, and research. This funding would also help to build capacity and improve quality of epidemiologic and laboratory science through developing a training program in this area.
- Supporting development, implementation and expansion of state and local monitoring and surveillance programs for health and environmental indicators.
- Supporting state and local protective plans to anticipate and reduce the health threats of climate change; this should include identifying and prioritizing especially vulnerable communities and populations and assessing impacts of land use changes.
- Represent HHS to the U.S. Climate Change Science Program which contributes to scientific research for health issues related to climate change.

2. Funding HHS to promote public health in the course of reducing greenhouse gas emissions or to protect public health from adverse impacts related to climate change. In addition to creating a climate change program at CDC, APHA supports funding at HHS for:

- Developing an applied research program, with both intramural and extramural components, focused on protecting the public from adverse health and food security effects of climate change.
- Development of public education and outreach programs to promote greenhouse gas reduction behaviors that are also health-promoting.
- Establishing and chairing an interagency workgroup to: 1) identify, assess the health and economic benefits of, and prioritize critical infrastructure projects related to climate change impacts; and 2) coordinate preparedness for climate change health impacts.

3. Funding the National Institutes of Health (including the National Institute of Environmental Health Sciences) to study water, food and vector borne infectious diseases; pulmonary effects, including responses to aeroallergens; cardiovascular effects, including impacts of temperature extremes; hazardous algal blooms; mental health impacts of climate change; protecting the health of refugees, displaced persons, and vulnerable communities; and local and community-based health interventions for climate-related health impacts.

4. Funding the Environmental Protection Agency for research and intervention activities and to assess the health benefits and risks associated with alternative fuels and fuel additives and associated land use changes, improved energy efficiency in buildings, alternative methods of energy generation, community and transportation designs that maximize transportation efficiencies; and identifying and prioritizing climate-related threats to drinking water and available technologies to mitigate those threats.

5. Funding the Department of Agriculture for research and intervention studies on the impacts of climate change on food supply and food security.

6. Through **federal transportation legislation,** Congress should promote energy conservation, including ensuring responsible fuel-economy standards; improvements in energy efficiency; the development of renewable fuel sources for energy production; and strengthen controls for greenhouse gas emissions and air hazardous pollutants.

7. Require and providing funding for Health Impact Assessments in relevant legislation to assure a better understanding of the effect of policy on short and long term health outcomes.

Conclusion

Growing scientific consensus shows us that the climate is changing in ways that increasingly affect the health of people around the world. Because climate influences how people live, breathe and eat as well as the availability of water, populations everywhere, including the United States, may already be experiencing the health impacts of these changes. This is especially true among our most vulnerable populations, children, the elderly and the poor.

We cannot wait to address the health impacts of climate change. We strongly urge Congress to ensure that public health and other health impacts are addressed in any climate change legislation passed by Congress this year. We appreciate the opportunity we have had to work with you and your staff on this important issue and we look forward to continuing our efforts as Congress moves forward with its consideration of climate change legislation this year.

Ms. SOLIS. Thank you. Thank you very much, Dr. Benjamin. It is a pleasure working with you.

Our next speaker is Dr. Dana Best; she represents the American Academy of Pediatrics. This is a nonprofit professional organization of 60,000 primary care pediatricians, pediatric medical sub-specialists, and pediatric surgical specialists, dedicated to health, safety, and the well-being of infants, children, adolescents, and young adults.

Dr. Best is an assistant professor of pediatrics at the George Washington University School of Medicine and an attending physician at Children's National Medical Center in Washington, D.C. She serves also on the American Academy of Pediatrics Committee on Environmental Health, and in October 2007, the committee published their report, "Global Climate Change and Children's Health."

Thank you, Dr. Best, for being here. You can begin your testimony.

STATEMENT OF DANA BEST

Dr. BEST. Thank you, Madam Chairwoman.

Good morning to all of you. I appreciate this opportunity to testify today on the impact of climate change on child health, and I am proud to represent the American Academy of Pediatrics in this regard.

Human health is affected by the physical environment. As the climate changes, environmental hazards will change and often increase, and children are likely to suffer disproportionately from these changes. Anticipated health threats from climate change include extreme weather events and weather disasters, increases of infectious disease, and air pollution. Within all of these categories, children have increased vulnerability compared to other groups.

The health consequences associated with extreme weather events include death, injury, infectious disease, and post-traumatic mental health and behavior problems. Experiences with Hurricanes Katrina and Rita demonstrated the difficulties with tracking children's whereabouts, keeping children and caregivers together, and the special needs of hospitalized infants and children during and after major natural disasters.

Vector-borne infections are affected by climate change as well. Both the hosts—for example, rodents, insects, and snails—and the pathogens—such as bacteria, viruses, and parasites—are sensitive to climactic variables such as temperature, humidity, and rainfall.

For example, malaria is a climate-sensitive vector-borne illness to which children are particularly vulnerable. Because they have naive immunity, children experience disproportionately high levels of both sickness and death from malaria.

Climate change is expanding the range of mosquitoes to higher altitudes and latitudes, and warmer temperatures speed the development of the parasite within the mosquito itself. Small children will be most affected by the expansion of the malarial zones and the success or failure of our response to those changes.

Children are especially vulnerable to both short-term illness and long-term damage from air pollution. Children's lungs are developing and growing; they breathe faster than adults and they spend more time outdoors in vigorous physical activity.

Formation of ozone, in particular, is known to increase with increasing temperatures. Children who are active in outdoor sports in communities with high ozone are at increased risk of developing asthma, which has been well documented.

Rates of pre-term birth, low birth-weight, and infant mortality are increased in communities with high levels of particulate air pollution. Some investigators have argued that part of the global increase in childhood asthma can be explained by increased exposure to allergens in the air driven by climate change; those are allergens like pollen, as previously mentioned.

For all organisms there exists a range of ideal temperatures, above and below which sickness and death increase. Humans are no exception. As temperatures increase, the frequency of heat waves increase.

Children spend more time outside, often playing sports in the heat of the afternoon, which puts them at increased risk of heatstroke and heat exhaustion. Outdoor time during hot weather may also put children at increased risk of ultraviolet radiation-related skin damage, including skin cancer.

Food availability may be affected and land and ocean food productivity patterns shift. Water availability may change and be reduced in some regions.

Populations on the coasts may be forced to move because of rises in sea level, and massive migrations are conceivable, driven by abrupt climate change, natural disaster, or political instability, caused by increased demands for shrinking resources.

World population is expected to grow by 50 percent, to 9 billion people, by 2050, which would place additional stress on ecosystems and increase demand for energy, fresh water, and food. As these changes evolve, social and political institutions will need to respond with aggressive mitigation and adaptation strategies to preserve and protect public health, particularly for children.

In addition to its recommendations to pediatricians for reducing their own energy demands and incorporating sustainable practices into their personal and professional lives, the American Academy of Pediatrics calls upon government at all levels, from the smallest municipalities to the national and international levels, to implement aggressive policies to halt contributions to climate change caused by humans, and mitigate their impact on children's health.

First, policymakers should develop aggressive long-term policies to reduce the major contributing factors to global climate change. For example, the Environmental Protection Agency should set the national ambient air-quality standard for ozone at 0.060 parts per million.

Our government should invest in prudent and vital preparations for our public health care systems, including immunization programs and disease prevalence reporting and tracking. And that means they have to be funded, too.

Policymakers should give specific attention to the needs of children in emergency management and disaster response. Governments should support education and public awareness of the threats from climate change and their implications for public and children's health now and in the future. Governments should fund interdisciplinary research to develop, implement, and measure outcomes of innovative strategies to both mitigate and adapt to climate change, particularly those effects that have direct implications for children's health.

In order that members may have access to the full information on this topic that we have prepared, I would like to ask that our statement—the American Academy of Pediatrics' policy statement and technical report, both called, "Climate Change and Children's Health"—be included in the hearing record.

In conclusion, the American Academy of Pediatrics commends you, Madam Chairwoman, for holding this hearing today to call attention to the potential impacts of global climate change on children's health. We look forward to working with Congress to prevent the adverse impacts on child health caused by global climate change, and plan for those we may be unable to avert.

I appreciate this opportunity to testify. Thank you.

[The statement of Dr. Best follows:]

TESTIMONY OF DANA BEST, MD, MPH, FAAP ON BEHALF OF THE AMERICAN ACADEMY OF PEDIATRICS

SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING

"Healthy Planet, Healthy People: Global Warming and Public Health"

April 9, 2008

Department of Federal Affairs
The Homer Building
601 Thirteenth Street, N.W.
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202-347-8600 / 800-336-5475 / Fax 202-393-6137

Good morning. I appreciate this opportunity to testify today before the Select Committee on Energy Independence and Global Warming on the impact of climate change on child health. My name is Dana Best, MD, MPH, FAAP, and I am proud to represent the American Academy of Pediatrics (AAP), a non-profit professional organization of 60,000 primary care pediatricians, pediatric medical sub-specialists, and pediatric surgical specialists dedicated to the health, safety, and well-being of infants, children, adolescents, and young adults. I am an Assistant Professor of Pediatrics at the George Washington University School of Medicine and an attending physician at Children's National Medical Center in Washington, D.C. I also serve on the AAP's Committee on Environmental Health.

There is strong consensus among expert scientists that Earth is undergoing rapid, global climate change.[1,2] Human activities, primarily the burning of fossil fuels, are very likely (>90% probability) the main cause of this warming. In October 2007, the American Academy of Pediatrics issued a new policy statement and technical report, entitled, "Global Climate Change and Children's Health."[3,4] This statement sounded a warning to pediatricians and policymakers alike that we should expect global climate change to have a disproportionately severe impact on the health of children everywhere.

Impact of Global Climate Change on Child Health

Human health is affected by the condition of the physical environment.[5] Because of their physical, physiologic, and cognitive immaturity, children are often most vulnerable to adverse health effects from environmental hazards.[6] As the climate changes, environmental hazards will change and often increase, and children are likely to suffer disproportionately from these changes.[7] Anticipated health threats from climate change include extreme weather events and weather disasters, increases in certain infectious diseases, air pollution, and thermal stress. Within all of these categories, children have increased vulnerability compared with other groups.

Extreme Weather Events and Weather Disasters: The health consequences associated with extreme weather events include death, injury, increases in infectious diseases, and posttraumatic mental health and behavior problems.[8] Unfortunately, few studies have specifically examined such consequences in children.

Children everywhere are at risk of injury and death from storms and floods.[9] In the developed world, infectious disease outbreaks follow natural disasters when sanitation, sewage treatment, and water-purification plants become damaged or overwhelmed, refrigeration and cooking facilities are disrupted, and people are unusually crowded in temporary shelter. These outbreaks are usually mild and well controlled, which is in contrast to the aftermath of similar catastrophes in developing nations, where disease outbreaks can be deadly.[10] Mosquito-borne and other vector-borne illnesses may also be increased when storms or floods create large amounts of standing water suitable for breeding.

Mental and emotional distress documented for children and adolescents after weather disasters include posttraumatic stress disorder and high rates of sleep disturbance, aggressive behavior, sadness, and substance use and/or abuse.[11] Some studies have suggested that children have more persistent symptoms than adults who experience the same disaster,[12] but more studies specific to children's experience are required.[13] Community support services[14] and early therapeutic intervention and postdisaster counseling[15,16] can significantly reduce the medium- and long-term mental health burden on children. Experiences with Hurricanes Katrina and Rita demonstrated the difficulties with tracking children's whereabouts, keeping children and caregivers together, and special needs of hospitalized infants and children during and after major natural disasters.

Infectious Diseases: Vector-borne infections are affected by climate change.[17] Both the hosts (eg, rodents, insects, snails) and the pathogens (eg, bacteria, viruses, parasites) can be sensitive to climatic variables such as temperature, humidity, and rainfall. The ability to predict disease rates related to climate change is complicated by a large number of additional variables such as topography, land use, urbanization, human population distribution, level of economic development, and public health infrastructure.[18] There is no easy formula that predicts climate change–related infection risk with confidence.

For example, malaria is a climate-sensitive vector-borne illness to which children are particularly vulnerable. Because they lack specific immunity, children experience disproportionately high levels of both sickness and death from malaria; 75% of malaria deaths occur in children younger than 5 years. The young are also more susceptible to cerebral malaria, which can lead to lifelong brain damage in those who survive. Climate change is expanding the range of host mosquitoes to higher altitudes and higher latitudes, and warmer temperatures speed the development of the parasite within the host vector.[19] Small children will be most affected by the expansion of malaria zones and the success or failure of societal response to this change.

Ambient Air Pollution: Children are especially vulnerable to both short-term illness and long-term damage from ambient air pollution, because their lungs are developing and growing, they breathe at a higher rate than adults, and they spend more time outdoors engaging in vigorous physical activity.[20] Air pollution (such as ozone and particulate matter) causes respiratory and asthma hospitalizations, school absences, increased respiratory symptoms, and decrements in lung function.[17] Formation of ozone, in particular, is known to increase with increasing temperature, even without increases in the precursor primary pollutants (volatile organic hydrocarbons and oxides of nitrogen).[21] Children who are active in outdoor sports in communities with high ozone are at increased risk of developing asthma.[22] In addition, high levels of particulate matter and other pollutants affect the ability of children's lungs to grow regardless of history of asthma.[23] Rates of preterm births, low birth weight, and infant mortality are increased in communities with high levels of particulate air pollution.[24]

A second change that is being observed is the temperature-related increases in pollen production and other allergens in some regions and some cities. Increased temperature causes increases in amounts of pollens produced by some plants[25] and can also affect spatial distribution and density of plants, fungi, and molds that produce allergens.[26] To the extent that exposure to allergens contributes to the incidence, prevalence, and severity of asthma, allergic reactions, and other respiratory disease, climate change will affect the pattern of disease in children. Some investigators have argued that part of the current global increase in childhood asthma can be explained by increased exposure to aeroallergens driven by climate change.[27]

Thermal Stress: For all organisms, there exists a range of ideal temperature above and below which mortality increases. Humans are no exception, although temperature-mortality relationships vary significantly by latitude, climatic zone, and level of socioeconomic development.[28] As ambient temperatures increase, the frequency of heat waves will increase. Populations that live in temperate climates, such as in the United States and Europe, are likely to be hard hit initially, because global warming is most dramatic in these latitudes and there has been little time for populations to acclimatize to changes in temperature.

Heat-related deaths and hospitalizations are most common in the elderly, especially if they are ill.[29,30] One study has found that infants and young children may represent a second, albeit smaller, higher-risk group,[31] but effects on children have not been studied adequately. In addition, children spend more time outside, especially playing sports in the heat of the afternoon, which puts them at increased risk of heat stroke and heat exhaustion.[32] Increased outdoor time during hot weather may also put children at increased risk of UV radiation–related skin damage, including skin cancer.[33]

Additional Long-Term and Indirect Impacts: Food availability may be affected as land and ocean food-productivity patterns shift.[34] Water availability may change and become much reduced in some regions, including during summer in the snow run-off–dependent American west coast.[35] Coastal populations could be forced to move because of rises in sea level, and massive forced migrations, driven by abrupt climate change, natural disaster, or political instability over resource availability, are conceivable.[36] In addition, world population is expected to grow by 50% to 9 billion by 2050, which would place additional stress on ecosystem services and increase the demand for energy, fresh water, and food.[37] As these changes evolve, social and political institutions will need to respond with aggressive mitigation strategies and flexible adaptation strategies to preserve and protect public health, particularly for children.

Recommendations

In addition to its recommendations to pediatricians for reducing their energy demands and incorporating sustainable practices into their personal and professional lives, the American Academy of Pediatrics calls upon government at all levels, from the smallest municipalities to the national and international levels, to implement aggressive policies to halt man-made contributions to climate change and to mitigate its impact on children's health. Policymakers should:

- Develop aggressive, long-term policies to reduce the major contributing factors to global climate change. For example, the Environmental Protection Agency should set the National Ambient Air Quality Standard for ozone at 0.060 parts per million.[38]

- Invest in prudent and vital preparations for our public health care systems, including immunization programs and disease surveillance, reporting, and tracking.
- Give specific attention to the needs of children in emergency management and disaster response.[39,40]
- Support education and public awareness of the threats from climate change and their implications for public and children's health now and in the future.
- Fund interdisciplinary research to develop, implement, and measure outcomes of innovative strategies to both mitigate and adapt to climate change, particularly in areas with direct implications for children's health.

In conclusion, the American Academy of Pediatrics commends you, Mr. Chairman, for holding this hearing today to call attention to the potential impacts of global climate change on children's health. We look forward to working with Congress to prevent the adverse impacts on child health caused by global climate change and to plan for those that may be unavoidable. I appreciate this opportunity to testify, and I will be pleased to answer any questions you may have.

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Ms. SOLIS. Thank you, and without objection we will receive your additional report information.

[The information follows:]

American Academy of Pediatrics
DEDICATED TO THE HEALTH OF ALL CHILDREN™

POLICY STATEMENT

Global Climate Change and Children's Health

Organizational Principles to Guide and Define the Child Health Care System and/or Improve the Health of All Children

Committee on Environmental Health

ABSTRACT

There is broad scientific consensus that Earth's climate is warming rapidly and at an accelerating rate. Human activities, primarily the burning of fossil fuels, are very likely (>90% probability) to be the main cause of this warming. Climate-sensitive changes in ecosystems are already being observed, and fundamental, potentially irreversible, ecological changes may occur in the coming decades. Conservative environmental estimates of the impact of climate changes that are already in process indicate that they will result in numerous health effects to children. The nature and extent of these changes will be greatly affected by actions taken or not taken now at the global level.

Physicians have written on the projected effects of climate change on public health, but little has been written specifically on anticipated effects of climate change on children's health. Children represent a particularly vulnerable group that is likely to suffer disproportionately from both direct and indirect adverse health effects of climate change. Pediatric health care professionals should understand these threats, anticipate their effects on children's health, and participate as children's advocates for strong mitigation and adaptation strategies now. Any solutions that address climate change must be developed within the context of overall sustainability (the use of resources by the current generation to meet current needs while ensuring that future generations will be able to meet their needs). Pediatric health care professionals can be leaders in a move away from a traditional focus on disease prevention to a broad, integrated focus on sustainability as synonymous with health.

This policy statement is supported by a technical report that examines in some depth the nature of the problem of climate change, likely effects on children's health as a result of climate change, and the critical importance of responding promptly and aggressively to reduce activities that are contributing to this change.

BACKGROUND

"Warming of the climate system is unequivocal."[1] According to the National Climatic Data Center, all records indicate that during the past century, global surface temperatures have increased at a rate near 0.6°C per century (1.1°F per century); this trend has been 3 times larger since 1976.[2] Human activity, particularly the burning of fossil fuels, has very likely (>90% probability) driven this rise by greatly increasing atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases (GHGs).[1]

There is strong consensus among expert scientists that Earth is undergoing rapid, global climate change,[1,3] although there remains uncertainty about how rapidly and extensively the climate will change in the future. Overall scientific predictions agree, however, that temperatures and sea level will continue to rise

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Key Words
climate change, global warming, child, pediatric, health, sustainable development

Abbreviation
GHG—greenhouse gas

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throughout the 21st century.[1,4] Even if GHG emissions were abruptly reduced to zero, the planet would continue to warm for decades until the energy stored in the system equilibrates.[5] The possibility of reaching a tipping point at which abrupt, large, and irreversible change could be superimposed on current trends adds both urgency and further ambiguity to the situation.[6] Current human activities are accelerating these changes, and future human activities will affect their trajectories; the window of opportunity for successful mitigation, therefore, may be very short.[7] Actions made in the coming decade will have a profound effect on global health and, in particular, on children's health.

DIRECT EFFECTS OF CLIMATE CHANGE ON CHILDREN'S HEALTH

Because of their physical, physiologic, and cognitive immaturity, children are often most vulnerable to adverse health effects from environmental hazards.[8] As the climate changes, environmental hazards may shift and possibly increase (Fig 1), and children are likely to suffer disproportionately from these changes.[9] Anticipated direct health consequences of climate change include injury and death from extreme weather events and natural disasters, increases in climate-sensitive infectious diseases, increases in air pollution–related illness, and more heat-related, potentially fatal, illness. Within all of these categories, children have increased vulnerability compared with other groups (see the accompanying technical report[10]).

INDIRECT EFFECTS OF CLIMATE CHANGE AND IMPLICATIONS FOR FUTURE GENERATIONS

Additional effects of climate change, with profound implications for the health and welfare of future generations of children, are anticipated. Food availability could be reduced as land and ocean food productivity patterns shift and species diversity declines.[11] Water availability will change and become too abundant in some regions (flooding) and much reduced in others (drought).[12] Coastal populations will be forced to move because of the rising sea level. Large-scale, forced migrations are conceivable, driven by abrupt climate change, natural disaster, or political instability over resource availability.[13]

The speed with which global GHG emissions can be reduced will have a significant effect on the rate and degree of warming, but even the most optimistic scenarios describe continued warming into the next century.[1,5] As climate change progresses, social and political institutions must respond with aggressive mitigation and flexible adaptation strategies to preserve and protect public health, particularly for children.

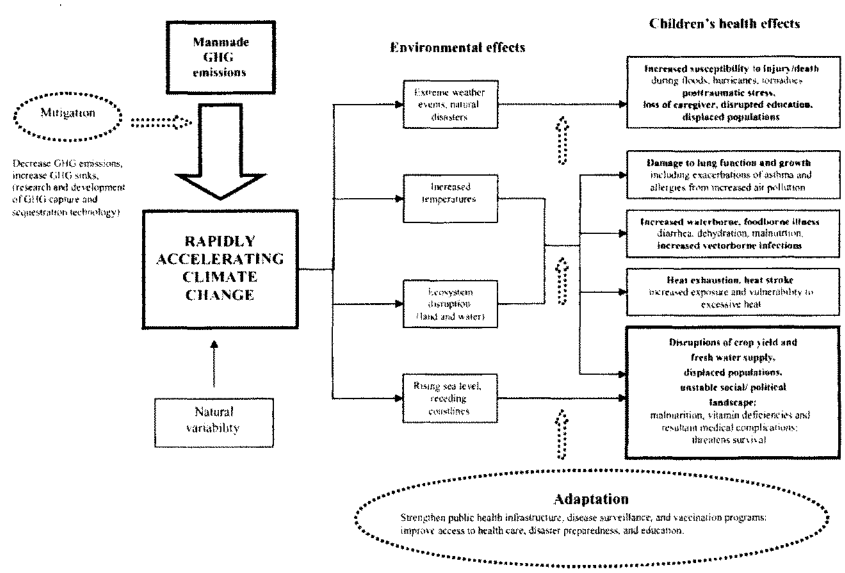

FIGURE 1
Potential effects of global climate change on child health. (Adapted from McMichael et al[14] and Haines and Patz[15].)

MITIGATION AND ADAPTATION STRATEGIES

Strategies to address the effects of climate change (mitigation and adaptation) are concepts that focus on both primary and secondary prevention strategies in pediatric health care (Fig 1). Mitigation (primary prevention) involves reducing GHG concentrations in the atmosphere with the goal of reducing climate change. Adaptation (secondary prevention) involves developing public health strategies to minimize and, in some cases, eliminate local and regional adverse health outcomes that are anticipated from climate change.

A wide variety of governmental and nongovernmental organizations have developed detailed lists of mitigation and adaptation strategies, from international conventions such as the Kyoto Protocol[14] to individual actions such as reducing automobile use.[15]

However, any solutions that address climate change must be developed within the context of overall sustainable development (the use of resources by the current generation to meet current needs while ensuring that future generations will be able to meet their needs). Given the health implications of climate change for current and future generations of children, the disease-prevention role for pediatric health care professionals includes advocating for environmental sustainability.

RECOMMENDATIONS TO PEDIATRICIANS

Pediatricians are dedicated to the promotion and protection of children's health. Climate change threatens the health, welfare, and future of current and subsequent generations of children. Pediatricians can incorporate considerations of the effects of climate change on health into their professional practice and personal lives in many ways, including patient education, lifestyle practices, and political advocacy. Some possible approaches might include the following.

1. Recognize and educate yourself about the links between child health and climate change. Existing anticipatory guidance already incorporates many issues that can help mitigate climate change. For example, encouraging families and children to walk or ride bicycles more may reduce automobile emissions.
2. Advocate for comprehensive local and national policies that address climate change to improve the health of children now and in the future. Educate elected officials on the health risks to children from climate change; write letters to the editor, attend public meetings, or provide expert testimony. Work with local schools, child care centers, community organizations, and businesses on projects that will help reduce GHGs. Support policies to expand parks and green spaces, strengthen public transport, improve sidewalks and bicycle lanes, and create local award systems for energy-efficient businesses, buildings, organizations, and households.
3. Serve as a role model for practices that promote environmental sustainability. Emphasize energy conservation in your workplace, encourage and model reduced dependency on automobile travel, and consider the environmental and energy costs when making major purchases for your practice or institution.
4. Help to build and support coalitions across disciplines and institutions to search for novel, comprehensive approaches to mitigate and adapt to climate change in your community and region. Work with local and state health departments to strengthen public health infrastructure, disease surveillance and reporting, and disaster preparedness.
5. Work to ensure that concepts related to the pediatric health implications of climate change are part of pediatric training and curricula.

RECOMMENDATIONS TO GOVERNMENT

Government at all levels, from the smallest municipalities to the national and international levels, should implement aggressive policies to halt man-made contributions to climate change and to mitigate its impact on children's health.

1. Develop aggressive, long-term policies to reduce the major contributing factors to global climate change.
2. Invest in prudent and vital preparations for our public health care systems, including immunization programs and disease surveillance, reporting, and tracking.
3. Give specific attention to the needs of children in emergency management and disaster response.[13,16]
4. Support education and public awareness of the threats from climate change and their implications for public and children's health now and in the future.
5. Fund interdisciplinary research to develop, implement, and measure outcomes of innovative strategies to both mitigate and adapt to climate change, particularly in areas with direct implications for children's health.

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Ms. SOLIS. Our next speaker, and our last speaker, is Dr. Mark Jacobson. Dr. Mark Jacobson is director of the Atmosphere and Energy Program and professor of civil and environmental engineering at Stanford University.

He has been at the forefront of developing models to better understand the effects of air pollutants on climate and air quality. In 2000, he discovered that black carbon, the main component of soot, may be the second leading cause of global warming, after carbon dioxide.

In 2001, he developed the first global through urban scale air pollution weather climate model. His latest publication is titled, "On the Causal Link Between Carbon Dioxide and Air Pollution Mortality."

Dr. Jacobson, welcome, and thank you for coming. You have 5 minutes.

STATEMENT OF MARK JACOBSON

Mr. JACOBSON. Thank you, Madam Chair. I would like to thank the committee for inviting me to testify today.

I will discuss scientific findings on the effects of carbon dioxide emitted during fossil fuel combustion on air pollution health in California, relative to the United States as a whole. I will then discuss how these findings compare with the two main assumptions made by Environmental Protection Agency administrator Stephen L. Johnson that formed the basis of his decision to deny California's request for a waiver of Clean Air Act preemption.

On March 6, 2008, EPA Administrator Johnson published a summary of his decision to deny the California Air Resources Board request for a waiver. The decision was made on two grounds.

First "Greenhouse gas emissions from California cars are not a causal factor for local ozone levels any more than greenhouse gas emissions from other sources of greenhouse gas emissions in the world," he says. And second, "While I find that the conditions related to global climate change in California are substantial, they are not sufficiently different from the conditions in the nation as a whole to justify separate state standards. These identified impacts are found to affect other parts of the United States, and therefore these effects are not sufficiently different compared to the nation as a whole."

These two issues are questions of scientific fact, which I will address here with results from a published study I performed, funded in part by the EPA, and subsequent analysis. The study began about 2 years ago, before the waiver issue became an issue, and before EPA funding commenced on the project.

It was also the culmination of research on the effects of climate change on air pollution that I started 8 years ago and of research on the causes and effects of air pollution that I started 18 years ago. I first examined the effects of temperature alone, and separately, water vapor alone, on ozone using an exact solution to a set of several hundred chemical equations in isolation.

The figure on the screen now shows the resulting ozone at low and high pollution levels. A comparison of the solid line, base temperature, with the dashed line, 1.8 degrees Fahrenheit or one degree Kelvin higher temperature, in the figure shows that the increase in temperature increases ozone when ozone is already high at all water vapor levels, but has little or no effect on ozone when ozone is low. The figure also shows that water vapor, the horizontal axis, independently increases ozone when ozone is high, but can slightly decrease ozone when ozone is low.

This result implies immediately that higher water vapor—sorry, higher temperatures and water vapor—should increase ozone where it is already high. It is also known that California has six of the 10 most polluted cities in the United States, with respect to ozone, including Los Angeles, Visalia, Bakersfield, Fresno, Merced, and Sacramento. So it is expected from this result alone that a warmer planet should increase ozone pollution in California more than in the U.S. as a whole.

The next step was to evaluate whether carbon dioxide could trigger the temperature and water vapor changes sufficient to effect ozone when many other processes are considered simultaneously, and to evaluate effects in California. For this, a three-dimensional global model of the atmosphere that focused at high resolution over the United States was used.

The next set of figures show differences in temperature, water vapor, and ozone over the United States due solely to historically emitted fossil fuel carbon dioxide from the simulation. Carbon dioxide increased near-surface temperatures and water vapor, and both sped back to increase near-surface ozone—the last figure shown—as expected from the previous analysis.

Carbon dioxide similarly increased particles in populated areas for several reasons described in the written testimony. The changes in ozone particles and carcinogens were combined with population and health effects data to estimate that carbon dioxide increased the annual U.S. air pollution death rate by about 1,000 per 1.8 degree Fahrenheit, or one degree Kelvin, with about 40 percent of these increased deaths due to ozone.

These annual additional deaths are occurring today, as historic temperatures are about 1.5 degrees Fahrenheit, or 0.85 Kelvin, higher than in pre-industrial times. Of the additional deaths, more than 30 percent occurred in California, which has only 12 percent of the U.S. population. As such, the death rate per capita in California was over 2.5 times the national average death rate per capita due to carbon dioxide-induced air pollution.

A simple extrapolation from U.S. to world population gives about 21,600—there is an error bar—deaths per year worldwide, per one degree Kelvin or 1.8 degree Fahrenheit, due to carbon dioxide. Carbon dioxide increased carcinogens as well, but the increase was relatively small.

Next, let us examine the effects of controlling California's carbon dioxide as if its local emissions instantaneously mixed globally, which it does not. In such a case, controlling local carbon dioxide in California still reduces the air pollution-related death and illness rate in California at a rate 2.5 times greater, per capita, than it reduces the death rate in the U.S. as a whole.

However, carbon dioxide emissions do not immediately mix globally. Instead, carbon dioxide levels in polluted cities are much higher than in the global average, as shown with data in the figure now on the screen. This is from Salt Lake City, Utah. Although the global background carbon dioxide is currently about 385 parts per million, the data indicate that a medium-sized city's downtown area can have an average of 420 to 440 parts per million of carbon dioxide, and a peak over 500 parts per million of carbon dioxide.

The figure now on the screen—this is almost done here—show computer simulations of carbon dioxide effects in California for a month of August, due solely to local carbon dioxide emissions. The elevated carbon dioxide over the urban areas is consistent with the expectations from the data.

The increases in local carbon dioxide led to increases in water vapor and ozone over California. Since carbon dioxide emissions outside of the grids shown were not perturbed for the simulations, the simulations demonstrate that the effects on ozone found here were due solely to locally emitted carbon dioxide. In sum, locally emitted carbon dioxide is a fundamental causal factor of air pollution in California.

The final slide here demonstrates compares modeled and measured parameters over each hour of a month and demonstrates the ability of the computer model used here to simulate the weather at specific times and locations.

In conclusion, this analysis finds the following:

Global warming due specifically to carbon dioxide currently increases the air pollution death rate of people in California more than it increases the death rate of people in the United States as a whole, relative to the respective population. The reason is that higher temperatures and water vapor due to carbon dioxide increased pollution the most where it is already high, and California has six of the 10 most polluted cities in the U.S. The deaths are currently occurring and will increase in the future.

Controlling carbon dioxide from California will reduce the air pollution-related death rate and illness rate in California 2.5 times faster than it will reduce the death rate of the U.S. as a whole.

And finally, carbon dioxide levels in cities are higher than in the global atmosphere. Such elevated levels of CO_2 were found to increase ozone in California. As such, locally emitted carbon dioxide is a causal factor in increasing air pollution.

These results contradict the main assumptions made by Mr. Johnson in his stated decision, namely, there is no difference in the impact of globally emitted carbon dioxide in California vs. the U.S. health, and locally emitted carbon dioxide does not affect California's air pollution any more than carbon dioxide–than anywhere else in the world. I am unaware of any scientific publication that supports either assumption.

Thank you.

[The statement of Mr. Jacobson follows:]

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Testimony for the Hearing,
"Healthy Planet, Healthy People: Global Warming and Public Health"
Select Committee on Energy Independence and Global Warming
United States House of Representatives
The Honorable Ed Markey, Chair
The Honorable F. James Sensenbrenner Jr., Ranking Member
April 9, 2008, 10:00 a.m.

By Mark Z. Jacobson

I would like to thank the Honorable Chairman and Ranking Member and the committee for inviting me to testify today. I will discuss scientific findings on the effects of carbon dioxide, emitted during fossil-fuel combustion in California, the U.S., and the world, on air pollution and health in California relative to the U.S.. I will then discuss how these scientific findings differ from the two main assumptions made by Environmental Protection Agency (EPA) Administrator Stephen L. Johnson that formed the basis of his decision to deny California's request for a waiver of Clean Air Act Preemption on March 6, 2008 (Johnson, 2008). These assumptions were (a) there is no difference in the impact of globally-emitted carbon dioxide on California versus U.S. health and (b) locally-emitted carbon dioxide does not affect California's air pollution any more than does carbon dioxide emitted anywhere else in the world.

Summary

On March 6, 2008, EPA Administrator Stephen L. Johnson published a summary of his decision to deny the California Air Resources Board request for "a waiver of the Clean Air Act's Prohibition on adopting and enforcing its greenhouse gas emission standards as they affect 2009 and later model year new motor vehicles" (Johnson, 2008). The decision was made following consideration of two issues:

> "The appropriate criteria to apply therefore is whether the emissions of California motor vehicles, as well as California's local climate and topography, are the fundamental causal factors for the air pollution problem of elevated concentrations of greenhouse gases, and in the alternative whether the effect in California of this global air pollution problem amounts to compelling and extraordinary conditions (Johnson, 2008, p. 12162)."

With regard to the first issue, Mr. Johnson decided that

> "GHG (greenhouse gas) emissions from California cars are not a causal factor for local ozone levels any more than GHG emissions from other sources of GHG emissions in the world (Johnson, 2008, p. 12163)."

In other words, Mr. Johnson believes that because GHGs emitted in California eventually mix globally, California's GHG emissions do not affect California ozone any more than another state or country's GHG emissions affect California's ozone. With regard to the second issue, Mr. Johnson ruled,

> "While I find that the conditions related to global climate change in California are substantial, they are not sufficiently different from conditions in the nation as a whole to justify separate state standards. As the discussion above indicates, global climate change has affected and is expected to affect, the nation, indeed the whole world, in ways very similar to the conditions noted in California. While proponents of the waiver claim that no other state experiences the impacts in combination as does California, the more appropriate comparison in this case is California compared to the nation as a whole, focusing on averages and extremes, and not a comparison of California to the other states individually. These identified impacts are found to affect other parts of the United States and therefore these effects are not sufficiently different compared to the nation as a whole. (Johnson, 2008, p. 12168).

The two questions raised by Mr. Johnson are questions of scientific fact. Because no publicly-available scientific paper(s) on these specific issues (namely the effects of global carbon dioxide on California versus U.S. air pollution health and the effects of California versus global carbon dioxide emissions on California air pollution health), were available prior to 2008 and no such study was cited in Johnson (2008), it appears reasonable to conclude that Mr. Johnson made his decision based on his own assumption that what he stated was scientific fact. The appearance that the decision was made on his assumption rather than scientific information is relevant since Johnson (2008, p. 12159) states, "As the court in MEMA I stated, 'here, too, if the Administrator ignores evidence demonstrating that the waiver should not be granted, or if he seeks to overcome that evidence with unsupported assumptions of his own, he runs the risk of having his waiver decision set aside as 'arbitrary and capricious.'"

The purpose of this document is to address the questions Mr. Johnson raised from a scientific approach. In particular, I report results from a recent peer-reviewed scientific study submitted for publication on June 22, 2007 and published on February 12, 2008 (Jacobson, 2008) and funded in part by the EPA, additional analysis of data from that study, and results from a follow up study that have not yet been published. Research published in this paper commenced about two years ago, before the waiver question became an issue and before EPA funding commenced on the project. It was also the culmination of research on the effect of climate change on air pollution that I started eight years ago and of research on the causes and effects of air pollution that I started 18 years ago.

Results from the studies and analyses are as follows

(a) Global warming due specifically to carbon dioxide currently increases the air-pollution-related death rate of people in California more than it increases the death rate of people in the United States as a whole, relative to their respective populations. Specifically, for every 1 degree Celsius (1.8 degrees Fahrenheit) temperature rise due to carbon dioxide, the U.S. death rate due to ozone and particle pollution increases above the baseline air pollution death rate of about 50,000-100,000 per year by approximately 1000 (350-1800) per year. Of these additional deaths, more than 30% occur in California, Since California has only 12 percent of the U.S. population, California suffers disproportionately (2.5 times) more deaths per person than the U.S. as a whole due to carbon-dioxide-induced global warming. The reason is that higher temperatures and water vapor due to carbon dioxide increase pollution the most where it is already high (Jacobson, 2008), and California has six of the ten most-polluted cities in the United States. The deaths are currently occurring and will occur more as temperatures increase in the future.

(b) Any emissions of carbon dioxide, whether in California or elsewhere, increase air pollution health problems in California at a rate 2.5 times higher than in the United States as a whole, even if the carbon dioxide becomes well-mixed in the atmosphere immediately after emissions, which it does not. Conversely, controlling carbon dioxide from California will reduce the air-pollution-related death and illness rate in California at a rate 2.5 times faster than it will reduce the death rate of the U.S. as a whole.

(c) Emissions of carbon dioxide do not mix immediately to the global atmosphere. Instead, carbon dioxide mixing ratios in polluted cites are higher than are those in surrounding areas. Although carbon dioxide in cities disperses to the global atmosphere, their continuous emissions from vehicles and power plants keep their levels high over cities. It is shown here that such elevated levels of carbon dioxide increase air pollution, particularly ozone. As such, locally-emitted carbon dioxide is a causal factor in increasing local air pollution.

The three conclusions here – that (a) carbon-dioxide-induced global warming increases air pollution health problems more in California per capita than it does in the U.S. as a whole, (b) controlling California carbon dioxide emissions will decrease the California death rate at more than 2.5 more per capita than it will decrease the death rate of the U.S. as a whole, and (c) local carbon dioxide emissions from vehicles in California causally increase local air pollution and health problems in California contradict both assumptions made by Mr. Johnson in his stated decision, namely (a) there is no difference in the impact of globally-emitted carbon dioxide on California versus U.S. health and (b) locally-emitted carbon dioxide does not affect California's air pollution any more than does carbon dioxide emitted anywhere else in the world.

Discussion

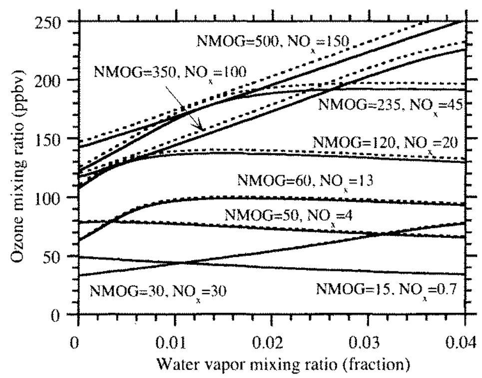
The effects of carbon dioxide on air pollution and the resulting effects on health can be determined only from large-scale computer model simulations, where the model treats the physics, chemistry, and meteorology of the atmosphere and has been evaluated thoroughly. Data measured in the atmosphere (e.g., from surface measurements, radiosonde, aircraft, satellite) can be used to show correlation only, not cause and effect. As such, it is not possible to use data alone to answer the question of the effects of carbon dioxide on air pollution. A computer model can show cause and effect when one input parameter at a time is changed. In the present case, the input parameter is carbon dioxide, and the goal is to determine the effect of carbon dioxide emissions on air pollution-related health problems in California and the United States.

Prior to 2008, many computer modeling studies had examined the sensitivity of near-surface ozone to temperature (Sillman and Samson, 1995; Zhang et al., 1998), the regional or global effects of climate change from all greenhouse gases on near-surface ozone (Thompson et al., 1989; Evans et al., 1998; Dvortsov et al., 2001; Mickley et al., 2004; Stevenson et al., 2005; Brasseur et al., 2006 Murazaki and Hess, 2006; Steiner et al., 2006; Racherla and Adams, 2006) or near-surface aerosol particles (Aw and Kleeman, 2003; Liao et al., 2006; Unger et al., 2006), and the effects of future global warming on regional ozone-related health problems (Knowlton et al., 2004; Bell et al., 2007). These studies generally found that higher temperatures increased ozone. However, no study had isolated the effect of carbon dioxide alone, emitted to date, on ozone, particles, or carcinogens, applied population and health data to the pollution changes over the U.S. as a whole, or examined the problem with a global-through-regional climate/air pollution model that treated feedback of gases and particles to clouds and meteorology. Jacobson (2008) performed a study accounting for these factors. The study used the computer model GATOR-GCMOM, which is a model developed over the last 18 years. It is described by Zhang (2008) as the first and still only unified, consistent global-to-urban scale air-quality-climate model worldwide and the "first fully-coupled online model to account for all major feedbacks among major atmospheric processes based on first principles (p. 1844)." As such, it was the most appropriate model for the type of study described here. The model had been evaluated against data in several published papers (e.g., Jacobson, 2001, 2004, 2007).

The model was first used to examine the effects of temperature alone and, separately, water vapor alone on ozone due to chemical reactions in the atmosphere. For this calculation, an exact numerical solver of chemical equations was used. No other process aside from photochemistry was solved. Figure 1 shows the resulting ozone predictions for a variety of initial levels of oxides of nitrogen (NO_x) and nonmethane organic gases (NMOGs). **A comparison of the solid lines (base temperature) with the dashed lines (higher temperature) in the figure**

shows that a 1 degree Kelvin or Celsius (= 1.8 degrees Fahrenheit) increase in temperature increases ozone when ozone is already high but has little or no effect on ozone when ozone is low. The figure also shows that water vapor (horizontal axis) independently increases ozone when ozone is high but generally has little effect or slightly decreases ozone when ozone is low.

Figure 1. Mixing ratio of ozone and several other gases as a function of water vapor mixing ratio after 12 hours of a box-model chemistry-only simulation initialized at 0430 under several NO_x and nonmethane organic gas (NMOG) mixing ratio combinations (ppbv) at 298.15 K (solid lines) and 299.15 K (dashed lines). The simulations assumed sinusoidally varying photolysis between 0600 and 1800.



The next step was to apply the numerical solution to chemical equations with solutions to equations for meteorological, aerosol microphysical, cloud, radiative, ocean, and surface processes within GATOR-GCMOM to examine the effect of carbon dioxide on ozone, particulate matter, and carcinogens. For this calculation, the model was set up in 'nested' mode whereby a high-resolution regional grid over the United States was fit within a coarser-resolved global grid. Both grids were three-dimensional and consisted of vertically-stacked layers of horizontally-adjacent boxes. Predicted meteorological, gas and aerosol variables from the global grid fed into the regional grid at the latter's boundaries. As such, it was possible to simulate the current global climate and the global climate with preindustrial levels of carbon dioxide emissions in both grids simultaneously and have the global-scale climate and air pollution variables from the global grid feed into the regional grid. Emissions for the simulations were spatially distributed. Thus, separate emissions occurred in each surface grid box in both grids.

Figures 2 shows results over the U.S. after taking the difference between the two simulations (e.g., one simulating present-day climate/air pollution and another simulating climate/air pollution at preindustrial carbon dioxide emission levels). It shows that human-emitted carbon dioxide caused an increase in near-surface temperatures and water vapor (Figures 2a,b). Increases in both thereby increased near-surface ozone (Figure 2c), as expected from Figure 1.

More specifically, Figure 2c indicates that carbon dioxide increased ozone by 0.12 ppbv over the U.S., with increases of 1-5 ppbv in the southeast and up to 2 ppbv along the northeast coast. In Los Angeles, the average temperature increase of 0.75 K (Figure 2a) and water vapor increase of 1.3 ppthv increased ozone by up to 5 ppbv.

Figure 2. Four-month (mid-July to mid-November) grid-averaged near-surface differences in (a) temperature, (b) water vapor, and (c) ozone between the present-day and preindustrial-carbon dioxide simulations. The grid-averaged (over land and water) change for each surface plot is given in parentheses.

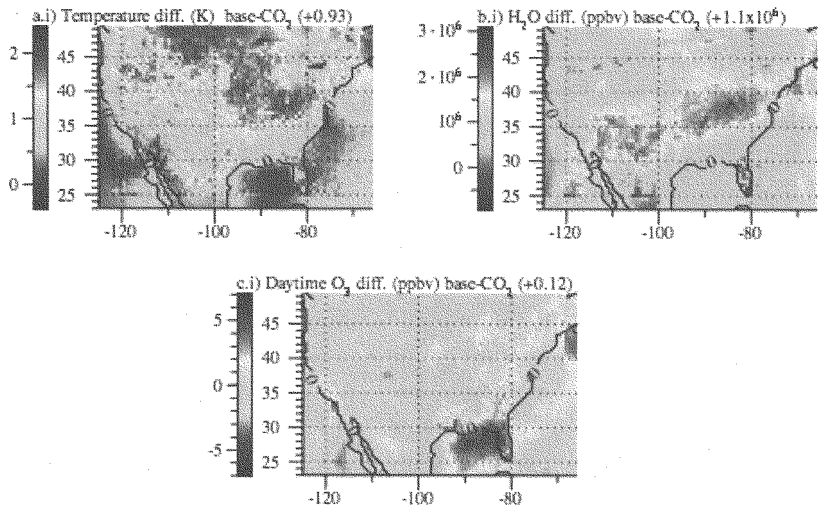


Table 1 indicates that the population-weighted ozone increase due to carbon dioxide was +0.72 ppbv, which compares with the land-averaged increase of 0.12 ppbv (Figure 2c), indicating a greater ozone increase over populated areas than less-populated areas. This result supports the hypothesis from the chemistry-only calculation that higher temperatures and water vapor due to carbon dioxide increase ozone the most where ozone is already high.

Carbon dioxide similarly increased particles in populated areas (Table 1) by warming the air more than the ground, decreasing vertical and horizontal pollution dispersion, increasing particle buildup near sources. The water vapor increase due to carbon dioxide also increased the relative humidity, swelling aerosol particles, increasing absorption of these particles by other gases, increasing the size of these particles. Carbon dioxide warming also increased land precipitation increasing aerosol removal, offsetting some of the increases in particle mass due to other processes, but not nearly enough to cause a decrease in particle levels.

The spatially-resolved changes in ozone, particles, and carcinogens (benzene, butadiene, formaldehyde, acetaldehyde) from Figure 2 and similar results were combined with population and health-effects data to produce estimates of the U.S. health effect changes due to enhanced air pollution from anthropogenic carbon dioxide. Table 1 provides resulting statistics. Mortality increases due to carbon dioxide were +415 (+207 to +620)/yr for ozone and +640 (+160 to +1280)/yr for particles per 1.07 K (Table 1) or a total of near +1000 (+350 to +1800) per 1.00 K (a 1.1% increase relative to the baseline death rate - Table 1), with about 40% due to ozone.

A simple extrapolation from U.S. to world population (301.5 to 6600 million) gives 21,600 (7400-39,000) deaths/yr worldwide per 1 K due to carbon dioxide above the baseline air pollution death rate (2.2 million/yr). The ozone portion of this (8,500 deaths/yr) is conservative compared with 15,500 deaths/yr, calculated from *West et al.* (2006), who examined the global health effects of ozone changes, but with a lower threshold for ozone health effects (25 ppbv versus 35 ppbv here).

Carbon dioxide increased carcinogens, but the increase was small. Isoprene increases due to higher temperatures increased formaldehyde and acetaldehyde. Reduced dispersion increased exposure to these carcinogens as well as benzene and 1,3-butadiene.

Table 1. Summary of CO_2's effects on cancer, ozone mortality, ozone hospitalization, ozone emergency-room (ER) visits, and particulate-matter mortality. Results are shown for the present-day ("Base") and present-day minus preindustrial ("no-fCO_2") 3-D simulations. All mixing ratios and concentrations are near-surface values averaged over four months (mid-July to mid-November) and weighted by population (!). Divide the last column by 1.07 K (the population-weighted CO_2-induced temperature change from Table S4) to obtain the health effect per 1 K.

	Base	Base minus no fCO_2
Carcinogens		
Formaldehyde (ppbv)	3.61	+0.22
Acetaldehyde (ppbv)	2.28	+0.203
1,3-Butadiene (ppbv)	0.254	+0.00823
Benzene (ppbv)	0.479	+0.0207
USEPA cancers/yr+	389	+23
OEHHA cancers/yr+	789	+33
Ozone		
8-hr ozone (ppbv) in areas ≥35 ppbv%	42.3	+0.724
Pop (mil.) exposed in areas ≥35 ppbv#	184.8	184.8
High ozone deaths/yr*	6230	+620
Med. ozone deaths/yr*	4160	+415
Low ozone deaths/yr*	2080	+207
Ozone hospitalizations/yr*	24,100	+2400
Ozone ER visits/yr*	21,500	+2160
Particulate matter		
PM2.5 ($\mu g/m^3$) in areas > 0 $\mu g/m^3$$	16.1	+0.065
Pop (mil.) exposed in areas ≥ 0 $\mu g/m^3$	301.5	301.5
High PM2.5 deaths/yr^	191,000	+1280
Medium PM2.5 deaths/yr^	97,000	+640
Low PM2.5 deaths/yr^	24,500	+160

(!) A population-weighted value is defined in the footnote to Table S4.

(+) USEPA and OEHHA cancers/yr were found by summing the product of individual CUREs (cancer unit risk estimates=increased 70-year cancer risk per $\mu g/m^3$ sustained concentration change) by the population-weighted mixing ratio or mixing ratio difference of a carcinogen, by the population, and air density, over all carcinogens, then dividing by 70 yr. USEPA CURES are 1.3×10^{-5} (formaldehyde), 2.2×10^{-6} (acetaldehyde), 3.0×10^{-5} (butadiene), 5.0×10^{-6} (=average of 2.2×10^{-6} and 7.8×10^{-6}) (benzene) (www.epa.gov/IRIS/). OEHHA CUREs are 6.0×10^{-6} (formaldehyde), 2.7×10^{-6} (acetaldehyde), 1.7×10^{-4} (butadiene), 2.9×10^{-5} (benzene) (www.oehha.ca.gov/risk/ChemicalDB/index.asp).

(%) 8-hr ozone ≥35 ppbv is the highest 8-hour-averaged ozone during each day, averaged over all days of the four-month simulation in areas where this value ≥35 ppbv in the base case. When base O_3>35 ppbv and no-fCO_2 O_3<35 ppbv, the mixing ratio difference was base O_3 minus 35 ppbv.

(#) The 2007 population exposed to ≥35 ppbv O_3 is the population exposed to a four-month-averaged 8-hour averaged ozone mixing ratio above 35 ppbv and was determined from the base case.

(*) High, medium, and low deaths/yr, hospitalizations/yr, and emergency-room (ER) visits/yr due to short-term O_3 exposure were obtained from Eq. 2 applied to each model cell, summed over all cells. The baseline 2003 U.S. death rate (y_0) was 833 deaths/yr per 100,000 [*Hoyert et al.*, 2006]. The baseline 2002 hospitalization rate due to respiratory problems was 1189 per 100,000 [*Merrill and Elixhauser*, 2005]. The baseline 1999 all-age emergency-room visit rate for asthma was 732 per 100,000 [*Mannino et al.*, 2002]. These rates were assumed to be the same in each U.S. county although they vary slightly by county. The fraction increases (β) in the number of deaths from all causes due to ozone were 0.006, 0.004, and 0.002 per 10 ppbv increase in daily 1-hr maximum ozone [*Ostro et al.*, 2006]. These were multiplied by 1.33 to convert the risk associated with 10 ppbv increase in 1-hr maximum O_3 to that associated with a 10 ppbv increase in 8-hour average O_3 [*Thurston and Ito*, 2001]. The central value of the increased risk of hospitalization due to respiratory disease was 1.65% per 10 ppbv increase in 1-hour maximum O_3 (2.19% per 10 ppbv increase in 8-hour average O_3), and that for all-age ER visits for asthma was 2.4% per 10 ppbv increase in 1-hour O_3 [*Ostro et al.*, 2006] (3.2% per 10 ppbv increase in 8-hour O_3). All values were reduced by 45% to account for the mid-July to mid-November and year-around O_3 >35 ppbv ratio, obtained from detailed observations [*H. Tran, pers. comm.*].

($) This is the simulated 24-hr $PM_{2.5}$, averaged over four months, in locations where $PM_{2.5} \geq 0$ $\mu g/m^3$.

(^) The death rate due to long-term $PM_{2.5}$ exposure was calculated from Eq. 2. *Pope et al.*, [2002] provide increased dearth risks to those ≥30 years of 0.008 (high), 0.004 (medium), and 0.001 (low) per 1 $\mu g/m^3$ $PM_{2.5}$ >8 $\mu g/m^3$ based on 1979-1983 data. From 0-8 $\mu g/m^3$, the increased risks were conservatively but arbitrarily assumed =¼ those >8 $\mu g/m^3$ to account for reduced risk near zero $PM_{2.5}$. Assuming a higher risk would strengthen the conclusion found here. The all-cause 2003 U.S. death rate of those ≥30 years was 809.7 deaths/yr per 100,000 total population. No scaling of results from the 4-month model period to the annual average was performed to be conservative, since $PM_{2.5}$ concentrations from July-November are lower than in the annual average based on California data [*H. Tran, pers. comm.*].

Impacts of Carbon Dioxide on California Versus U.S. Air Pollution Health

In sum, Jacobson (2008) showed by cause and effect that carbon dioxide emitted regionally around the global increases ozone, particle, and carcinogen air pollution health problems in the United States. The study also found that pollution increases the most where air pollution is already high. Subsequently, data from the study have been extracted to calculate the portion of air pollution health problems that occurred in California. The result was that, of the additional 1000 (+350 to +1800) deaths per year in the United States due to carbon dioxide, more than 30% (>300) occurred in California, which has only 12% of the U.S. population. As such, the death rate per capita in California was over 2.5 times the national average death rate per capita due to carbon dioxide-induced air pollution. This result is not a surprise since 6 of the 10 most polluted cities in the United States, with respect to photochemical smog, are in California: Los Angeles, Visalia-Porterville, Bakersfield, Fresno, Merced, and Sacramento (e.g., www.citymayors.com/environment/polluted_uscities.html).

The disproportionate effect of carbon-dioxide-induced global warming on California compared with the rest of the United States found in this analysis contradicts a major assumption by Mr. Johnson in his decision to deny California a waiver, namely that there is no difference in the impact of globally-emitted carbon dioxide on health in California versus the U.S. as a whole. (Johnson, 2008, p. 12168).

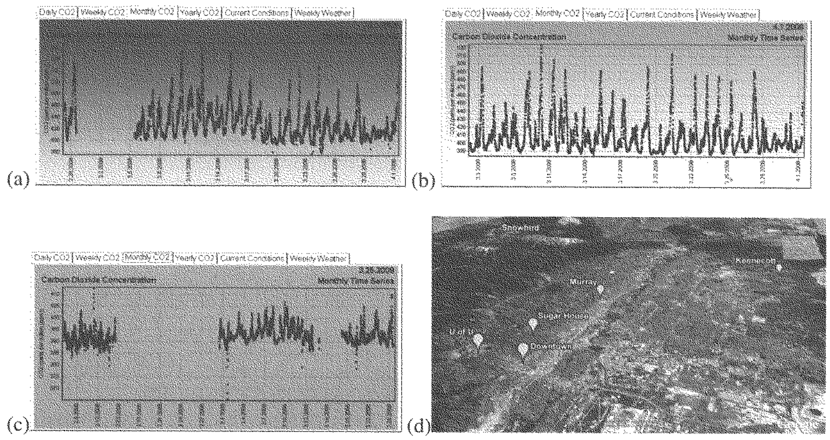
Impacts of California-Emitted Carbon Dioxide on California Health.

The results from Jacobson (2008) and the subsequent analysis of the disproportionate death rate in California versus the U.S. as a whole due to carbon dioxide provide further insight into the effect of locally-emitted carbon dioxide on local California air pollution health.

First, let's examine the effect of carbon dioxide as if local emissions were instantaneously mixed globally, which is not the case in reality. In such a case, the carbon dioxide emitted from California or the United States has the effect of increasing the death rate more in California than the rest the United States because increases in global-scale carbon dioxide increase air pollution health problems more per capita in California than in the United States as a whole (analysis above). As such, controlling local carbon dioxide in California alone would reduce the air-pollution-related death and illness rate in California at a rate 2.5 times greater per capita than it would reduce such rates in the U.S. as a whole.

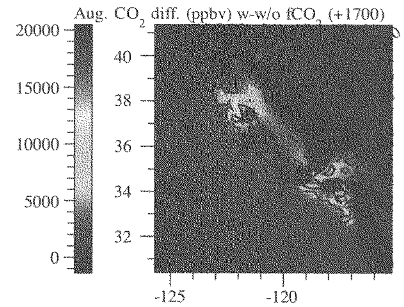
The above discussion assumed that carbon dioxide emissions mix quickly to the global atmosphere, as Mr. Johnson assumed in his waiver denial (Johnson, 2008, p. 12160). However, emissions of carbon dioxide do not mix immediately to the global atmosphere. Instead, carbon dioxide mixing ratios in polluted cites are much higher than are those in surrounding areas, as shown with data in Figure 3. Although the global background mixing ratio of carbon dioxide is currently about 385 ppmv (http://www.esrl.noaa.gov/gmd/ccgg/trends/), the data in Figure 3 indicate that the average mixing ratios in a medium-sized city's downtown area (Fig. 3a) or nearby (Fig. 3b) can be 420-440 ppmv and can peak at over 500 ppmv. Even just outside of a city, mixing ratios can average about 395 ppmv (Fig. 3c).

Figure 3. Measured mixing ratios (ppmv) of carbon dioxide in (a) downtown Salt Lake City, (b) the Sugar House monitoring site in Salt Lake City, and the Kennecott monitoring site in Salt Lake City over a month or more preceding April 1, 2008. (d) Map of the locations. Data and maps from the Ehleringer Lab at the University of Utah (http://co2.utah.edu).

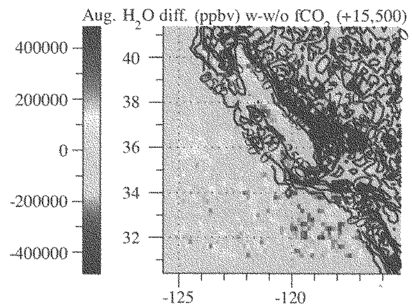


Although carbon dioxide in cities disperses to the global atmosphere, its continuous emissions from vehicles, power plants, and other sources keep its levels high over cities. It is shown here that such elevated levels of carbon dioxide can increase ozone. Figure 4a shows the computer-modeled changes in carbon dioxide in California for the month of August when simulations with and without carbon dioxide emissions were run. The elevated carbon dioxide over the urban areas (Los Angeles, San Francisco, Central Valley) is consistent with the expectations of elevated carbon dioxide in a city, as determined from data (e.g., Figure 3). It should be noted that the model grid cells for the simulations had resolution of around 15 km. A more highly-resolved domain results in higher peaks in carbon dioxide. For example, with a 5 km domain, the peak carbon dioxide above the background in Los Angeles is about 90 ppmv.

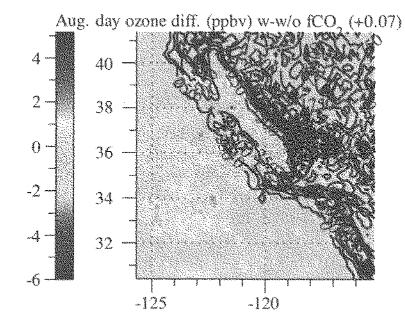
Figure 4. Modeled difference in the mixing ratios (all ppbv) of (a) carbon dioxide, (b) water vapor, and (c) daytime ozone in California during August when two simulations were run: one with fossil-fuel emissions of carbon dioxide (fCO_2) and one without such emissions. For both simulations, two nested grids were used: a global and California grid. Initial ambient levels of carbon dioxide were the same in both simulations on the California grid. Both emissions and ambient levels of carbon dioxide were the same in the global and grids in both simulations in order to ensure that local effects of carbon dioxide in California were isolated. This differs from Jacobson (2008), where both ambient and emission levels of carbon dioxide were set to preindustrial values in all grids to test whether global and local carbon dioxide would impact local pollution. The numbers in parentheses are average changes over all land points in the figure.



a)



b)



c)

Figure 4b shows that the increases in carbon dioxide in California led to an increase in water vapor, and this resulted in a net increase in ozone over all land in California, with increases in the Central Valley of up to 2 ppbv and in Los Angeles of up to 4-5 ppbv. These changes compare with polluted-air mixing ratio of above 100 ppbv and California-average daytime ozone mixing ratios in August of around 55 ppbv. Decreases also occurred in some location, but ozone increased on average over land (Figure 4c). The increases should be larger over a longer simulation period as the carbon dioxide changes from Figure 4a spread to a greater extent horizontally and vertically over California. Nevertheless, since carbon dioxide emissions outside of the grids shown were not perturbed for the simulations, the simulations during the limited time simulated demonstrate that the effects on ozone found here were due solely to locally-emitted carbon dioxide. The figures thus demonstrate by cause and effect (since carbon dioxide emission in California was the only variable changed) that increases in locally-emitted carbon dioxide increase local ozone in California.

In sum, locally-emitted carbon dioxide is a fundamental causal factor of air pollution in California. This result contrasts with Mr. Johnson's assumption that "GHG emissions from California cars are not a causal factor for local ozone levels any more than GHG emissions from other sources of GHG emissions in the world (Johnson, 2008, p. 12163)."

Conclusions

This analysis finds the following:

1) Globally-emitted carbon dioxide increases air pollution-related mortality and other health problems in California at a rate at least 2.5 times that of the United States as a whole. The main reason is that higher temperatures and water vapor due to carbon dioxide increase pollution the most where pollution is already bad, and California has the highest levels of air pollution in the United States.

2) If emitted carbon dioxide were mixed instantaneously to the globe, which it doesn't, a decrease in California-emitted carbon dioxide would decrease the local air pollution death rate in California by at least a factor of 2.5 times more than it would decrease the death rate of the U.S. as a whole. Similarly, decreases in U.S.-emitted carbon dioxide would decrease the air pollution death rate in California at a rate at least 2.5 times higher than it would decrease the death rate of the U.S. as a whole.

3) Continuous local carbon dioxide emissions cause an increase in local outdoor carbon dioxide relative to the global average, particularly in cities. The higher carbon dioxide in cities, increasing ozone. As such, carbon dioxide is a fundamental causal factor of local air pollution.

4) Scientific findings 1-3 contradict the two assumptions that served as the basis for Mr. Johnson's decision to deny California a waiver – namely that (a) there is no difference in the impact of globally-emitted carbon dioxide on California versus U.S. health and (b) the effect of locally-emitted carbon dioxide emissions on California air pollution is no greater than the effect of U.S. or worldwide carbon dioxide emissions on California air pollution. I am unaware of any scientific publication or unpublished study that supports either assumption.

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Climate Change Effects on Air Pollution

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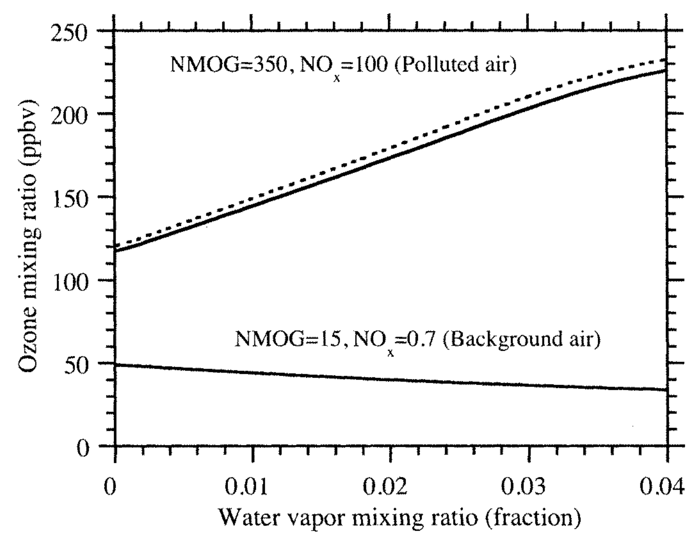
Select Committee on Energy Independence and Global Warming
United States House of Representatives
April 9, 2008

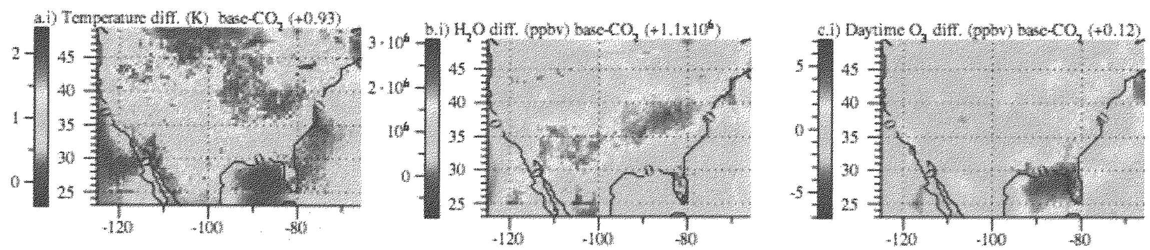
Increases in Water Vapor and Temperature Both Increase Ground-Level Ozone in Polluted Air But Not in Clean Air



→ Global warming increases ozone where it is already high – in polluted cities. California has the most polluted U.S. cities.

Effect of CO_2 to Date on Air Pollution

CO_2 alone increases temperature, H_2O, ozone, particles



Δ Temperature Δ Water vapor Δ Ozone

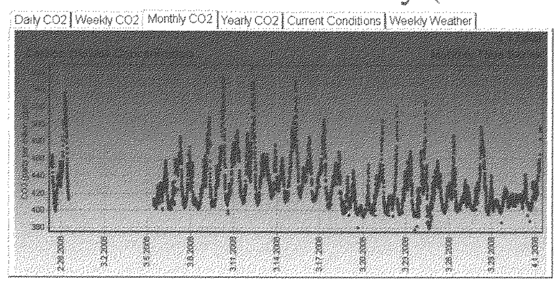
Additional U.S. pollution deaths/yr per 1.8 °F (1 K) +1000 (350-1800)

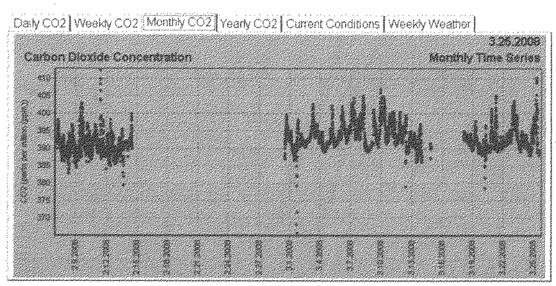
40% due to ozone; 60% due to aerosol particles

Additional world deaths/yr per 1.8 °F (1 K) +21,600 (7400-39,000)

High Measured CO_2 in a City

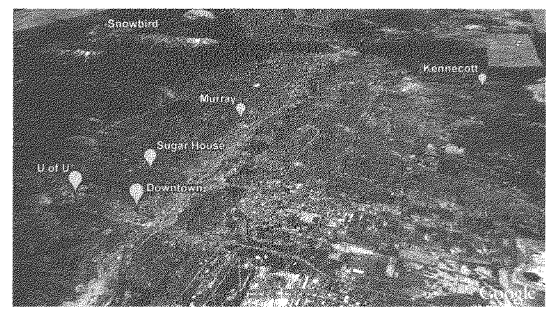
Downtown Salt Lake City (420-440 ppmv)





Kennecott (390-395 ppmv)

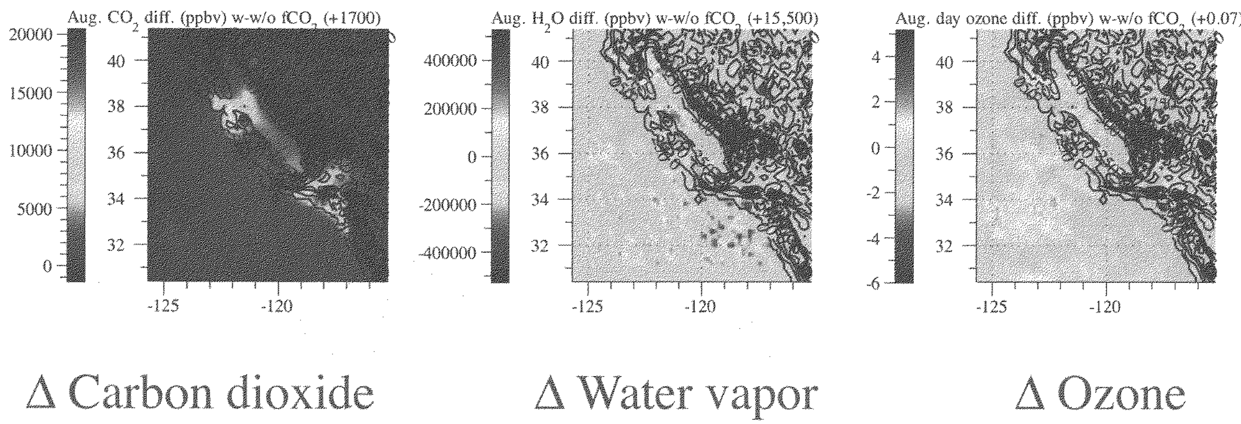
Salt Lake City



Global background 385 ppmv

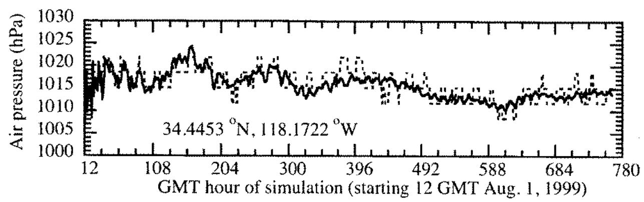
http://co2.utah.edu/

Locally-Emitted Carbon Dioxide Increases Local Ozone in California



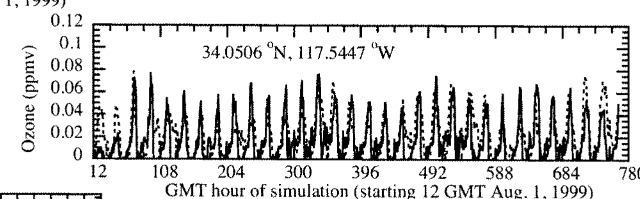
Carbon dioxide in cities is higher than in the background air, triggering local increases in water vapor and ozone.

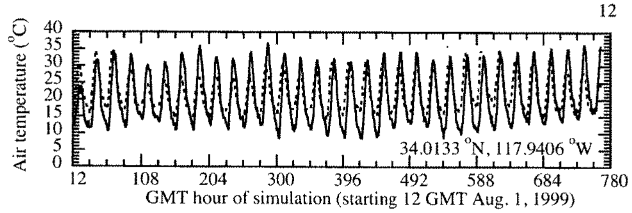
30-Day Model Predictions vs. Data



Pressure

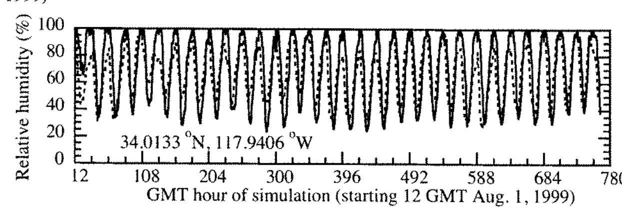
Ozone





Temperature

RH



Data from U.S. EPA

Ms. SOLIS. Thank you very much.

We will now begin questioning, and I will begin with myself for a 5-minute round of questioning.

Dr. Jacobson, thank you very much for being here. According to your presentation, you were stating, or underscoring, that there is a correlation between urban cities and the high incidence of emittance of carbon dioxide and the negative effects it has in different cities in California.

Now, Los Angeles is very different from, say, Bakersfield or the Central Valley. Can you just touch on that, what some of those—you know, how that is occurring with that process there?

Mr. JACOBSON. Okay. In terms of carbon dioxide, well—one of the pollution in the Central Valley is due to particulate matter air pollution as well as ozone, and in Los Angeles it is also due to particulate matter and ozone, but sometimes different times of the year. Carbon dioxide is emitted more—there is more carbon dioxide emitted in Los Angeles, so the CO_2 levels in Los Angeles will be higher.

However, the Central Valley does receive—emit its own, and also receives a lot of carbon dioxide from the San Francisco Bay Area as well as coming from the south, from Los Angeles. And there are going to be—the Central Valley is more spread out, so you expect the ozone changes in particular will be over a larger area, but it has a quite lower population and concentration, in terms of its concentration compared to Los Angeles.

The pollution in Los Angeles will be affected the most, I mean, the health impacts will be greater—expected to be greater—in Los Angeles because you have such a high population and the levels of ozone are generally higher in Los Angeles than in the Central Valley. And the pollution will get worse where the pollution is already bad.

Ms. SOLIS. What will happen if we take no action?

Mr. JACOBSON. Well, right now, historically, temperatures have already risen due to carbon dioxide, and this is currently causing about, I would say, estimate a medium value of about 800 additional deaths per year, compared to the background of about 50,000 deaths per year due to air pollution. The background air pollution death rate in the U.S. is 50,000 to 100,000, and per one degree Celsius or 1.8 Fahrenheit increase in temperatures; that is estimated as about 1,000 additional deaths, with a range of 350 to 1,800 per year.

So far, the temperatures have already risen about 80 percent of this, and so deaths are already occurring. In the future they are expected to occur more. So the problem is already here; the deaths are already occurring.

Ms. SOLIS. Do you agree with the decision that EPA made? Do you have any comment on that?

Mr. JACOBSON. No. I disagree with the decision for the reasons I cited in my testimony, that there is no basis in science that we know of right now for the two main reasons that were cited by Administrator Johnson.

Those were assumptions that he made that—the two assumptions that he made were that first, CO_2 just mixes globally, there is no differential effect on health in California versus the U.S. as a whole, and there is no effect of local carbon dioxide on air pollution in California. Those assumptions were just those assumptions; they weren't based on any science that I am aware of.

Ms. SOLIS. Were you aware of—if there were any scientific evidence that was put out prior to what your research told you, was there any information from EPA that you may have seen?

Mr. JACOBSON. No. I am sure there have been no studies, because the study I did, which was published on February 12, 2008, is the first study to look at the effects of carbon dioxide specifically on air pollution, ozone, and particulate matter and carcinogens in the United States as a whole, and on public health. There have been no previous public studies at all.

Ms. SOLIS. All right. Thank you.

My next question is for Dr. Frumkin, and I apologize if I can't get to everyone. You all had very good testimony, and I want to thank you for that.

But Dr. Frumkin, we have heard from your colleagues that there seems to be a need to increase funding in the area of global climate change and its relationship to health and children and the need to kind of fast-forward funding so that we can be prepared. In your opinion, what can we do to help provide more support for your particular office?

Dr. FRUMKIN. We are doing what we can now, in terms of public health preparedness and prevention with respect to climate change. We have technical assistance underway, we have research programs in a very small way underway, we are building the science base, and so on.

We recognize the possibility of doing more. Further public health activities would involve further research; we need to build our science base considerably. Technical assistance to state and local health departments would need to increase.

Ms. SOLIS. Is your budget adequately funded to provide for these kinds of research developments that we need to undertake?

Dr. FRUMKIN. As I said, we are doing everything we can within existing resources now. We do recognize the possibility and the opportunity of doing more.

Ms. SOLIS. So you could use more financial support, funding for research, preparedness, yes or no?

Dr. FRUMKIN. With further resources we would be able to do more.

Ms. SOLIS. Okay. Very good.

I think my time is up, but certainly we will come back and ask another round of questions so we can get to some more of you.

I want to, at this time, recognize our next colleague here who has 5 minutes for questioning, and that is the Congressman, Mr. Walden, from Oregon.

Mr. WALDEN. Thank you. Thank you, Madam Chair, and I appreciate the witnesses and your testimony, and I have been on this select committee—Congress, and I think you all provided some really superior testimony, especially compared to some we have had. I appreciate the detail that you have offered.

Dr. Jacobson, I am curious: Aren't there already communities in California that have not met the clean air standards under federal law today, that are out of attainment?

Mr. JACOBSON. Yes, that is correct.

Mr. WALDEN. And what effect does that have on public health? Have you studied that?

Mr. JACOBSON. Well, that is pretty well known to be a serious effect on public health, so I mentioned there are about 50,000 to 100,000 people die each year in the United States due to air pollution, and a good portion die in California—prematurely, that is—due to air pollution. And that is due to existing health problems due to mostly fossil fuel combustion.

Mr. WALDEN. And have you studied what the health outcomes would be if California just met the existing clean air requirements and got those cities into attainment status?

Mr. JACOBSON. I can't say I can give you the—I haven't studied that specifically in terms of provide numbers for it. But I should point out that even if California were in attainment there would still be premature deaths, because with 0.08 parts per million standard, that is still way above the health threshold for ozone pollution health effects, which is about 0.035 parts per million, or 35 parts per billion. So, the standard is 80 parts per billion, and the health effect threshold is 35 parts per billion. So even if you met the standard, you would still have health problems.

Mr. WALDEN. What level are those cities at now that are not in attainment?

Mr. JACOBSON. Los Angeles can get up to 150, I think in the—right now, I mean, it used to, in the 1950s it would get up to 560 parts per billion, but that doesn't happen anymore.

Mr. WALDEN. So 150 for L.A. right now, parts per——

Mr. JACOBSON. Parts per billion of ozone. And, well, I think it may even, some days it gets up to 200 parts per billion, which is a stage one——

Mr. WALDEN. And the federal limit is supposed to be 80?

Mr. JACOBSON. Well, that is for 8 hours. The 1-hour standard is 120 parts per billion. These high levels are generally for a shorter period of time, so they might just be exceeding the 1-hour standard rather than the 8-hour standard.

Mr. WALDEN. Okay. I wonder, as we look at the balance, how long would it take to get temperatures in the globe to actually come down? I mean, that depends on what all we may or may not do here, but I look at Europe—they have got a cap and trade system, and yet their carbon dioxide emissions actually went up 1.1 percent last year, even with their framework in place.

I am trying to figure out—I have read some data that it would be at least 50 to 100 years where you would see a trend line go the other direction. Is that what you are finding in your data?

Mr. JACOBSON. With carbon dioxide, the lifetime of carbon dioxide, which is the time it decreases to about 38 percent of the original value, is about 35 to 50 years, and so you can imagine over 35 years you will start to get some feedback. You will get down to—you will get a reduction of two-thirds, almost, not quite two-thirds, 60 percent.

However, there are other chemicals that cause, like black carbon, for example—which is the main component of soot—which has a much shorter lifetime of a few weeks. So if you control that, you can actually get the feedbacks within one to 4 or 5 years. And so if you control soot, that is kind of the fastest way to slow global warming; controlling methane is probably—that has a faster feedback than carbon dioxide, and carbon dioxide is one of the longer-lived greenhouse gases, if not the longest.

Mr. WALDEN. So, what could we do that would control soot most effectively?

Mr. JACOBSON. Well, aside, I mean, the shortest-term is diesel particle filters and off-road vehicles, construction equipment—equipment, but the next step is really to convert all the diesel to clean electric-type vehicles eventually, or hydrogen fuel cell vehicles powered by clean, renewable——

Mr. WALDEN. So, I understand that in Europe they have always used more diesel——

Mr. JACOBSON. Yes.

Mr. WALDEN [continuing]. In their vehicles than we do, which is part of why they get higher mileage. But they have also, subsequently, ended up with more premature deaths because of the added pollution in the air. Is that because of the soot?

Mr. JACOBSON. Correct. That is one of the reasons. Their death rate—while the U.S. is 50,000 to 100,000, Europe is maybe 300,000 to 350,000 per year, and a lot of that is due to the fact that they have, like 40 or 50 percent of their cars are diesel, putting out particles. So there is a lot more particle pollution in Europe, and particles are the main component of air pollution health problems.

Mr. WALDEN. One final question for each of you, perhaps, if there is time. My understanding is that under some of the cap and trade provisions like the Warner-Lieberman bill—I have talked to some power companies that rely a lot on coal for production of electricity, and they indicate that their cost of power would go 4.8 percent to 11.5 percent, or more than double.

When we think about health issues, I think about heating for elderly in the winter and cooling in the summer in the hotter climates. Have any of you studied the effects of increased energy prices on health care, especially among either the young or the elderly, if you more than doubled the electricity cost in the country?

Fifty-two percent of our power comes from coal, if that is what the model shows when you run it through, that it is a two and a half times increase in electricity. I am wondering, have we looked at that, too, as we look long range?

Dr. Frumkin.

Dr. FRUMKIN. We haven't looked at that question at the CDC, but I would be happy to look for information on that and get back to you.

Mr. WALDEN. Would you?

Dr. FRUMKIN. Yes, sir.

Mr. WALDEN. That would be helpful.

Dr. Benjamin, anything from——

Dr. BENJAMIN. No, we haven't, although if we are simply looking at cost, I think the thing we would want to put in the equation is the cost of health care, which would offset some of the fiscal dollars.

Mr. WALDEN. Yes. I want to look at all the costs and the effects. Because I know we hear anecdotally when there is a huge heat wave the number of people that die in their homes because they don't have adequate air conditioning. And then when it is really cold, we hear about those who freeze and are—you see the pictures on television every winter of people bundled up, especially seniors. So I am just trying to figure out all of these input costs, and certainly the tradeoffs——

Dr. BENJAMIN. We would love to look at the health care costs——

Mr. WALDEN. Yes.

Dr. BENJAMIN [continuing]. Not just the deaths, but the people——

Mr. WALDEN. Sure.

Dr. Best or——

Dr. BEST. The impacts of these extreme temperatures are very real for children. In terms of cost, that is not a calculation that the Academy has a stand on, nor do we do research. But we do know that there are groups who have done this, and we will be happy to report on that.

Mr. WALDEN. Thank you.

Dr. PATZ. I work with energy policy experts in our Center, and a couple points that they have told me is that the competitive price of renewables is coming way down; wind power is becoming competitive. But moreover, I would like to point out, too, historically the arguments against the Clean Air Act, where the argument was, "This is way too expensive. It is going to cost our economy; it is going to hurt us." And there were major concerns.

And once the Clean Air Act was implemented, there were some analyses conducted that found that, by far, the benefits, especially health benefits and environmental benefits—but especially health benefits—made the Clean Air Act much favorable. In fact, the concern of the cost was unwarranted.

Mr. WALDEN. So you don't think there is any concern with a, perhaps, two and a half-fold increase in cost of electricity produced from coal? That that won't have any health effect or any effect on the economy?

Dr. PATZ. Well, I think that is a great research question.

Mr. WALDEN. Right.

Dr. PATZ. I think that the argument about economy versus environmental protection is a false argument.

Mr. WALDEN. I am not making that argument; I am trying to find out——

Ms. SOLIS. Time is way over, and I thank you. But we will have another round of questioning. I am going to excuse myself; I have to go vote in another subcommittee, and I am going to turn the gavel over to Congressman Inslee for his 5 minutes of questioning.

Mr. INSLEE [presiding]. Thank you. Dr. Jacobson I think has been too modest here. I think he is actually the author of a paper called, "A Renewable Energy Solution to Global Warming," which talks about the electrification of our transportation system, and it causes significant optimism. I will share that with Mr. Walden; he might find it interesting.

Mr. WALDEN. I would love to see it.

Mr. INSLEE. I will do that. Do you want to make any comments about that at all?

Mr. JACOBSON. Sure. I am happy to. So, we have looked at, what is the possibility of converting the entire vehicle fleet in the United States to electric vehicles powered by renewable energy, primarily wind and solar—a combination, actually, of wind, solar, geothermal, hydroelectric, and tidal wave power. And, well, one analysis we focused primarily on wind and looked at, well, how many wind turbines would we need to power the entire vehicle fleet?

And it turned out to be, with infused 5-megawatt, which are large turbines that are currently existing in Europe—they are not in the United States right now, but they are manufactured by a company—if you put them in locations where the wind speed is between seven and a half and eight and a half meters per second on the annual average, then it turns out you would need between 70,000 and 120,000 5-megawatt wind turbines to power the entire U.S. vehicle fleet with electric vehicles. And part of this is because electric vehicles are so efficient—compared to internal combustion they are about four to five times more efficient—so you need less energy, basically, to run them.

But there is plenty of wind to actually do this. By the way, this number—70,000 to 120,000—that is less than the 300,000 airplanes that were produced in World War II over a period of 7 years, most of those in the last 3 years. And the space you need for this is not that great. It turns out, well, just for the turbine spacing—you need to separate them by a certain distance so they don't interfere with each other—but for this it is about 0.5 percent of the United States; it could be a lot of it offshore.

But that compares to, if you wanted to do the same thing with ethanol-fueled vehicles you would need about 15 percent of the entire United States, which is 30 times more land area, or even cellulosic ethanol would be 20 times more land area for that than doing it with wind. And the actual land area you would need for the turbine spacing touching the ground is really only two square kilometers, because they can use—for all these turbines, because they are just poles in the ground—you could use all the land underneath for farming and ranching and open space. And a lot of this could also go offshore, so it doesn't actually have to go over land.

Mr. INSLEE. Doctor, I have got to make sure—I have got another question. I was really heartened by your research, because it confirms sort of what I believed, and there are a couple books that talk about that theory out there, one called, "Earth: The Sequel," which is the typical—another one is called, "Apollo's Fire." And they both are optimistic visions, and I appreciate your research on that, and I will try to share with my colleagues.

Dr. Frumkin, the U.S. Supreme Court decision in Massachusetts v. EPA required the EPA to determine whether greenhouse gas emissions can be reasonably anticipated to endanger public health and welfare. Despite, apparently, EPA's staff's finding that it did, the administration refused to sign off on that endangerment decision. I just want to ask you, based on your considerable expertise in public health, do you believe that greenhouse gas emissions cause or contribute to air pollution, which may reasonably be anticipated to endanger public health?

Dr. FRUMKIN. Thank you for the question. I recognize that there are legal and regulatory dimensions to the question. CDC doesn't have a position on those issues, nor does it have a position on any of EPA's regulatory decisions. What I can do is speak to the public health science. The science is clear that carbon dioxide does contribute to climate change, and as I and others have testified here today, climate change does pose a number of public health challenges.

Mr. INSLEE. I kind of take that as a yes, that it does have the capacity to endanger public health, but, you know, is that a fair statement?

Dr. FRUMKIN. I think I would let my words speak for themselves.

Mr. INSLEE. I think we get the message; I wish the White House did.

I wanted to read a quote, actually, which was one of the—if you believe in irony, this is one of the great ironies. In turning down California's request for regulation of greenhouse gases, the administrator of the EPA said "Severe heat waves are projected to intensify in magnitude and duration over the portions of the United States where these events already occur, with likely increases in mortality and morbidity, especially among elderly, young, and frail. Ranges of vector-borne and tick-borne diseases in North America may expand both modulation by public health measures and other factors."

Would anyone disagree with the position that if you conclude that, by necessity you have concluded that carbon dioxide has the capacity or capability to endanger public health? Does anybody disagree with that on this panel? If you were—that, I will take that no one disagrees with that.

Next question: As public health experts, we have been struggling with how we get America to move on global warming. You have seen the federal government largely acting, in the last 7 years under this administration, much more the ostrich with the head in the sand and the tail feathers in the air rather than the American eagle, and we need to change that.

As public health experts, can you help us on what you think the best messaging is to the American people on trying to tackle this beast? You know, you have been successful in seatbelts, in changing behaviors, and you have had some success with tobacco usage. What messaging works to help move America in that direction?

Dr. BENJAMIN. Mr. Inslee, I think, just from the American public health perspective, we need to change the message from, "The end of the world, there is nothing we can do," to, "This is a very significant problem, and every one of us can do something and implement a way to make a big difference."

I think that what often happens with a big problem like this, people get overwhelmed. And so, my perspective of simply telling people again, you know, travel differently, do some things differently at home, do some things differently at work, and letting them know that every little bit helps, will make a big difference.

Mr. INSLEE. Dr. Patz.

Dr. PATZ. Yes. If I could just add, I think that the issue of co-benefits, that in fact this could be a great opportunity if we think about changing some of our energy policies, especially in the area of transportation—60 percent of Americans do not meet the minimum recommended level of exercise, and this is one where we have sort of designed unhealthy cities. And this is a great opportunity when we think about greening cities, reducing greenhouse gases and automobile traffic. We have a great opportunity to enhance personal fitness.

Another point that I think is both locally, as Dr. Jacobson pointed out, regarding CO_2 emission affecting California, but also that, in fact, our CO_2 emissions do affect the world. And just like the argument of secondhand tobacco smoke, where what one individual does when he lights up a cigarette and that smoke affects someone else, this is actually a global problem as well, and that our energy emissions are, in fact, hurting other countries, not only our own. So I think that is a message as far as an ethical issue.

Mr. INSLEE. I appreciate it.

Dr. Frumkin, did you have something?

Dr. FRUMKIN. Yes, sir, just to let you know that the CDC has been holding a series of expert workshops on various aspects of climate change, and the most recent one was on health communication regarding climate change, precisely because we recognize the question that you just posed, that public health communication has been very successful in many domains; what can we learn from that to apply to climate change communication?

We know, for example, that bad or threatening news is difficult for people to take, but if it is coupled with constructive recommendations about what you can do, it is much easier for people to accept that news.

Mr. INSLEE. Well, some of us believe—and I appreciate Dr. Benjamin's comment—that we need to switch from doom and gloom to a sense of a can-do, innovative, optimistic spirit of America. That is an American message, I believe, that will succeed here.

I will now hear 5 minutes from Representative Cleaver.

Mr. CLEAVER. Thank you, Mr. Chairman. I apologize for being late. Like everybody, we are all running between several hearings, but I didn't want to miss this for a number of reasons. And the primary reason is the panel; those of you here offer—great perspective on this issue. And I grew up in an all black neighborhood in Texas, and we lived a few yards away from the waste treatment—well, actually, it did not get the anticipated name of waste treatment plant until a few years ago. [Laughter.]

But, you know, I also realize that the incidence of some diseases, most particularly asthma, is highest among African-Americans. And when you look at where the waste treatment plant was, and also where the city dump was located, you see that that has got a 99.9 percent African-American community. And I know specifically Dr. Patz, you used the term “disproportional vulnerability,” and it caught my attention earlier.

And is the climate change and environment placing at risk the poorest people, the people of color who live in areas where we have chosen, with some great intentionality, to locate these facilities that emit, I think at the least, unpleasant odors and maybe even some other particles that would be damaging?

Dr. PATZ. This is a very good point regarding the different portions of the population that would be most vulnerable to climate change. And what we are dealing with when we talk about climate change are extreme and environmental conditions, be it a heat wave, a flood, a drought, or severe storm.

Certainly we know that it is the poor that are most at risk in heat waves, especially the poor elderly. As far as flooding, you know, people that live in flood plains would be more at risk. And when you deal with ozone pollution, it is true that African-Americans do have a higher rate of asthma.

So there are certainly—when you, you know, when you look at Hurricane Katrina, which, you know, simply was a—you know, we don't know—I won't make any judgments about why it occurred, but when Hurricane Katrina hit, it really was the poor, and most African-Americans in New Orleans that simply did not have the means or the ability to get out of town and avoid that disaster.

So I think to the extent, in this country, absolutely there are populations at risk that are primarily the poor; and if you look globally, it is the same situation. Compare a sea-level rise in Holland versus Bangladesh, and you can see that a population with very little capability to react is at more risk.

Mr. CLEAVER. Thank you.

Dr. Benjamin, would you say that there are things in landfills that could become airborne that would do damage—medical damage—to people who live nearby?

Dr. BENJAMIN. Absolutely. Obviously there are lots of things dumped in landfills that are toxic. If you really look at it, there are probably four raw areas that disproportionately affect vulnerable communities, particularly minorities. One, more vulnerable to extreme weather events, much more lower baseline health status.

Then you place people near toxic environments like that, and then they, as a community, the community capacity to recover is diminished. So all four of those things, including the toxic issue that you are concerned about, are measures that need to be——

Mr. CLEAVER. I have gone down to New Orleans twice—we have held hearings down there. The flood was one issue that was terrible and devastating; I had a son down there in college——

The issue that I am concerned about more now than the flood is, when we went down there we all had to wear masks when we went into the Ninth Ward. There is a—I grew up in public housing—there is a stench down in New Orleans like nothing I have ever experienced in my life, and of course the landfill was washed into the Ninth Ward.

And my fear is that we don't know the damage of Katrina right now, that it may not come into fruition for a few years down the road, but I cannot imagine that we are not going to have some prolonged damage to lungs and probably much more in the years to come. Do any of you have any comments on—my time is expired, but do any of you have any comments?

Dr. BEST. I second your concern, and I also want to emphasize that it is children who are having—reaping the permanent harm from these exposures, and because they have a longer shelf life, they will suffer those harms for longer periods of time than an adult who was exposed to the same event. So we need to consider children, especially, when we think about these kinds of disasters and environmental harm.

Ms. SOLIS [presiding]. Thank you very much.

We can go for another round of questioning if you would like, and I certainly would like to ask some questions.

But I would like to go back to Dr. Frumkin, and just a basic question here: Do you believe that greenhouse gases do have an impact on health—an adverse effect on health?

Dr. FRUMKIN. I think that was a question we addressed while you were out of the room, Madam Chair. What I mentioned was that that is a complex question with regulatory and legal dimensions, and the CDC doesn't have a position on the regulatory and legal dimensions of that question. As for the science, there is strong evidence that carbon dioxide is a greenhouse gas that contributes to climate change, and there is strong evidence that climate change threatens health in a number of ways.

Ms. SOLIS. Have any studies in your department that you have been involved in indicated that?

Dr. FRUMKIN. I am sorry, indicate——

Ms. SOLIS. That there is a correlation, and in fact this is evidence.

Dr. FRUMKIN. One example of research that we have done would be looking at heat waves, and characterizing the epidemiology of heat waves, identifying who is the most vulnerable and how the deaths and illnesses occur from heat waves. Heat waves are expected to become more common with climate change.

Ms. SOLIS. So that is a yes. Okay. You had mentioned something earlier as well, in your opening statement and your testimony, alluding to differing views within the administration, and I wanted to ask you if you could, kind of, at least give me an idea what that means, what the difference is between your agency, OMB, and the administration. What differing views were you talking about?

Dr. FRUMKIN. What I was referring to is that we have a considerable amount of work going on on climate change at the CDC; it is extensive. It is well represented on our Web site and in our publications, but I don't know that all of that work has been carefully vetted across the administration, so it isn't necessarily the case that all of our work has—represents a consensus across the administration.

Ms. SOLIS. But they are given all that information from you, OMB, and the administration?

Dr. FRUMKIN. I don't know and can't speak to the level of attention that all of our work has had.

Ms. SOLIS. Okay. All right. Thank you. Thank you, Dr. Frumkin.

I wanted to ask, Dr. Best, you talked extensively about children and public health prevention and preparedness, and you mentioned that we should really have more of an organized method here of preparing children for these negative health effects that are going on. Can you be specific and give me some idea of what we could do that currently isn't in existence that can help us prepare for that?

Dr. BEST. Well, we have talked in broad generalizations about some of the issues today. A good public health infrastructure that is supported and funded appropriately is key.

In terms of children's health, we also need health insurance for children. We need to make sure that children have access to health care through appropriate placement of workforce.

We also need to think about children when we think about cost-benefit calculations. The cost of an immediate—you know, the costs incurred by improving the quality of our air are not just borne by the industry that pollutes the air; they are also borne by the children throughout their lives.

Ms. SOLIS. Have you seen any differences—we talked a little bit about disparities that exist between communities of color and the general population. Are you seeing any of that with respect to how negative health——

Dr. BEST. I see it every day. With my——

Ms. SOLIS [continuing]. With respect to air pollution——

Dr. BEST. Yes. Yes, ma'am.

Ms. SOLIS. And can you elaborate?

Dr. BEST. I serve the low-income minority population of Washington, DC every day in my clinical practice; those are the children that I care for. And they suffer asthma, adverse permanent harm to their lung function because of the air pollution effects in the city. And they have poor access to care because of the fact that Washington, DC is yet another example of an urban island where children aren't treated as well.

Ms. SOLIS. Right. Okay.

Dr. Patz, do you want to chime in?

Dr. PATZ. Yes. I would just like to make a comment about, you know, about the research and what is available, what is out there, what do we know, and what do we need to do. You know, Dr. Frumkin mentioned that the CDC is doing everything that it can because they understand how climate change is a very important public health issue.

I have been doing climate change health research for about 14 years, and have received some grants from the EPA, NOAA; these are not large programs. To date, I really don't think there has been much funding at CDC for preventing some of the health effects of climate change.

There is an intention; they understand the problem. They are holding workshops. They want to do something, but I don't see funding at the CDC. I think their hands are tied when it really comes to serious protection of the American public from the health effects of climate change.

Likewise, NIH has really not been funding climate change health research. They are now talking—they are actually meeting next week, and hopefully they will have some mandate to actually allocate funding to public health research.

But I think that we really—you know, I have been applying for these grants, and—the CDC really has hardly any funding to support their efforts to protect us from climate change, and I think that is a huge need.

Ms. SOLIS. Thank you very much.

Dr. Jacobson, I want to thank you for your testimony, first of all, and just tell you that the area that I represent in California is one of the heavier-polluted communities. We have freeways that just transfer us across our communities there, and I have often wondered also, as my colleague Mr. Cleaver asked, about ambient air pollution and the cause and effect for our children, as was mentioned earlier, having so much activity outside and not being properly—or the folks that should be—the gatekeepers should be some-how helping to try to provide more information in terms of safety for our children.

Can you maybe touch on that?

Mr. JACOBSON. I assume it is Los Angeles?

Ms. SOLIS. Yes. Los Angeles. East Los Angeles.

Mr. JACOBSON. Okay. Yes, living near a freeway is a dangerous place to live, because you have particles coming right from the tailpipe, and that is when the concentrations are the highest. Particles, by the way, are the most damaging component of air pollution and there is no threshold to the health problems due to particles. You can go down to almost zero, and you get health problems due to particles.

And vehicles are emitting particles even though they are a lot—the emissions are much lower than they used to be. They are still emitting these particles, and they are pretty concentrated as they go downwind of the freeway, even, like 100 meters, 500 meters, you know, even a kilometer down, you know, they will get diluted, but the concentrations are going to be highest near the freeway.

And these particles—these are the ones emitted. Now, that doesn't mean other people aren't affected downwind, so there is this local air pollution right near the freeway. But then there are other types of particles that form in the atmosphere due to chemical reactions involving the sun and gases, and converting gases to particles, and there are also gases that—although ozone isn't emitted from a tailpipe, it is formed in the atmosphere.

So actually, downwind in Los Angeles, particularly on the east side of Los Angeles because most of the emissions are on the west side—although there are a lot on the east side, but most of them are on the west side—and these emissions get transformed and moved by the wind to the east side, where the concentrations of the chemicals formed in the atmosphere build up the most. So people far downwind actually also have a big—are affected by the air pollution significantly.

So there is this local effect, where people near freeways have bad health effects——

Ms. SOLIS. So it is compounded?

Mr. JACOBSON. Yes. Well, it is not—well, I would say if you are on the west side you are not getting so much of the secondary pollution——

Ms. SOLIS. Right.

Mr. JACOBSON [continuing]. You are getting more of the primary pollution. If you are on the east side you get more of the secondary pollution, so it is——

Ms. SOLIS. Where lower-income people tend to be living or working——

Mr. JACOBSON. Near the freeways, probably. So yes. So you are getting more of the primary pollution, but all populations are getting the secondary pollution, really, depending on—because it just spreads out all over Los Angeles.

Ms. SOLIS. And just a last comment on soot. Something that you didn't mention was marine vessels, and that is something that we are looking into. Have you done any research on that?

Mr. JACOBSON. Yes. It includes marine vessels and aircrafts in terms of their—because aircraft is another unregulated source of soot emissions, and marine vessels are, I guess I am not sure what the status of the regulation is, but they are pretty much unregulated on the global scale. And that is an area where you can get—especially in ports.

I mean, when you are out to sea there is going to be some impact, but it is not going to affect the health as much as right near ports, if marine vessels are idling. I think in California there have been some recent laws to have them plug in—so that kind of stuff is a really good idea.

Ms. SOLIS. Okay. My time is up, so we will go next to Mr. Walden for questioning.

Mr. WALDEN. Thank you. Thank you, Madam Chair. I appreciate that.

Dr. Jacobson, I am going to go back on this issue of wind turbines. I represent a 70,000 square mile district in eastern Oregon, home for the northwest, probably, to some of the most wind turbines in the area, with many more coming up online. And I know that it works well there because of the dams that allow us to have hydropower.

There are some—even some on this committee—who would like to tear out some of those dams, and I don't know what the replacement power is, but it is going to have a bigger carbon footprint than hydro. But because the wind isn't firm energy, that becomes a bit of a problem. And I know the Bonneville Power Administration has told me there is a capacity to how much wind they can actually put on the grid.

Are you aware of studies that give us some ideas, regionally, where we can put the wind? My understanding is in the Dakotas, actually, there is much more wind potential than other places. Have you looked at those infrastructure issues?

Mr. JACOBSON. Yes. So, two points. One, we did produce a world wind map, and it is actually the only map of the world's winds at 80 meters, which is the height of modern turbines. And that is publicly available; I would be happy to send it to you.

Second, we have looked at combining different renewables together to firm the capacity, and having—the west coast is really well-suited for this because it has a lot of hydro, and the hydro is excellent for, yes, dealing with the intermittency and filling in gaps because you can turn it off within 15 or 20 seconds in spinning reserve mode.

But you can actually combine also solar, because a lot of places wind peaks at night and solar peaks during the day, so you can even combine wind and solar and balance the load better there, and use the hydro to fill in all the gaps from that. So we did a study for California—it was kind of a rough study; we are doing some more detailed study now—but we found that for 2020, if we actually looked hour by hour, that if we combined these renewables together—solar, wind, hydroelectric, geothermal, those are the ones we looked at—you can get an exactly smooth output of supply without anything else.

Mr. WALDEN. Wow.

Mr. JACOBSON. But, I mean, that was in California, and I assume it is the same in Oregon, too, and Washington.

Mr. WALDEN. Yes, I would think so. The Geo-Heat Center at the Oregon Institute of Technology in Klamath Falls—they have spent a lot of time looking at geothermal potential and told me that there is enough in Oregon to produce two-thirds of our electricity needs——

Mr. JACOBSON. Yes.

Mr. WALDEN [continuing]. With geothermal, because these new advances in the last year and a half—being able to produce electricity at a lower allows the delta between the cold water and the hot at lower, and we have got a 10-meg geothermal plant just sited in my district.

So, the key that we will have out west is we have the potential; a lot of it rests on federal land. And there are few on this committee, or on the committees in charge of this Congress today, who will allow us to access those resources. And it seems to me if we are serious about dealing with some of these energy issues, you have to be able to site the wind where it is needed, where it can produce with wind turbines, within boundaries, I understand.

We are starting to get pushback on that visual impact. You mentioned offshore. You know, Massachusetts, they didn't want it where they could see it. Nobody wants any of this stuff where they can see it, by the way.

And in terms of geothermal, I think we are going to face some challenges to accessing that. I mean, have you looked at that?

Mr. JACOBSON. Yes. Well, geothermal is a baseload, so it doesn't really have the intermittency issues——

Mr. WALDEN. That is great.

Mr. JACOBSON. Yes. It is a great baseload. I haven't looked at that with a lot of detail, but it is a good source.

In terms of siting the wind turbines, keep in mind that the total area if you really want to solve this problem is pretty—it is not a large amount of area you would need.

Mr. WALDEN. Right.

Mr. JACOBSON. So the question is, do you want to look at the wind turbines, or would you rather look at a coal fire power plant? I mean, it is not really a—nobody wants to add anything; it is really a question of what you are replacing.

Mr. WALDEN. Right.

Mr. JACOBSON. And so if you have a coal fire power plant that is, you know, emitting stuff that is hurting your children downwind, you know, you would think people would rather look at the wind turbines. There are about, I think it is like 20 or 25 offshore wind proposals in the United States right now; and the only one you ever hear about is the one in Massachusetts, but in fact, all the other ones, they don't have this same problem——

Mr. WALDEN. Good.

Mr. JACOBSON [continuing]. In terms of—well, I am not saying they don't have problems, but in terms of actually getting implemented. But they don't have as much public controversy as that one.

Mr. WALDEN. Well, and I am real interested, too, in the notion of plug-in hybrids. I bought a Prius last July that will more than double my gas mileage here in Washington, and last month I bought a Ford Escape hybrid, and getting 66 percent better mileage than the SUV I used to have. I would love to be able to charge it up at night on the grid, but you can't do that yet.

In terms of battery development and domestic investment, we have done that in various energy bills; we have put money out there to invest in new technology for battery life. What are you seeing on the scientific side of things? How far away are we from really making a leap forward on batteries?

Mr. JACOBSON. Well, Tesla rolled out their first pure electric vehicle on lithium-ion laptop batteries, and so they are starting to produce them. So they exist now; there are a very small number. I think they put out one—one of them is actually on the road now, and I think there are another——

Mr. WALDEN. (OFF MIKE)

Mr. JACOBSON. So they do exist, and there are many electric vehicle companies following in the wings. And from what Tesla says, you know, these batteries a while. I mean, I have a Prius myself. I got it in 2001 or 2002, and I haven't had to change the battery. And that is not with these lithium-ion batteries; that is with the older version.

So they last pretty long. The older ones even last pretty long, from my own personal experience. And the lithium-ion, from what they say, should also last quite a while as well. So I don't know a lot about the details of the battery industry, but I can say that I am pretty optimistic about it.

But that is the idea, is to plug in your own home; so you have, maybe, solar panels on your roof, you have smart meters that control when you get the electricity, so that is another way to smooth out the supply of intermittent renewable energy. And in California, PG&E is doing that; they are developing smart meters so that they can control when you get your power if you plug in your car at night.

So it is really a combination of all these renewables with a smart electric grid, and actually organizing the grid in such a way in the United States so that we can not only have—we know where the wind farms should go—but we have the transmission between them, because that is really the limiting factor in the expansion of wind, is transmission, and we need an organized transmission grid. And also, that reduces the intermittency too, if we connect two wind farms that are far apart enough, then you smooth out the supply, too. So there is a benefit—a financial and a wind benefit.

Ms. SOLIS. Thank you, Dr. Jacobson. Thank you.

Mr. WALDEN. Thank you, Dr. Jacobson. I appreciate it.

Ms. SOLIS. Now I would like to recognize Mr. Cleaver for another round of questioning.

Mr. CLEAVER. Thank you, Madam Chair. Could I ask, if people leave the room and risk intellectual damage by not hearing everything that goes on here, if you would hold the door when you go out. It is creating sound pollution.

The question that I would like each of you to answer is, we know the issues of challenge.

We will start with you, Mr. Jacobson. What would you do if you were a member of Congress, in terms of legislation, that would have the greatest impact in reducing the health risks of the American public, particularly its children, as a result of climate change?

Mr. JACOBSON. I would do two things. One relates to providing better renewable energy sources, and the other relates to—if we go back to the issue I was discussing, which is the waiver issue, being able to allow states to actually control their emissions, and then that also is effectively the same thing, which allows them to try to find ways to reduce their carbon and cars, be it by a low fuel standard or some more renewable energy.

But more specifically, having a national program, as I mentioned, for expanding renewable energy on a large scale—because if you look at the individual states' portfolio standards, they are, you know, they have expansion of renewables to 20 percent, let us say, of their total electricity. But that is not enough; you need an 80 percent reduction in carbon to address climate change.

So you need a huge infrastructure change that is much larger than anybody is proposing at state levels. And so to do this, you really need this kind of national, sort of Apollo-like, program to go to true renewables, which are wind, solar, geothermal, hydroelectric, tidal wave powers. But in order for that to work, you need a better transmission system to interconnect these.

So having kind of an organized transmission system with a large-scale renewable energy program would make a lot of these problems go away because—especially if you start using battery-electric vehicles instead of the, you know, fossil fuel vehicles, then you make a lot of these air pollution problems go away automatically with better technologies. But in the meantime, allowing states like California to control their own CO_2 has a similar effect, because other states then follow.

California has been an example for 50 years, basically, since 1948, when the Los Angeles Air Pollution Control District started making regulations, and it is actually—the very first motor vehicle control act in the world was a California 1959 Motor Vehicle Control Act from California. So you really need to have states control their pollution, and also to scan renewable energy.

Mr. CLEAVER. Thank you.

I am going to ask that each of you would do a short response, because my time is running out.

Thank you very much, Dr. Jacobson.

Dr. FRUMKIN. Well, Dr. Jacobson spoke to energy and transportation policy. I am going to speak to public health actions that we need to take.

These are the standard public health protection steps: We need surveillance and tracking, good data collection, so that we have a sense of where we are both on environmental risk factors and on health. We need public health preparedness planning, so that states and localities can forecast the problems that they may face and take steps to protect the public.

We need research so that we better understand the health implications of climate change. We need good communication so that people understand the issue and the steps they can take.

All of those are the standard tools in the public health toolbox and the steps—what we can do to promote those actions would go a long way toward helping us protect public health.

Mr. CLEAVER. Thank you.

Dr. Benjamin.

Dr. BENJAMIN. Let me concur with my former colleagues on what they said, particularly the comments from Dr. Frumkin about investing more in the public health infrastructure. Let me talk about two very specific things as well.

One, I would like to see a program actually officially authorized within the Center for Disease Control and Prevention around climate change. And obviously, also, funded as well.

Secondly, really paying a lot of attention to policy. There are a lot of things that often aren't thought of as health policy. Again, the farm bill, the transportation bill, lots of things that we do around adult environments that have huge health implications, and for Congress to think about health impact assessments in all of those pieces of legislation. And obviously we would be eager to help you as you think through that.

Mr. CLEAVER. Thank you.

Dr. BEST. And I would second all of my colleagues' comments. I would also urge a long-term force perspective, rather than short-term immediate gain.

When we think about children, again, we think about how long they are going to be on the Earth, and we need to think about how an exposure or a catastrophe that they experience during childhood affects the rest of their lives. We also need to think in the micro-level as well, and think about how we, as individuals, can reduce, reuse, recycle, and think about how we, as employees and coworkers and patients in hospitals, how we can make sure that those principles are part of our daily lives.

Dr. PATZ. Yes. That is a great question. I think that climate change can influence so many different risks to health that have been outlined throughout the hearing. I think it is very important to Congress' understanding to integrate the nature of the health risks of climate change.

So that will demand a concerted effort across both the public and private sector. Addressing climate change policy should include aspects of self-preparedness, as Dr. Frumkin has mentioned, and Dr. Georges Benjamin has mentioned, that we need to have specific targeted funding for CDC to address climate change.

Urban planning is part of this issue. Natural resource utilization, as far as actual vulnerability to a population when experiencing extreme climates. So natural resources and energy policy; energy policy and public policy really should be linked.

So it is a truly new type of challenge, and it is going to demand serious legislative measures, unlike many of the other health effects that we have studied in the past. I think this is truly one of the most, you know, serious broad-reaching issues that cannot just be put in a box and focused in isolation. Climate change touches on so many of these other areas that ultimately affect the health of our population.

Mr. CLEAVER. Thank you, Madam Chair.

Ms. SOLIS. Thank you very much.

I wanted to personally thank all of you for coming and providing us with your testimony, and for speaking before the select committee. It means a great deal to us that are working on this issue, and especially this topic for some of us is just so important.

It is a priority for many of us, and as a member of the Energy and Commerce Committee that I sit on, and Health Subcommittee, this is something that I have been longing to see more discussion about. So, we don't just have to have it in the select committee, but it should be in other committees of similar jurisdictions.

But I wanted to make one comment, and then I will go to each of you and ask you to give me a 1-minute kind of wrap-up of what we should take away from your discussion today. And one is, for me right now, I am often confounded that we are not able to get the research data that indicates that we are having adverse effects, chronic illnesses, and how that, then, is contiguous with many of the environmental—the particulate matter, the smog, the ozone—and where that is easily accessible for the public.

It is great that we have the science and the research, but if it is not correlated or brought together in some format, the public and the voting public is not fully aware of what those implications are. We see it manifested years out, especially with children and our elderly. We talk about asthma; this is one example.

But that is something that I know that I have been frustrated over for a number of years, given the proximity of where I live, in a part of southern California where the ozone, smog, water contaminants, many, many adverse contaminants that are affecting our population, that will have an impact for years to come. And we don't have a good thermometer, or gauge, on what we should be doing to turn that around.

So anyway, that is my one cent, for what it is worth. And then I will go to Dr. Patz and give you each a minute to kind of give us something here on the committee that we can take away, that we should be thinking about.

Dr. PATZ. So we really, you know, we do understand that climate change does pose these risks, and we need to be prepared. We do need more research; we do need to understand the nature of these risks more.

We are beginning to make some headway as far as looking at place-based, you know, location-based problems. And I think that that is where, you know, where climate will actually have an impact and where we can really look at one place and look at the vulnerability based on its natural resources, or be it Los Angeles, the basin, and there have been studies showing that heat waves may even triple in California, so these types of analysis.

But I also think that we have brought in this issue of health impact assessment, which is more than just looking at adverse risks that we are used to studying, but to look at both the negative effects and potential positive effects from changes in policy. And this is where I think we really need to get a better handle of—that will get a better quantification of the true story when you change policy and you reduce greenhouse gases, for example, in an urban population.

You know, the multiple co-benefits to air pollution reduction, increased fitness, and reduced greenhouse gases, it has got to be a comprehensive-type analysis to really get an understanding of assessing that policy intervention for climate change.

Dr. BEST. As a pediatrician—and as you know, I am here to represent children—I would urge you to consider children and children's health every time you make a decision, because what is good for children is good for the rest of us, it is good for the environment, it is good for our education system, it is good for business.

We need to remember that children are here for longer than I am, or at least their potential life is longer than mine, and that everything we do that improves the climate, that improves our education system, that improves our health care system has a manyfold impact on their lives. And that includes public health infrastructure as well.

Ms. SOLIS. Thank you. Thank you.

Dr. Benjamin.

Dr. BENJAMIN. Let me just state uncategorically that climate change is here and it has health effects. Number two, we can and should address it now. And number three, let me just focus very specifically on the area of vulnerable populations, because I know others will talk about the broader public health issues.

And one, we need to begin looking at, very specifically, the science around how this affects these vulnerable populations. Number two, trying to engage them now in the conversation, and I use the word conversation very specifically so that we don't just talk to people, or talk at people, we actually engage in a two-way dialogue.

And number three, engage them now so that we can begin to craft solutions that make sense for their world. Their world is different than the world that I may live in, the world that you may live in, depending on socioeconomic status, et cetera, or other capacities, and we need to very specifically engage them in their world for solutions.

Ms. SOLIS. Thank you.

Dr. Frumkin.

Dr. FRUMKIN. Representative Solis, thank you very much, and thank your colleagues as well, on this committee, for shining a spotlight on this very important problem. Climate change is a major public health challenge. There is a lot we in the public health sector can do to tackle it.

The conventional terms mitigation and adaptation correspond to what we in public health call prevention and preparedness, and those are standard public health efforts. We need better research so we understand the science better. We need preparedness planning, so that we can take steps to protect public health.

We need to communicate effectively the things we learn and the recommendations we develop. As we do all of that, we need to focus on the most vulnerable among us: poor communities, communities of color, those with particular vulnerabilities, so that we can take special steps to be sure those communities are protected.

We at CDC stand ready to work with other agencies, with state and local public health, with organizations across the health sector, and with partners in transportation, energy, and other sectors so that we can do the very best we can to protect public health.

Thank you.

Ms. SOLIS. Thank you. Thank you.

Dr. Jacobson.

Mr. JACOBSON. Well, I think we—thank you very much for inviting me, again—I think we know that climate change is going to increase, and it does currently increase air pollution the most where the pollution is already the highest. And right now the pollution is highest in California, and so that would give a reason for California to be able to control its own air pollution.

If we look more broadly at what are some solutions to climate change, then there are these large-scale renewable energy solutions that are feasible in terms of the resources available, if we just put our mind to it. I think it really requires kind of a focus on that issue, and part of the problem I have seen—the reason there hasn't been more of a focus on renewable energy solutions—is that a lot of the, not only the funding, but also the, just the talk, is really on solutions that are really less than official, from a climate or air pollution point of view.

I speak specifically of, for example, bio-fuels, which there is really no demonstration that it actually improves climate or air pollution. There is this carbon sequestration, there is, you know, clean coal, other technologies that have been pushed by industries, which the science hasn't shown that these are actually proven benefits. So I think there is a good change of focus.

Ms. SOLIS. Right. Thank you so much.

That will conclude our hearing, and I want to thank the members that came this morning, and also our witnesses and to the audience. Hopefully this will be the first in a series of discussions we will have on the environment, climate change, and health care.

So thank you very much. Thank you. This meeting is adjourned.

[Whereupon, at 11:53 a.m., the committee was adjourned.]

THE SELECT COMMITTEE ON
ENERGY INDEPENDENCE AND GLOBAL WARMING

Dear Dr. Jonathan Patz:
Following your appearance in front of the Select Committee on Energy Independence and Global Warming, members of the committee submitted additional questions for your attention. I have attached the document with those questions to this email. Please respond at your earliest convenience, or within 2 weeks. Responses may be submitted in electronic form, at aliya.brodsky@mail.house.gov. Please call with any questions or concerns.

Thank you,
Ali Brodsky

Ali Brodsky
Chief Clerk
Select Committee on Energy Independence and Global Warming
(202)225-4012
Aliya.Brodsky@mail.house.gov

1) We currently research and create technologies to do things like provide safe drinking water, properly treat sewage, develop needed vaccines, and other health functions. Is there anything new and different that climate change causes, or are we really looking at possible exacerbation of health problems that we are already working to curb?

While we are not fully certain, at this time I would say the latter; that is, climate change will exacerbate many of the health challenges that we already face. The unique and potentially large risks posed by climate change come from the fact that we are not dealing with a 'single hazard' issue. This is why I rank climate change as one of our greatest public health challenges. From heat waves and storm or drought disasters, to stagnant air pollution episodes, heavy downpours that threaten water quality, and biological effects on infectious diseases, climate change can intensify many health problems of today. But we will also be entering 'uncharted waters' as far as climatic extremes and so there will inevitably be some surprises that may be difficult to anticipate. One example from the 2003 European heat wave, was that temperatures became so hot, the French were forced to shut down a nuclear power plant because the water became too warm for cooling the facility (and thereby less electrical power was available during the heat wave). Also it may be difficult to predict potential synergies. For example, what might it mean for asthmatics if the summer ozone season spreads into times of peak pollen production? These consequences certainly demand more consideration and preparedness planning.

2) If energy resources were more scarce or people could not pay their power bills here in the United States, would we see more extreme heat and extreme cold related deaths?

I think this would be a reasonable assumption. Certainly air conditioning saves lives in heat waves (and ideally the electricity should come from renewables so as not to postpone risks to the next generation).

3) You note that "the poor and elderly are especially at risk of dying in heat waves," but isn't this also true of extreme cold? Aren't the poor and elderly always the more at risk population for anything from catching the flu to lead poisoning to heat waves?

Elderly are particularly at risk in heat waves because they: 1) are more likely to have heart conditions, and thermal loading puts a strain on the heart (to pump blood to the skin for evaporative cooling); 2) have less ability to sense temperature change; and 3) may be on medicines, for example diuretics for high blood pressure, that increase risk of becoming dehydrated. It is true that the elderly are at more risk of serious complication from the flu because of a weaker immune system. Lead poisoning is more of a risk for children, especially younger than 2 years because the brain is still growing up to that age.

4) In terms of heat related deaths, do you think it would help the poor and elderly more to have a program like LIHEAP well funded to keep their power – and hence air conditioner on – than to spend money for yet another climate change research program?

This approach would be rather short-sighted. If we simply focus on the acute problems, without addressing the original causes of the problem then we are simply postponing the real challenge to be dealt with by our children. We need to address both the immediate and the longer-term (yet broader) problems simultaneously.

5) There are already solutions – such as pesticide use – to curb the mosquitoes that carry West Nile Virus and Malaria. Is it possible that immediate elimination of the threat would save more lives that the long term programs that we aren't sure will decrease carbon and possibly affect the temperature of the earth?

This way of thinking is similar to #4 above. Of course it would be foolish to assume that to decarbonize our energy would be more cost effective in reducing malaria than to have community bednet and mosquito control programs. However, just as with question #4, if we only focus on each individual problem without recognizing that climate change is a root cause of very many interlinked problems (see the myriad of risks identified by IPCC), then we will be constantly chasing the next unattended to hazard. Again, we do need to attend to urgent and immediate crises of malaria and malnutrition, for example, but if we ignore climate change's influence on many interrelated problems, then in a sense we will be mopping up a mess…while at least one faucet is still running.

6) Do you think that the medical advances and the international aid that the United States provides to developing nations is not leadership in the area of public health, and thereby assistance for their adaptation to climate change?

Medical assistance to developing countries is a meritorious activity and should of course continue. The further 'upstream' the assistance is in confronting the causal chain of disease, the more people can be helped. So preventive measures such as vaccines, sanitation and drinking water engineering, and sustainable agricultural development will have the greatest benefit (versus more downstream medical interventions). But very few of these efforts –with the exception of typhoon and/or drought warning and preparedness programs– specifically addresses the many threats posed by climate change. A better coordinated and cross-sectoral adaptation program is required. In addition, there are many "co-benefits" to greenhouse gas mitigation and the separation between 'adaptation' and 'mitigation' efforts ought to be a very thin and permeable division.

APHA American Public Health Association

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Protect, Prevent, Live Well

June 20, 2008

Ali Brodsky
Chief Clerk
Select Committee on Energy Independence and Global Warming
B243 Longworth House Office Building
Washington, DC 20515

Dear Ms. Brodsky:

I am writing to respond to the additional questions submitted to me by members of the Select Committee on Energy Independence and Global Warming. My responses are listed below.

1. In the priority list for the American Public Health Association (APHA), what is the number one health need in America?

It is always difficult to pick the one most important issue to improve health in America but, APHA believes a strong and effective public health system is amongst the most important health needs in America. Public health protects individuals, families and communities from serious, often preventable, health threats—ranging from diabetes to pandemic influenza. Despite the importance of public health to the health of our society, our system is facing critical challenges, namely a precipitous decline in the number of public health workers and dwindling resources. This resource decline is at a time when the public health system is expected to be fully prepared for new and emerging health problems and large-scale public health emergencies, ranging from pandemic influenza to bioterrorism and now the negative health impacts of climate change. It is essential that we adequately invest in our public health infrastructure so that public health is able to fulfill all of its responsibilities, ranging from the prevention of chronic disease, injury and infectious disease, and responding to natural and manmade disasters.

2. Does the American Public Health Association have anyone on staff with personal experience with the energy industry, the automobile industry or the renewable fuels industry?

We do not have an employee with experience in those industries. However, APHA's membership is very diverse and we do have members with experience in some of those areas.

3. Would you say that compared to the rest of the world, our health system is one of the best?

While the U.S. health system has many fine qualities, we are not as competitive as we could be with many industrialized nations. Our system has not been shown to provide the best quality at the best price, we have failed to cover 47 million of our citizens and we have significant variances in the equity of care. Most strikingly we have neglected to adequately invest in population health and prevention in ways that reduce the cost of care for all and protect our citizens from harm. It is critical that we address these issues as well as provide the resources to our public health system at the federal, state and local levels to ensure a healthier population overall.

4. When you say that the local public health community needs resources, do you mean money?

The public health community needs a variety of resources to undertake the tremendous responsibility of keeping our nation healthy. These resources include funding, technology, research, education and a trained workforce. The public health system will be a first line responder to potential emergency situations caused by climate change. We must insure that they have the manpower, technology and training to respond effectively.

5. Are there any situations that would arise from diseases exacerbated by climate change that would necessitate drastically different equipment or supplies in health facilities?

The main concern with climate change over the next few decades are increases in the geographic range and incidence of a range of health outcomes sensitive to temperature, precipitation, and/or other weather variables. In most cases, similar equipment and supplies will be needed – with more equipment and supplies needed in areas that will see increases. For example, projected increases in ozone concentrations could lead to more hospitalizations for respiratory diseases, requiring more equipment and trained personnel in these areas.

The need for public health response is unlikely to change in a linear fashion. For example, vector-borne disease surveillance and control activities had to be significantly changed once West Nile was introduced and persisted in the U.S. Climate change is providing conditions for a variety of vector-borne diseases to alter their geographic range, which can place new demands on health facilities.

Please feel free to contact me with any additional questions. We look forward to continuing to work with members of the Committee on addressing the health impacts of climate change.

Sincerely,

Georges C. Benjamin, MD, FACP, FACEP (E)
Executive Director
American Public Health Association

American Academy of Pediatrics
Responses to additional questions submitted by members of the Select Committee on Energy Independence and Global Warming
June 2008

1) **Is it safe to say that children are always more at risk for any type of danger because they are smaller, less developed, and less able to provide themselves protection? And poor children are even more at risk?**

Children are often, though not always, at increased risk due to their size, developmental stage, and other factors. There are, for example, certain infectious diseases to which adults are more vulnerable than children. In general, however, it is advisable to consider children to be at increased risk for most hazards. Children from low-income families or communities are often at additional risk beyond other children due to the lack of resources and other challenges they may face. For example, poor nutritional status may increase a child's vulnerability to certain diseases, poor access to medical services may leave them vulnerable to preventable or treatable infections, and lack of financial resources may prevent families from evacuating in advance of foreseeable danger.

2) **On page 5 of your testimony, you note that "preterm births, low birth weight and infant mortality are increased in communities with high levels of particulate air pollution." Aren't these issues also symptomatic of inner cities where you find more poor children whose mothers don't necessarily get the prenatal care or nutrition that they need? If you were going to prioritize funds to deal with the issue, would you put them into climate change policy or pre-natal care?**

Like so many other issues, global climate change will not impact everyone equally – disparities will exist. Tragically, the greatest burden will likely be borne by those who can afford it least, including populations that are already grappling with the toll of other disparities such as poverty, malnutrition, and poor access to health care.

A variety of factors may increase risk of pregnancy complications, low birth weight, pre-term delivery, or infant mortality. However, the studies linking exposure to high levels of particulate air pollution with these outcomes carefully controlled for these other factors in order to determine that the results were not confounded by outside variables.

Congress must not fall into the trap of making a Hobson's choice between dedicating resources to climate change and other priorities, such as prenatal care. Limiting the impact of climate change is an important public health priority with global implications. Similarly, quality prenatal care is vital for healthy pregnancies and healthy babies. Our nation can and must pursue both goals simultaneously.

3) **On page 8 of your testimony, you note a specific range that you think should be set for ozone. I want to note here that we have been working toward reducing ozone through the Clean Air Act already and no new global warming initiative is required to make that determination. But also on that page, you note that we should improve public health care systems with immunization programs and disease surveliance, reporting and tracking – isn't that also going on already?**

The current federal efforts in disease surveillance, reporting and tracking are limited and must be expanded if they are to be utilized effectively. The Centers for Disease Control and Prevention (CDC) surveillance programs (http://www.cdc.gov/ncidod/osr/index.htm) are capable of tracking certain types of outbreaks, but not all states track the same conditions. Initiatives to track trends such as school absences, emergency department visits for respiratory conditions, or pharmacy sales are in their infancy and should be developed further.

4) **On the issue of emergency management and disaster response, is the American Academy of Pediatrics working with the Disaster Preparedness and Emergency Response Association to be sure that those who are truly responsible for emergency management understand the needs of children in a crisis?**

The American Academy of Pediatrics works with a wide range of groups on disaster preparedness issues. The AAP leads the Partnership for Children's Disaster Preparedness, a coalition of over 40 advocacy organizations that work on pediatric readiness issues. The AAP has built vigorous relationships with the Department of Homeland Security, the Department of Health and Human Services, and numerous agencies to advance these efforts. AAP members and representatives sit on bodies including the National Commission on Children and Disasters and the National Biodefense Science Board. The AAP works with other organizations that represent disaster management professionals and would be pleased to work with the Disaster Preparedness and Emergency Response Association.

5) **You state on page 6 of your testimony that, "Some investigators have argued that part of the current global increase in childhood asthma can be explained by increased exposure to aeroallergens driven by climate change." What evidence do you have to support this claim?**

Temperature-related increases in pollen production and other aeroallergens have been reported in some regions and some cities. Increased temperature causes increases in amounts of pollens produced by some plants[1] and can also affect spatial distribution and density of plants, fungi, and molds that produce aeroallergens.[2] To the extent that exposure to aeroallergens contributes to the incidence, prevalence, and severity of asthma, atopy, and other respiratory disease, climate change will affect the pattern of disease in children. Some investigators argue that part of the current global increase in childhood asthma can be explained by increased exposure to aeroallergens driven by climate change.[3]

6) **You state in your testimony, "Populations that live in temperate climates such as in the United States and Europe are likely to be hard hit initially, because global warming is most dramatic in these latitudes and there has been littlie time for**

[1] Beggs PJ. Impacts of climate change on aeroallergens: past and future. *Clin Exp Allergy*. 2004;34:1507-1513.
[2] Ziska LH, Gebhard DE, Frenz DA, Faulkner S, Singer BD, Straka JG. Cities as harbingers of climate change: common ragweed, urbanization, and public health. *J Allergy Clin Immunol*. 2003;111:290-295.
[3] Beggs PJ, Bambrick HJ. Is the global rise of asthma an early impact of anthropogenic climate change? *Environ Health Perspect*. 2005;113:915-919.

populations to acclimatize to changes in temperature." Haven't humans adapted to different climates for ages, and don't folks in the Midwest adapt from very hot summers to very cold winters currently? Why do you think that people will not be able to adapt to gradual changes in temperature over the span of multiple decades?

While human beings are remarkably resilient, experience has taught us that many people struggle when temperatures drop above or below a certain range. This is especially true for those most vulnerable to physical stresses, such as children and the elderly. In summer 2003, unusually hot and dry conditions in Europe are believed to have caused anywhere from 22,000[4] to 44,000[5] excess deaths due to a combination of the heat itself, increased air pollution, and the role of heat in aggravating certain pre-existing conditions. Over 2,000 excess deaths were estimated to have occurred in England and Wales alone.[6] In 1995, a heat wave resulted in the death of approximately 600 individuals in five days in the city of Chicago.[7] In winter 2008, a harsh cold snap was responsible for the deaths of almost 1000 people in Afghanistan[8], over 125 in China[9], and 200 in India[10]. The biological changes necessary to adapt to temperature changes of these magnitudes would likely have to take place over thousands of years, rather than decades. Other adaptive changes, such as widespread air conditioning, cooling stations and social networking to reach out to isolated, elderly and ill at-risk populations have been effective in reducing mortality during heat waves. As climate change accelerates, however, these adaptive changes which require energy should be powered by renewable, clean energy sources to avoid creating a vicious cycle of trying to avoid harm from heat waves in the short term but creating conditions that promote more heat waves in the medium and long term.

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[4] Kovats S, Wolf T, Menne B. Heatwave of August 2003 in Europe: provisional estimates of the impact on mortality. *Eurosurveillance*, Volume 8, Issue 11, 11 March 2004.

[5] Kovatsky T. The 2003 European Heat Waves. *Eurosurveillance*, Volume 10, Issue 7, 01 July 2005.

[6] Johnson H, Kovats RS, McGregor G, Stedman J, Gibbs M, Walton H. The Impact of the 2003 Heat Wave on Daily Mortality in England and Wales and the Use of Rapid Weekly Mortality Estimates. *Eurosurveillance*, Volume 10, Issue 7, 01 July 2005.

[7] Whitman S, Good G, Donoghue ER, Benbow N, Shou W, Mou S. Mortality in Chicago attributed to the July 1995 heat wave. *Am J Public Health*. 1997 September; 87(9).

[8] Afghan Winter Death Toll Reaches 926. Associated Press, Feb 15 2008.

[9] Report: China's cold, snowy winter has left 129 people dead. Associated Press Worldstream. Feb 23 2008.

[10] Rain brings relief to farmers in Punjab, Haryana; toll reaches 200. United News of India. Feb 3 2008.

In addition, climate has profoundly affected communities' built environment as structures and systems were developed to keep people comfortable depending upon the expected temperature range. In many temperate zones, air conditioning is rare. When those areas begin experiencing more frequent heat waves, significant resource shifts may be necessary to keep people not only comfortable but healthy. If energy resources become more limited, the ability to create a safe, comfortable climate may be reduced. In addition, some events may compound others; in June 2008, a series of violent thunderstorms knocked out electricity for hundreds of thousands of customers in the metropolitan Washington DC area and was then followed by a 4-day heat wave, resulting prolonged exposure to dangerous heat levels for many individuals and families.

THE SELECT COMMITTEE ON
ENERGY INDEPENDENCE AND GLOBAL WARMING

Dear Dr. Jacobson:
Following your appearance in front of the Select Committee on Energy Independence and Global Warming, members of the committee submitted additional questions for your attention. I have attached the document with those questions to this email. Please respond at your earliest convenience, or within 2 weeks. Responses may be submitted in electronic form, at aliya.brodsky@mail.house.gov. Please call with any questions or concerns.

Thank you,
Ali Brodsky

Ali Brodsky
Chief Clerk
Select Committee on Energy Independence and Global Warming
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1) Even though the EPA did not approve California's waiver, aren't there a number of programs underway to curb carbon emissions in California?

Vehicles emit about 40% of California's carbon dioxide. As far as I am aware, California has a fuel standard for lifecycle carbon emissions but not an emission standard for carbon dioxide from vehicles. A fuel standard is one that requires that new fuels have lifecycle carbon emissions less than a given value. As such, there is no requirement or expectation for carbon dioxide tailpipe emissions to be reduced. Since the lifecycle of most fuels occurs out of cities and outside of California (e.g., oil is mined worldwide), there is also no expectation that carbon dioxide emissions in California cities will decrease relative to carbon dioxide emissions worldwide as a result of a fuel standard. Since carbon dioxide emitted in cities affects air pollution in the same cities, it would appear that a lifecycle fuel standard will have less of an impact on air pollution in California than will a carbon dioxide emission standard that reduces emissions directly in cities.

2) If California wants to limit growth or ban cars, could the state put an environmental tax on fuel or any number of other measures?

A tax is certainly beneficial from an emission standpoint, but a tax would not decrease emissions substantially since gasoline supply / demand is relatively inelastic.

More important, history has indicated that a command and control method of reducing emissions is very effective at not only spurring emission reductions but also spurring new technologies that benefit the United States in terms of patents and health benefit savings. For example, the CAAA 70 requirements to reduce NOx, CO, and HC emissions by 90% within 5 years led directly to the invention of the catalytic converter, which not only accomplished this goal but also put America at the forefront of air pollution control technology innovation. Similarly, a requirement to reduce CO2 emissions will lead to new innovation, either in new vehicle types or fuels or control devices that will keep America at the forefront. A recent (e.g., a couple of years ago) GAO report I saw indicated that CAAA 70 regulations benefitted the U.S. financially around 7 to 8 times greater (from my recollection) more than it cost. A tax, while helpful at reducing demand, does not address the fundamental problem of how to eliminate combustion from fossil-fuel vehicles.

3) Given that southern California has been the most notable and consistent area in non-compliance with current Clean Air Act requirements, should California first focus on reaching attainment under existing standards prior to forcing more stringent standards on the rest of the country, who have largely been in compliance?

If a CO2 waiver is granted to California, other states have the option to set the same emission requirements as California, but are not required to do so. As such, other states would not be "forced" to meet the California standard.

There is not currently a vehicle emission standard for CO2. With respect to emission standards for other pollutants, such standards are all being met by California in that new cars sold must meet state and federal emission standards. Yet, air pollution still persists. As such, emission standards for all chemicals, including CO2, need to be tightened further if we are truly interested in reducing the health risk to Americans.

Further, health effect damage (e.g., mortality, hospitalization, respiratory illness, cardiovascular disease) occurs at ambient pollution levels far below the standards for ozone and PM, so it is important not only to meet the standard but also to reduce pollution far below the standard.

4) In your testimony you state that there have been no scientific papers on the effects of global carbon dioxide on California vs. U.S. air pollution health, but didn't the IPCC detail regional effects of climate change? Do the regional studies by the IPCC verify that greenhouse gas emissions will have negative consequences that are not constrained solely to California?

No paper previously or to this day, except for the paper I published, has examined the effect of global carbon dioxide specifically on air pollution mortality over the U.S.. IPCC summarize scientific results from other studies. They have not reported any study on the effect of carbon dioxide alone on regional climate change or on gas, particle, and carcinogenic air pollution mortality in the U.S. as a whole due to carbon dioxide alone.

IPCC has reported studies of all greenhouse gases together on regional climate change that show different consequences of climate change on weather/climate in different locations. However, regional climate change studies do not account for or report changes in air pollutants nor do they map air pollution changes to population changes and health effects changes. As such, no regional or other climate change

study has quantified the effect of climate change on air pollution mortality in California versus in any other state.

5) In discussing your study on air pollution in California, you state, "the reason (for higher deaths proportionally in California) is that higher temperatures and water vapor due to carbon dioxide increase pollution the most where it is already high and California has six of the ten most-polluted cities in the United States." Further in the discussion of your findings, you note that increase in temperature have a higher impact on ozone when ozone is already high and has little effect or slightly decreases ozone when ozone is low. When considering the drastic measures that California is seeking in order to mitigate an increase in temperature, which the state will have only a minimal impact, shouldn't California first seek to lower their local particulate pollution and ozone pollution prior to seeking changes in national standards, such as fuel economy?

I think there is a misunderstanding here. California' request for a waiver has nothing to do with a national fuel economy standard. California is seeking to control its own CO2 emissions from vehicles. Such controls may be replicated by other states, but there is no requirement for other states to follow. Such a waiver request does not change the national fuel economy standard from my understanding.

One of the conclusions in my testimony is that locally-emitted carbon dioxide also impacts local air quality (in addition to globally-emitted carbon dioxide affecting local air quality). As such, local controls of CO2 will impact gas and particle air pollution locally. The statement that "which the state will have only a minimal impact" has, to my knowledge, not been shown scientifically with a 3-D model of the atmosphere; instead, it is an argument drawn only from the relative emissions of carbon dioxide to those of the world. As I discussed in my testimony, the local effects of local CO2 emissions differ from globally-averaged effects.

6) What role does population density play in your calculations of additional deaths due to carbon dioxide? Would your models show similar results for other areas that have comparable population densities?

I accounted for the actual population distribution of the U.S. at about 50 km resolution. Thus, the conclusion that I drew (e.g., that 30% of the deaths in the U.S. due to globally-emitted CO2 occur in California, which has about 12% of the population) was based on a calculation that treated the spatial variation of population.

7) Your model predicted only strict increase in ground O3 and particulate matter but that is not consistent what has been observed improvement of air quality of the last 30 years using similar parameters—all these decreases in ground O3 and indices for particulate matter are occurring while local and global atmospheric CO2 are rising rapidly. Why believe your model extrapolation results?

My model has been evaluated rigorously against ozone and air pollution data in California and in the U.S. in many studies.

In the present study, I was not examining the change in air quality in California or the U.S. during the last 30 years, I was looking at the effect of CO2 alone on air pollution under today's (2002) emissions of all other pollutants aside from CO2.

Under today's emissions, the model matches the data well (e.g., see the last slide I showed in the oral testimony). The effect of CO2 was determined by examining the change in air pollution under today's emissions by removing only CO2.

8) Where were the epidemiological data for the connection of those air pollutants and health you extrapolated and show in your table 1: were those actual deaths for citizens of California, USA and the whole world caused by the air pollutants you listed? Have your

analyses included beneficial effects of rising atmospheric CO2 for plant and food production---why show results that only address risks but not benefits?

The epidemiological data I used are referenced in the paper located at

http://www.stanford.edu/group/efmh/jacobson/Ve.html

The data provide correlations between actual deaths in U.S. cities and measured outdoor levels of individual air pollutants.

The EPA Administrator has pointed out that a waiver can be granted based only on air quality impacts of global warming (e.g., please see the two reasons cited in my testimony). The Administrator has indicated that other effects of CO2 are not so relevant. As such, I did not focus on them.

Nevertheless, the effects of CO2 on plant and food production are ambiguous. During the last 10 years of a cherry farm owned by our family in Sunnyvale, California, the farm produced fewer and fewer cherries until the trees stopped producing entirely, and the reason was a decrease in the number of cooling-degree days per year. This illustrates that the effect of climate change can damage agriculture as well as improve it in some other cases (e.g., grapes for wine grow better in warmer climates).

9) Ozone-forming emissions have declined, even as the world has warmed. Moreover, already-adopted requirements will eliminate most remaining air pollutant emissions during the next two decades. Given these facts, why did you estimate global warming health effects using emissions from 2002?

In the U.S. and Europe, emissions per vehicle have declined and this should result in the future in lower air pollution than today. Because of population increase, such reductions will not be so great as if the population did not increase. Further, under IPCC scenarios, emissions of pollution in most countries of the world will increase,

not decrease, in the future, as many countries will start to use more combustion technologies.

We did a study that showed that, in 2020, even with a future improvement in vehicle emissions, vehicle emissions alone will still kill more than 10,000 people per year in the U.S.

www.stanford.edu/group/efmh/jacobson/E85vWindSol

in part because population will increase and pollution will not decrease as significantly as it needs to. As such, the statement that "already-adopted requirements will eliminate most remaining air pollutant emissions during the next two decades " is not correct.

We used 2002 emissions since these are the most reliable. Further, the deaths found from the present study are occurring today due to carbon dioxide emitted today and in the past.

If we ran a simulation for 2020 or 2030, I would suspect the results would be similar since, although background air pollution in the U.S. will be lower, carbon dioxide will be much higher, temperatures will be higher, and water vapor will be higher; thus CO2 would have a greater impact on the lower pollution, causing a higher percent change in pollution of lower magnitude than the results for 2002.

10) John Christy calculates that even if the entire world adopts California's emission standards, and all cars everywhere average 43 mpg, this will avert only 0.05F of warming by 2100. Environmental officials and Jim Hansen also testified under oath that the CA standards would not produce any measurable change in temperatures even if the entire world adopted them. How then do we get any measurable health benefit out of granting the California waiver?

These scientists were not addressing the impact of CO_2 emissions on local CO_2 levels, local temperatures, or local air pollution, so it does not appear that their testimony is so relevant to the science I reported in my testimony.

43 mpg is a start and will result in local CO_2 reductions that will result in local air pollution reductions not reflected in the globally-averaged temperature change reported.

Further, if California can control its own CO_2 emissions, it may eventually set a standard of zero emissions of CO_2, reducing up to 40% of its own CO_2, emissions reducing the local impact of CO_2 emissions on local air pollution more significantly.

American Academy of Pediatrics
DEDICATED TO THE HEALTH OF ALL CHILDREN™

TECHNICAL REPORT

Global Climate Change and Children's Health

Katherine M. Shea, MD, MPH, and the Committee on Environmental Health

ABSTRACT

There is a broad scientific consensus that the global climate is warming, the process is accelerating, and that human activities are very likely (>90% probability) the main cause. This warming will have effects on ecosystems and human health, many of them adverse. Children will experience both the direct and indirect effects of climate change. Actions taken by individuals, communities, businesses, and governments will affect the magnitude and rate of global climate change and resultant health impacts. This technical report reviews the nature of the global problem and anticipated health effects on children and supports the recommendations in the accompanying policy statement on climate change and children's health.

INTRODUCTION

Scientists[1] and governments[2] concur that Earth is warming; rapid global climate change is underway, and human activities are very likely (>90% probability) the main cause. Adverse human health and ecosystem consequences are anticipated,[3] and some are already being measured. Physicians have written on the projected effects of climate change on public health,[4,5] but little has been written specifically about anticipated effects of climate change on children's health.[6]

Children represent a particularly vulnerable group that is likely to suffer disproportionately from both direct and indirect adverse health effects of climate change.[7] Pediatric health care professionals must understand the escalating nature of these threats, anticipate their effects on children's health, and participate as children's advocates for strong mitigation and adaptation strategies now and at all levels, from local to global.[8] This technical report examines both direct and indirect threats to children's health and futures related to climate change.*

NATURE OF THE GLOBAL PROBLEM

"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperature, widespread melting of snow and ice, and rising global mean sea level."[1] According to the National Climatic Data Center, all records indicate that during the past century, global surface temperatures have increased at a rate near 0.6°C per century (1.1°F per century), but the trend has been 3 times larger since 1976.[9] The results of this warming on regional climate are not uniform. In general, land-surface temperatures are increasing faster than sea-surface temperatures.[9] The climate in latitudes between 40°N and 70°N is warming more quickly than that in lower latitudes, and some areas (eg, the southeastern United States) are actually cooling. Changes in precipitation that occur with climate change

www.pediatrics.org/cgi/doi/10.1542/peds.2007-2646

doi:10.1542/peds.2007-2646

*Since the writing of this technical report, the full reports of the 4th Assessment by the Intergovernmental Panel on Climate Change have become available, and additional studies have been published that include more detailed historical and current data documenting global climate change.

All technical reports from the American Academy of Pediatrics automatically expire 5 years after publication unless reaffirmed, revised, or retired at or before that time.

The guidance in this report does not indicate an exclusive course of treatment or serve as a standard of medical care. Variations, taking into account individual circumstances, may be appropriate.

Key Words
climate change, global warming, child, pediatric, health, sustainable development

Abbreviation
GHG—greenhouse gas

are also nonuniform.[10] Since 1900, precipitation has increased 5% globally, but it has increased 0.5% to 1% per decade in northern midlatitudes and decreased 0.3% per decade in subtropical latitudes.[11] In contrast, snowfall in the northern hemisphere has decreased by 10% since 1966.[11]

Examples of the effects of climate change have been widely reported.[11] Glaciers are in rapid retreat, and Arctic sea ice is melting.[12] As a result of thermal expansion, sea level has increased 1 to 2 mm/year over the past 100 years.[11] Oceans are acidifying as atmospheric carbon dioxide (CO_2) is absorbed by the marine buffer system.[13] Ecosystems and individual species are being affected in a variety of ways.[14] Changes in temperature affect the density and range of species; natural history traits such as migration, flowering, and egg laying; morphology such as body size and behavior; and genetic frequency shifts. In an analysis of 143 studies that span decades of observation,[15] more than 80% of 1468 species (mollusks to mammals and grasses to trees) are currently showing significant changes in temperature-sensitive species traits.

There is strong consensus among expert scientists that Earth is undergoing rapid, global climate change,[1,16] although there remains uncertainty about how rapidly and extensively the climate will change in the future. Given the range of possibilities, the Intergovernmental Panel on Climate Change has developed a suite of scenarios for different levels of mitigation and adaptation in response to anthropogenic (man-made) global climate change; all their cases predict that temperatures and sea level will continue to rise throughout the 21st century.[17] Recent analyses describe thermal inertia in Earth's climate system such that even if greenhouse gas (GHG) emissions were abruptly reduced to zero, the planet would continue to warm for decades until the energy stored in the system equilibrates.[18] The possibility of reaching a tipping point at which abrupt, large, and irreversible change could be superimposed on current trends adds both urgency and further ambiguity to the situation.[19] In this context, it is critical to understand that current human activities are accelerating climate change and that future human activities will affect their trajectories.[20]

ANTHROPOGENIC CAUSES OF THE CHANGE

The greenhouse effect is necessary to life on Earth as we know it (Fig 1). Without heat-trapping GHGs such as water vapor, CO_2, and other natural components of the atmosphere, Earth would be a lifeless, frozen planet (average temperature: −18°C) instead of the diverse biosphere we know today.[11] Since the onset of the industrial age, however, human activity has dramatically enhanced the greenhouse effect by rapidly adding large amounts of GHGs to the atmosphere (Table 1 [note that the United States leads total country and per-capita emissions]). Three GHGs, CO_2, methane, and nitrous oxide, are responsible for approximately 88% of the anthropogenic influences that enhance the greenhouse effect and have increased 35%, 155%, and 18%, respectively, since 1750 (the beginning of the industrial era).[21] Rates of increase in GHGs are accelerating, up 20% since 1990.

CO_2 is the most important GHG and is responsible for more than 60% of human-enhanced increases and more than 90% of rapid increase in the past decade.[21] Most CO_2 emissions are from the burning of fossil fuels such as coal, oil, and gas. Rising CO_2 is also related, to a lesser extent, to deforestation, which eliminates an important carbon sink (carbon sinks are reservoirs that absorb or take up released carbon from another part of the carbon cycle; the 4 major sinks on the planet are the atmo-

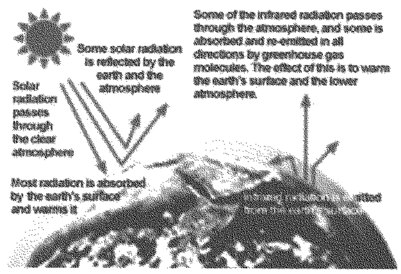

FIGURE 1
The greenhouse effect. Energy from the sun drives Earth's weather and climate and heats its surface; in turn, the earth radiates energy back into space. Atmospheric greenhouse gases (water vapor, CO_2, and other gases) trap some of the outgoing energy, retaining heat somewhat like the glass panels of a greenhouse. Without this natural "greenhouse effect," temperatures would be much lower than they are now, and life as known today would not be possible. Instead, thanks to GHGs, Earth's average temperature is a more hospitable 60°F. However, problems may arise when the atmospheric concentration of GHGs increases. (Source: US Environmental Protection Agency [http://yosemite.epa.gov/oar/globalwarming.nsf/content/climate.html].)

TABLE 1 2004 Carbon Dioxide Emissions From Fossil Fuel

Region and Country[a]	Total Emissions, Million Metric Tons	Emissions Per Capita, Metric Tons
North America	6886.88	15.99
United States	5912.21	20.18
Central and South America	1041.45	2.35
Europe[b]	4653.43	7.96
Eurasia[b]	2550.75	8.88
Russia	1684.84	11.70
Middle East[b]	1319.70	7.24
Africa[b]	986.55	1.13
Asia and Oceania	9605.81	2.69
China	4707.28	3.62
India	1112.84	1.04
Japan	1262.10	9.91
World Total	27 043.57	4.24

[a] Itemized if country's emissions exceed 1000 million metric tons.
[b] No single country in the region exceeds 1000 million metric tons.
Source: Energy Information Administration (www.eia.doe.gov/environment.html).

sphere, the terrestrial biosphere [eg, trees and freshwater systems], oceans, and sediments).[21] Currently, the atmosphere contains approximately 370 ppm of CO_2, which is the highest concentration in 420 000 years and perhaps as long as 2 million years.[11] Estimates of CO_2 concentrations at the end of the 21st century range from 490 to 1260 ppm, or a 75% to 350% increase above preindustrial concentrations.[11]

The importance of the magnitude of GHG emissions is linked to the rate of release. In the distant geologic past, similar concentrations of atmospheric CO_2 have occurred, but they accumulated over a 10 000-year period, allowing for the slow, global biogeochemical cycles to adjust to the increases. Current emissions are being added to the atmosphere at 300 times this rate.[11] This confluence of speed and quantity of emissions has created the current, unprecedented rapid climate change.

CLIMATE CHANGE–ASSOCIATED HEALTH EFFECTS ON CHILDREN

Human health is affected by the condition of the physical environment.[22] Because of their physical, physiologic, and cognitive immaturity, children are often most vulnerable to adverse health effects from environmental hazards.[23] As the climate changes, environmental hazards will change and often increase, and children are likely to suffer disproportionately from these changes.[8] Anticipated health threats from climate change include extreme weather events and weather disasters, increases in certain infectious diseases, air pollution, and thermal stress. Within all of these categories, children have increased vulnerability compared with other groups. These direct health threats are discussed in this section, with an emphasis on children in the United States.[24] Indirect threats are discussed briefly in "Long-term and Indirect Climate Change-Associated Health Threats to Children" below.

Extreme Weather Events and Weather Disasters

The Intergovernmental Panel on Climate Change predicts that it is "likely" or "extremely likely" that climate change will cause increased frequency and intensity of extreme weather events and weather disasters.[25] Often, these events are categorized as floods, storms, and droughts. Floods represented 43% of weather-related disasters between 1992 and 2001 and are the most frequent weather-related disaster. Although less prevalent, droughts and their associated famines are the most deadly weather-related disasters.[3] Developed countries such as the United States have systematically increased the risk to populations from flood events by developing coastlines and flood plains. In the United States, hurricanes and tornadoes may be the most dramatic and visible weather disasters. Evidence suggests that the frequency of category 4 and 5 hurricanes has increased over the past 30 years, but the observation period is still too short to attribute this change to increased sea-surface temperature and climate change with high confidence.[26]

The health consequences associated with extreme weather events include death, injury, increases in infectious diseases, and posttraumatic mental health and behavior problems.[27] Few studies have specifically examined such consequences in children. Globally, 66.5 million children annually were affected by disasters between 1990 and 2000.[28] Children everywhere are at risk of injury and death from storms and floods.[29] In the developed world, infectious disease outbreaks follow natural disasters when sanitation, sewage treatment, and water-purification plants become damaged or overwhelmed, refrigeration and cooking facilities are disrupted, and people are unusually crowded in temporary shelter. These outbreaks are usually mild and well controlled, which is in contrast to the aftermath of similar catastrophes in developing nations, where disease outbreaks can be deadly.[24] Mosquito-borne and other vector-borne illnesses may also be increased when storms or floods create large amounts of standing water suitable for breeding. Mental and emotional distress documented for children and adolescents after weather disasters include posttraumatic stress disorder and high rates of sleep disturbance, aggressive behavior, sadness, and substance use/abuse.[29] Some studies have suggested that children have more persistent symptoms than adults who experience the same disaster,[30] but more studies specific to children's experience are required.[31] Community support services[32] and early therapeutic intervention and postdisaster counseling[33,34] can significantly reduce the medium- and long-term mental health burden on children. Experiences with Hurricane Katrina demonstrated the difficulties with tracking children's whereabouts, keeping children and caregivers together, and special needs of hospitalized infants and children during and after major natural disasters.[35]

Infectious Diseases

Globally, infectious diarrhea is the second-leading cause of death in young children; water-borne gastroenteritis is projected to increase under conditions of global warming. Currently, the World Health Organization estimates that, approximately 1.62 million children younger than 5 years die of diarrhea annually, and most cases are attributable to contaminated water.[36] Although children in developed countries are unlikely to die of water-borne infections, they may suffer illness that is attributable indirectly to climate change. Events associated with El Nino serve as a model for global warming by altering weather for periods of several years in the direction of a hotter climate. During El Nino events, rates of hospitalizations of children for diarrhea increase.[37] (In 1 study, the rate of hospitalizations of children for diarrhea increased 8% per degree centigrade of temperature increase.[38]) Water-borne disease outbreaks in the United

States exhibit a positive correlation with excess precipitation events, which are likely to increase with climate change; over a 45-year period, 68% of water-borne illness outbreaks have been associated with precipitation above the 80th percentile.[39] Foodborne illness correlates positively with ambient temperature and is also likely to increase as the climate warms.[37,40,41]

Vector-borne infections are affected by climate change.[42] Both the hosts (eg, rodents, insects, snails) and the pathogens (eg, bacteria, viruses, parasites) can be sensitive to climatic variables such as temperature, humidity, and rainfall. The ability to predict disease rates related to climate change is complicated by a large number of additional variables such as topography, land use, urbanization, human population distribution, level of economic development, and public health infrastructure.[43] There is no easy formula that predicts climate change–related infection risk with confidence.

Malaria is a climate-sensitive vector-borne illness to which children are particularly vulnerable. According to the World Health Organization, malaria currently causes 350 million to 500 million illnesses annually and more than 1 million deaths.[44] Because they lack specific immunity, children experience disproportionately high levels of both morbidity and mortality from malaria; 75% of malaria deaths occur in children younger than 5 years. The young are also more susceptible to cerebral malaria, which can lead to lifelong neurologic damage in those who survive. In areas of sub-Saharan Africa, the death rate from malaria in children 0 to 4 years of age is 9.4 in 1000 vs 0.13 in 1000 in those older than 14 years.[45] More than 3 billion people live in malaria-prone areas today. Climate change is expanding the range of host mosquitoes to higher altitudes and higher latitudes, and warmer temperatures speed the development of the parasite within the host vector.[46] Small children will be most affected by the expansion of malaria zones and the success or failure of societal response to this change.

Three vector-borne diseases that affect the United States illustrate ways in which climate change can enhance disease burden: West Nile virus infection, Lyme disease, and hantavirus pulmonary syndrome.

West Nile virus infection was first reported in the United States in New York in 1999. Although it is still not known how it entered the United States, once introduced, it spread rapidly. A series of warm winters failed to kill the mosquito vectors. Warmer summers amplified the life cycle of the mosquitoes and increased the viral load. Drought and rain cycles, particularly as they affected urban landscapes, increased the contact of the bridging mosquito vectors with birds and humans.[46] Human populations with no herd immunity were highly susceptible to infection. In 1999, there were 62 human cases of West Nile virus infection, all reported from New York state. In 2003, there were 9862 human cases reported from 45 states and the District of Columbia.[47] Although this infection is primarily of concern for the elderly rather than children, the rapid spread illustrates the challenge of infection control in a warming climate.

The prevalence of Lyme disease has been increasing in the United States since it became a reportable disease in 1992.[48] The geographic distribution of *Ixodes* species ticks, the vectors for this bacterial infection, is expanding as well. Researchers in Sweden have documented a correlation between the expanding range for *Ixodes* ticks and climate change.[49] Children 5 to 14 years of age and adults 50 to 59 years of age are most likely to contract the illness. Lyme disease, although rarely fatal, occasionally causes long-term morbidity and represents another example of a disease that is likely to increase further as the climate warms.

Finally, the 1993 outbreak of hantavirus pulmonary syndrome in the southwest United States has been linked to the El Nino conditions of 1991–1992, with increased rainfall and pine nut production, which favored population growth among rodent vectors.[50] With a case fatality rate of 36%,[51] it is of concern that warmer climates may enhance vector populations further. As with most infectious diseases, human adaptations can reduce exposure risk and disease burden.[52]

Ambient Air Pollution

Air pollution is well established as a short-term contributor to hospital use[53] and premature death. Air pollutants such as fine particulates, nitrogen oxides, sulfur oxides, and ozone are likely to increase as countries adapt to hotter temperatures by using more energy to drive air conditioning and fans. The anticipated global population of 9 billion by 2050 will also be associated with increased energy demands, which, if met by burning more fossil fuels, will exacerbate both ambient air pollution and GHG emissions.[54] Children are especially vulnerable to both short-term illness and long-term damage from ambient air pollution, because their lungs are developing and growing, they breathe at a higher rate than adults, and they spend more time outdoors engaging in vigorous physical activity.[55] Air pollution (such as ozone and particulate matter) causes respiratory and asthma hospitalizations, school absences, increased respiratory symptoms, and decrements in lung function.[55] Formation of ozone, in particular, is known to increase with increasing temperature, even without increases in the precursor primary pollutants (volatile organic hydrocarbons and oxides of nitrogen).[56] Children who are active in outdoor sports in communities with high ozone are at increased risk of developing asthma.[57] In addition, high levels of particulate matter and other copollutants affect the ability of children's lungs to grow regardless of history of asthma.[58] Rates of preterm births, low birth weight, and infant mortality are increased in communities with high levels of particulate air pollution.[55]

A second change that is being observed is the temperature-related increases in pollen production and other aeroallergens in some regions and some cities. Increased temperature causes increases in amounts of pollens produced by some plants[59] and can also affect spatial distribution and density of plants, fungi, and molds that produce aeroallergens.[60] To the extent that exposure to aeroallergens contributes to the incidence, prevalence, and severity of asthma, atopy, and other respiratory disease, climate change will affect the pattern of disease in children. Some investigators have argued that part of the current global increase in childhood asthma can be explained by increased exposure to aeroallergens driven by climate change.[61]

Thermal Stress

For all organisms, there exists a range of ideal temperature above and below which mortality increases. Humans are no exception, although temperature-mortality relationships vary significantly by latitude, climatic zone, and level of socioeconomic development.[3] As ambient temperatures increase, the frequency of heat waves will increase. It is expected that there will be fewer cold-related deaths in a warmer world,[62] but whether this will offset the expected increase in heat-related deaths is unknown. Populations that live in temperate climates, such as in the United States and Europe, are likely to be hard hit initially, because global warming is most dramatic in these latitudes and there has been little time for populations to acclimatize to changes in temperature. Observations on heat and mortality have been reported for decades[63] and have gained recent attention with the heat waves of 2003 in Europe[64] and of 2006 in Europe and North America.[63,65] Heat-related deaths and hospitalizations are most common in the elderly, especially if they are ill.[66,67] One study has found that infants and young children may represent a second, albeit smaller, higher-risk group,[68] but effects on children have not been studied adequately. In addition, children spend more time outside, especially playing sports in the heat of the afternoon, which puts them at increased risk of heat stroke and heat exhaustion.[69] Increased outdoor time during hot weather may also put children at increased risk of UV radiation–related skin damage, including basal cell carcinoma and malignant melanoma.[70] Some data indicate that heat-related mortality in the United States has decreased in recent years, in part associated with increasing percentage of homes with air conditioners.[71] It is currently unknown how effective adaptation and acclimatization will be in preventing excess heat-related deaths and illness.[72,73]

LONG-TERM AND INDIRECT CLIMATE CHANGE-ASSOCIATED HEALTH THREATS TO CHILDREN

Long-term and indirect effects on children's health from climate change will depend on how the climate continues to change over the next decades and what sorts of mitigation and adaptation strategies are adopted now.[17] How quickly and comprehensively GHG emissions can be stabilized and then reduced will have a significant effect on the rate and degree of warming, but even the most optimistic scenarios describe continued warming through the end of this century.[17] Food availability may be affected as land and ocean food-productivity patterns shift.[74] Water availability may change and become much reduced in some regions, including during summer in the snow run-off–dependent American west coast.[75] Coastal populations will be forced to move because of rises in sea level, and massive forced migrations, driven by abrupt climate change, natural disaster, or political instability over resource availability, are conceivable.[24] In addition, world population is expected to grow by 50% to 9 billion by 2050, which would place additional stress on ecosystem services and increase the demand for energy, fresh water, and food.[54] As these changes evolve, social and political institutions will need to respond with aggressive mitigation strategies and flexible adaptation strategies to preserve and protect public health, particularly for children.

MITIGATION AND ADAPTATION STRATEGIES

Strategies to address the effects of climate change, known as mitigation and adaptation, are concepts that parallel the focus on both primary and secondary prevention strategies in pediatric health care. These strategies are discussed briefly here. The prevention or minimization of the effects of climate change on children's health is beyond the control of an individual pediatrician. Yet, pediatricians can play important public roles as advocates by individual example and through community participation, political involvement, or collective advocacy at the local, state, and national levels.[76,77]

Broadly, mitigation policies (Table 2) for reduction of atmospheric GHG include reducing emissions through energy efficiency and use of renewable energy sources, increasing carbon sinks by forest preservation and reforestation, and development of GHG-capture and -sequestration technologies (carbon sequestration is the fixation of atmospheric CO_2 in a carbon sink through an active process). Adaptation involves developing public health strategies to minimize adverse health outcomes that are anticipated from climate change. These strategies include improved disease surveillance and reporting, improved weather forecasting and early warning systems, advanced emergency management and disaster-preparedness programs, development and dissemination of appropriate vaccines and medicines, and public health education and preparedness. Category-specific examples

TABLE 2 Some Examples of Mitigation Strategies

	International	National and State	Community	Business, Nonprofits, Professional Societies	Individuals
Reduce emissions and increase use of renewable energy sources	Impose carbon-emissions caps by treaty	Create GHG inventory	LEED certification of public buildings	Energy audit of office and work toward LEED certification[a]	Drive less, use public transport, carpool
	Support clean, renewable technologies in developing countries	Impose carbon-emissions caps at national and/or state level	Energy audits and renovations for all public buildings	Reward carpoolers or employees who use public transport or walk/bike to work	Use vehicles that get the highest gas mileage
	Support research, development, and use of clean, renewable fuels	Increase solar, wind, energy-efficient biofuels, and other renewable energy sources	Efficient lighting in public spaces	Promote energy conservation	Perform energy audit of home or business and make associated changes
	Promote energy conservation	Invest in research, development, and use of clean, renewable fuels	Reward businesses and home owners for energy efficiency	Buy Energy Star office equipment	Buy Energy Star appliances
		Raise corporate average fuel efficiency standards for vehicles	Maximize public transport, ticket idling cars, tax individual parking spaces, create bike lanes, and enforce high-occupancy vehicle lanes	Support telecommuting and flexible hours	Buy local foods
		Promote energy conservation	Develop sustainability awards	Video and teleconference meetings	Engage in energy-conservation efforts
		Augment public transportation options	Promote energy conservation	Consider buying carbon offsets for travel to meetings[b]	Switch to compact fluorescent bulbs
Increase (protect) sinks	Arrest deforestation	Identify, protect, and restore carbon sinks	Plant trees	Increase green space	Plant trees and shrubs
	Restore forests and wilderness	Protect national forests and wilderness areas	Reward construction of green roofs Build parks and green space	Add plants and trees in parking areas	Support parks and greenways
Carbon trapping and sequestration	Support research and development	Support research and development	Support research and development	Support research and development	Support through personal investments

This information here is not exhaustive. Many strategies have been proposed and overlap among sectors. Additional information can be found at www.grida.no/climate/ipcc_tar/wg3/index.htm, http://epa.gov/climatechange/wycd/index.html, and www.princeton.edu/~cmi.

LEED indicates Leadership in Energy and Environmental Design

[a] The LEED Green Building Rating System is a nationally accepted benchmark for the design, construction, and operation of high-performance green buildings. LEED gives building owners and operators the tools they need to have an immediate and measurable impact on their building's performance. LEED promotes a whole-building approach to sustainability by recognizing performance in 5 key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality.

[b] Reduction of individual GHG production can be accomplished by buying carbon offsets whereby, in this principle, an individual or business can pay someone to reduce or remove GHG production in that company's name. For example, if a company agrees to buy 10 tons of carbon offsets, the seller guarantees that 10 fewer tons of GHG will enter the atmosphere.

can be found at www.grida.no/climate/ipcc_tar/wg2/646.htm#tab18-2. These adaptation strategies include policy and legislative actions, engineering responses, and personal behavior change.

Effective implementation of mitigation and adaptation strategies must involve actions from the global to local levels by governments, corporations, communities, and individuals. Furthermore, climate change is part of generalized global change, which includes population growth, land use, economic change, and evolving technology; all have effects on individual human and public health (Fig 2). Any solutions that address climate change must be developed within the context of overall sustainable development (the use of resources by the current generation to meet current needs while ensuring that future generations will be able to meet their needs). Protecting the health of current and future generations requires a fundamental shift in thinking for health professionals[78]; pediatricians, as advocates for children's health, can be leaders in a move away from a traditional focus on disease prevention to a broader, more integrated focus that encompasses sustainability as synonymous with health. Given the health implications for current and future generations of children, the disease-prevention role for pediatric health care professionals includes advocating for environmental sustainability.

SUMMARY

This technical report describes the broad scientific consensus that man-made climate change has begun

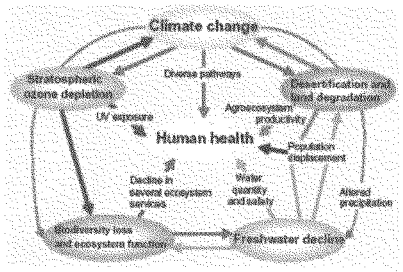

FIGURE 2
Global drivers that affect human health. Large-scale and global environmental hazards to human health include climate change, stratospheric ozone depletion, loss of biodiversity, changes in hydrological systems and the supplies of fresh water, land degradation, and stresses on food-producing systems. (Source: World Health Organization [www.who.int/globalchange/en/index.html].)

and is accelerating. The major cause of this change is the rapid release of CO_2 from burning of fossil fuel. All predictions indicate that climate change will continue for at least a century, but the trajectory of that change depends on human responses. There are anticipated effects on human health from extreme weather events, infectious diseases, air pollution, and heat stress. Although little research thus far has concentrated on the pediatric age group, it is likely that children will suffer disproportionately from climate change.[6] Furthermore, the state of the world of future children is uncertain and depends on actions taken to mitigate and adapt to climate change and other global-scale trends. Pediatric health care professionals are in an ideal position to advocate for action, not only to address climate change but also, more broadly, to ensure sustainability. Specific recommendations for pediatricians and governments are enumerated in the American Academy of Pediatrics policy statement[79] on climate change and children's health, which accompanies this technical report.

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14

North America

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Executive summary

North America has experienced locally severe economic damage, plus substantial ecosystem, social and cultural disruption from recent weather-related extremes, including hurricanes, other severe storms, floods, droughts, heatwaves and wildfires (very high confidence).
Over the past several decades, economic damage from severe weather has increased dramatically, due largely to increased value of the infrastructure at risk. Annual costs to North America have now reached tens of billions of dollars in damaged property and economic productivity, as well as lives disrupted and lost. [14.2.3, 14.2.6, 14.2.7, 14.2.8]

The vulnerability of North America depends on the effectiveness and timing of adaptation and the distribution of coping capacity, which vary spatially and among sectors (very high confidence).
Although North America has considerable adaptive capacity, actual practices have not always protected people and property from adverse impacts of climate variability and extreme weather events. Especially vulnerable groups include indigenous peoples and those who are socially or economically disadvantaged. Traditions and institutions in North America have encouraged a decentralised response framework where adaptation tends to be reactive, unevenly distributed, and focused on coping with rather than preventing problems. 'Mainstreaming' climate change issues into decision making is a key prerequisite for sustainability. [14.2.6, 14.4, 14.5, 14.7]

Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution (very high confidence).
Sea level is rising along much of the coast, and the rate of change will increase in the future, exacerbating the impacts of progressive inundation, storm-surge flooding and shoreline erosion. Storm impacts are likely to be more severe, especially along the Gulf and Atlantic coasts. Salt marshes, other coastal habitats, and dependent species are threatened by sea-level rise, fixed structures blocking landward migration, and changes in vegetation. Population growth and the rising value of infrastructure in coastal areas increases vulnerability to climate variability and future climate change. Current adaptation is uneven and readiness for increased exposure is low. [14.2.3, 14.4.3, 14.5]

Climate change will constrain North America's over-allocated water resources, increasing competition among agricultural, municipal, industrial and ecological uses (very high confidence).
Rising temperatures will diminish snowpack and increase evaporation, affecting seasonal availability of water. Higher demand from economic development, agriculture and population growth will further limit surface and groundwater availability. In the Great Lakes and major river systems, lower levels are likely to exacerbate challenges relating to water quality, navigation, recreation, hydropower generation, water transfers and bi-national relationships. [14.2.1, 14.4.1, 14.4.6, Boxes 14.2 and 14.3]

Climate change impacts on infrastructure and human health and safety in urban centres will be compounded by ageing infrastructure, maladapted urban form and building stock, urban heat islands, air pollution, population growth and an ageing population (very high confidence).
While inertia in the political, economic, and cultural systems complicates near-term action, the long life and high value of North American capital stock make proactive adaptation important for avoiding costly retrofits in coming decades. [14.4.5, 14.4.6, 14.5, Box 14.3]

Without increased investments in countermeasures, hot temperatures and extreme weather are likely to cause increased adverse health impacts from heat-related mortality, pollution, storm-related fatalities and injuries, and infectious diseases (very high confidence).
Historically important countermeasures include early warning and surveillance systems, air conditioning, access to health care, public education, vector control, infrastructure standards and air quality management. Cities that currently experience heatwaves are expected to experience an increase in intensity and duration of these events by the end of the century, with potential for adverse health effects. The growing number of the elderly is most at risk. Water-borne diseases and degraded water quality are very likely to increase with more heavy precipitation. Warming and climate extremes are likely to increase respiratory illness, including exposure to pollen and ozone. Climate change is likely to increase risk and geographic spread of vector-borne infectious diseases, including Lyme disease and West Nile virus. [14.2.5, 14.2.6, 14.4.5, 14.4.6, 14.5]

Disturbances such as wildfire and insect outbreaks are increasing and are likely to intensify in a warmer future with drier soils and longer growing seasons (very high confidence).
Although recent climate trends have increased vegetation growth, continuing increases in disturbances are likely to limit carbon storage, facilitate invasive species, and disrupt ecosystem services. Warmer summer temperatures are expected to extend the annual window of high fire ignition risk by 10-30%, and could result in increased area burned of 74-118% in Canada by 2100. Over the 21st century, pressure for species to shift north and to higher elevations will fundamentally rearrange North American ecosystems. Differential capacities for range shifts and constraints from development, habitat fragmentation, invasive species, and broken ecological connections will alter ecosystem structure, function and services. [14.2.4, 14.2.2, 14.4.2, Box 14.1]

14.1 Introduction

The United States (U.S.) and Canada will experience climate changes through direct effects of local changes (e.g., temperature, precipitation and extreme weather events), as well as through indirect effects, transmitted among regions by interconnected economies and migrations of humans and other species. Variations in wealth and geography, however, lead to an uneven distribution of likely impacts, vulnerabilities and capacities to adapt. This chapter reviews and synthesises the state of knowledge on direct and indirect impacts, vulnerability and adaptations for North America (comprising Canada and the U.S). Hawaii and other U.S. protectorates are discussed in Chapter 16 on Small Islands, and Mexico and Central America are treated in Chapter 13 on Latin America. Chapter 15, Polar Regions, covers high-latitude issues and peoples.

14.1.1 Key findings from the Third Assessment Report (TAR)

Key findings for the North America chapter of the Third Assessment Report (TAR) (Cohen et al., 2001) are:

Resources and ecosystems

- In western snowmelt-dominated watersheds, shifts in seasonal runoff, with more runoff in winter. Adaptation may not fully offset effects of reduced summer water availability.
- Changes in the abundance and spatial distribution of species important to commercial and recreational fisheries.
- Benefits from warming for food production in North America but with strong regional differences.
- Benefits from farm- and market-level adjustments in ameliorating impacts of climate change on agriculture.
- Increases in the area and productivity of forests, though carbon stocks could increase or decrease.
- Major role of disturbance for forest ecosystems. The forest-fire season is likely to lengthen, and the area subject to high fire danger is likely to increase significantly.
- Likely losses of cold-water ecosystems, high alpine areas, and coastal and inland wetlands.

Human settlements and health

- Less extreme winter cold in northern cities. Across North America, cities will experience more extreme heat and, in some locations, rising sea levels and risk of storm surge, water scarcity, and changes in timing, frequency, and severity of flooding.
- The need for changes in land-use planning and infrastructure design to avoid increased damages from heavy precipitation events.
- For communities that have the necessary resources, reduced vulnerability by adapting infrastructure.
- Increased deaths, injuries, infectious diseases, and stress-related disorders and other adverse effects associated with social disruption and migration from more frequent extreme weather.
- Increased frequency and severity of heatwaves leading to more illness and death, particularly among the young, elderly and frail. Respiratory disorders may be exacerbated by warming-induced deterioration in air quality.
- Expanded ranges of vector-borne and tick-borne diseases in North America but with modulation by public health measures and other factors.

Vulnerability and adaptation

- Increased weather-related losses in North America since the 1970s, with rising insured losses reflecting growing affluence and movement into vulnerable areas.
- Coverage, since the 1980s, by disaster relief and insurance programmes of a large fraction of flood and crop losses, possibly encouraging more human activity in at-risk areas.
- Responses by insurers to recent extreme events through limiting insurance availability, increasing prices and establishing new risk-spreading mechanisms. Improving building codes, land-use planning and disaster preparedness also reduce disaster losses.
- Awareness that developing adaptation responses requires a long, interdisciplinary dialogue between researchers and stakeholders, with substantial changes in institutions and infrastructure.
- Recognition that adaptation strategies generally address current challenges, rather than future impacts and opportunities.

14.1.2 Key differences from TAR

This assessment builds on the findings from the TAR and incorporates new results from the literature, including:

- Prospects for increased precipitation variability, increasing challenges of water management.
- The need to include groundwater and water-quality impacts in the assessment of water resources.
- The potential that multi-factor impacts may interact non-linearly, leading to tipping points.
- The potential importance of interactions among climate change impacts and with other kinds of local, regional and global changes.
- The potential for adaptation, but the unevenness of current adaptations.
- The challenge of linking adaptation strategies with future vulnerabilities.
- Availability of much more literature on all aspects of impacts, adaptation and vulnerability in North America.

14.2 Current sensitivity/vulnerability

Annual mean air temperature, on the whole, increased in North America for the period 1955 to 2005, with the greatest warming in Alaska and north-western Canada, substantial warming in the continental interior and modest warming in the south-eastern U.S. and eastern Canada (Figure 14.1). Spring and winter show the greatest changes in temperature (Karl et al., 1996; Hengeveld et al., 2005) and daily minimum (night-time) temperatures have warmed more than daily maximum (daytime) temperatures (Karl et al., 2005; Vincent and Mekis, 2006). The length of the vegetation growing season has increased an average of 2 days/decade since 1950 in Canada and the conterminous U.S., with most of the increase resulting from earlier spring warming (Bonsal et al., 2001; Easterling, 2002; Bonsal and Prowse, 2003; Feng and Hu, 2004). The warming signal in North America during the latter half of the 20th century reflects the combined influence of greenhouse gases, sulphate aerosols and natural external forcing (Karoly et al., 2003; Stott, 2003; Zwiers and Zhang, 2003).

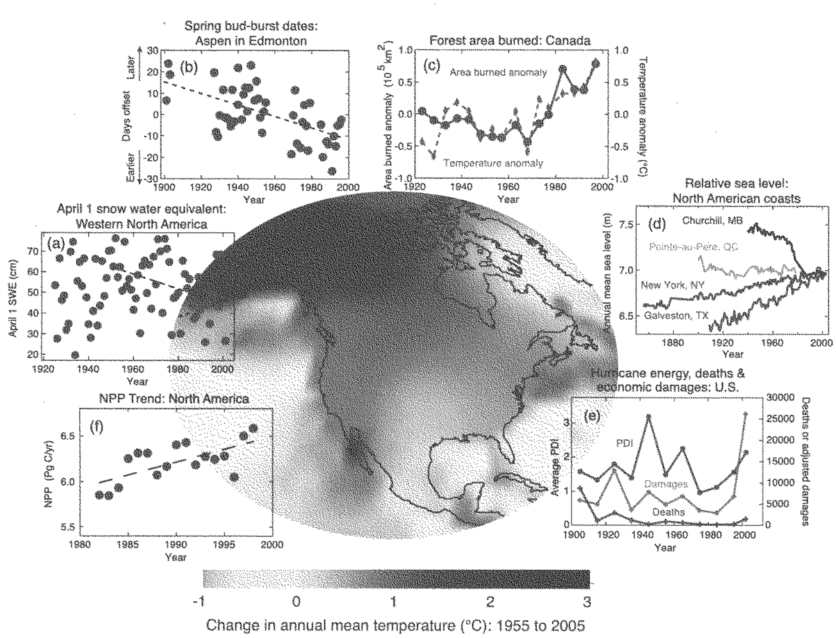

Figure 14.1. *Observed trends in some biophysical and socio-economic indicators. Background: change in annual mean temperature from 1955 to 2005 (based on the GISS2001 analysis for land from Hansen et al., 2001; and on the Hadley/Reyn_V2 analysis for sea surface from Reynolds et al., 2002). Insets: (a) trend in April 1 snow water equivalent (SWE) across western North America from 1925 to 2002, with a linear fit from 1950 to 2002 (data from Mote, 2003), (b) Spring bud-burst dates for trembling aspen in Edmonton since 1900 (data from Beaubien and Freeland, 2000), (c) anomaly in 5-year mean area burned annually in wildfires in Canada since 1930, plus observed mean summer air temperature anomaly, weighted for fire areas, relative to 1920 to 1999 (data from Gillett et al., 2004) (d) relative sea-level rise from 1850 to 2000 for Churchill, MB, Pointe-au-Père, QB, New York, NY, and Galveston, TX, (POL, 2006) (e) hurricane energy (power dissipation index (PDI) based on method of Emanuel, 2005), economic damages, million U.S. dollars (adjusted to constant 2005 US dollars and normalized accounting for changes in personal wealth and coastal population to 2004), and deaths from Atlantic hurricanes since 1900 (data from Pielke Jr. and Landsea, 1998 updated through 2005), and, (f) trend North American Net Primary Production (NPP) from 1981 to 1998 (data from Hicke et al., 2002).*

Annual precipitation has increased for most of North America with large increases in northern Canada, but with decreases in the south-west U.S., the Canadian Prairies and the eastern Arctic (see Working Group I Fourth Assessment (WGI AR4) Trenberth et al., 2007 Section 3.3.2.2, Figures 3.13 and 3.14) (Hengeveld et al., 2005; Shein, 2006). Heavy precipitation frequencies in the U.S. were at a minimum in the 1920s and 1930s, and increased to the 1990s (1895 to 2000) (Kunkel, 2003; Groisman et al., 2004). In Canada there is no consistent trend in extreme precipitation (Vincent and Mekis, 2006).

14.2.1 Freshwater resources

Streamflow in the eastern U.S. has increased 25% in the last 60 years (Groisman et al., 2004), but over the last century has decreased by about 2%/decade in the central Rocky Mountain region (Rood et al., 2005). Since 1950, stream discharge in both the Colorado and Columbia river basins has decreased, at the same time annual evapotranspiration (ET) from the conterminous U.S. increased by 55 mm (Walter et al., 2004). In regions with winter snow, warming has shifted the magnitude and timing of hydrologic events (Mote et al., 2005; Regonda et al., 2005; Stewart et al., 2005). The fraction of annual precipitation falling as rain (rather than snow) increased at 74% of the weather stations studied in the western mountains of the U.S. from 1949 to 2004 (Knowles et al., 2006). In Canada, warming from 1900 to 2003 led to a decrease in total precipitation as snowfall in the west and Prairies (Vincent and Mekis, 2006). Spring and summer snow cover has decreased in the U.S. west (Groisman et al., 2004). April 1 snow water equivalent (SWE) has declined 15 to 30% since 1950 in the western mountains of North America, particularly at lower elevations and primarily due to warming rather than changes in precipitation (Figure 14.1a) (see Mote et al., 2003; Mote et al., 2005; Lemke et al., 2007: Section 4.2.2.2.1). Whitfield and Cannon (2000) and Zhang et al. (2001) reported earlier spring runoff across Canada. Summer (May to August) flows of the Athabasca River have declined 20% since 1958 (Schindler and Donahue, 2006). Streamflow peaks in the snowmelt-dominated western mountains of the U.S. occurred 1 to 4 weeks earlier in 2002 than in 1948 (Stewart et al., 2005). Break up of river and lake ice across North America has advanced by 0.2 to 12.9 days over the last 100 years (Magnuson et al., 2000).

Vulnerability to extended drought is increasing across North America as population growth and economic development create more demands from agricultural, municipal and industrial uses, resulting in frequent over-allocation of water resources (Alberta Environment, 2002; Morehouse et al., 2002; Postel and Richter, 2003; Pulwarty et al., 2005). Although drought has been more frequent and intense in the western part of the U.S. and Canada, the east is not immune from droughts and attendant reductions in water supply, changes in water quality and ecosystem function, and challenges in allocation (Dupigny-Giroux, 2001; Bonsal et al., 2004; Wheaton et al., 2005).

14.2.2 Ecosystems

Three clear, observable connections between climate and terrestrial ecosystems are the seasonal timing of life-cycle events or phenology, responses of plant growth or primary production, and biogeographic distribution. Direct impacts on organisms interact with indirect effects of ecological mechanisms (competition, herbivory[1], disease), and disturbance (wildfire, hurricanes, human activities).

Phenology, productivity and biogeography

Global daily satellite data, available since 1981, indicate earlier onset of spring 'greenness' by 10-14 days over 19 years, particularly across temperate latitudes of the Northern Hemisphere (Myneni et al., 2001; Lucht et al., 2002). Field studies confirm these satellite observations. Many species are expanding leaves or flowering earlier (e.g., earlier flowering in lilac - 1.8 days/decade, 1959 to 1993, 800 sites across North America (Schwartz and Reiter, 2000), honeysuckle - 3.8 days/decade, western U.S. (Cayan et al., 2001), and leaf expansion in apple and grape - 2 days/decade, 72 sites in north-eastern U.S. (Wolfe et al., 2005), trembling aspen - 2.6 days/decade since 1900, Edmonton (Beaubien and Freeland, 2000)) (Figure 14.1b). The timing of autumn leaf fall, which is controlled by a combination of temperature, photoperiod and water deficits, shows weaker trends (Badeck et al., 2004).

Net primary production (NPP) in the continental U.S. increased nearly 10% from 1982 to 1998 (Figure 14.1f) (Boisvenue and Running, 2006), with the largest increases in croplands and grasslands of the Central Plains due to improved water balance (Lobell et al., 2002; Nemani et al., 2002; Hicke and Lobell, 2004).

North American forests can be influenced indirectly by climate through effects on disturbance, especially from wildfire, storms, insects and diseases. The area burned in wildfires has increased dramatically over the last three decades (see Box 14.1).

Wildlife population and community dynamics

North American animals are responding to climate change, with effects on phenology, migration, reproduction, dormancy and geographic range (Walther et al., 2002; Parmesan and Yohe, 2003; Root et al., 2003; Parmesan and Galbraith, 2004; Root et al., 2005). Warmer springs have led to earlier nesting for 28 migrating bird species on the east coast of the U.S. (Butler, 2003) and to earlier egg laying for Mexican jays (Brown et al., 1999) and tree swallows (Dunn and Winkler, 1999). In northern Canada, red squirrels are breeding 18 days earlier than 10 years ago (Reale et al., 2003). Several frog species now initiate breeding calls 10 to 13 days earlier than a century ago (Gibbs and Breisch, 2001). In lowland California, 70% of 23 butterfly species advanced the date of first spring flights by an average 24 days over 31 years (Forister and Shapiro, 2003). Reduced water depth, related to recent warming, in Oregon lakes has increased exposure of toad eggs to UV-B, leading to increased mortality from a fungal parasite (Kiesecker et al., 2001; Pounds, 2001).

Many North American species have shifted their ranges, typically to the north or to higher elevations (Parmesan and Yohe, 2003). Edith's checkerspot butterfly has become locally extinct in the southern, low-elevation portion of its western North American range but has extended its range 90 km north and 120 m higher in elevation (Parmesan, 1996; Crozier, 2003; Parmesan and Galbraith, 2004). Red foxes have expanded northward in northern Canada, leading to retreat of competitively subordinate arctic foxes (Hersteinsson and Macdonald, 1992).

14.2.3 Coastal regions

The North American coast is long and diverse with a wide range of trends in relative sea level (Figure 14.1d) (Shaw et al., 1998; Dyke and Peltier, 2000; Zervas, 2001). Relative sea level (see glossary) is rising in many areas, yet coastal residents are often unaware of the trends and their impacts on coastal retreat and flooding (O'Reilly et al., 2005). In the Great Lakes, both extremely high and extremely low water levels have been damaging and disruptive (Moulton and Cuthbert, 2000). Demand for waterfront property and building land continues to grow, increasing the value of property at risk (Heinz Center, 2000; Forbes et al., 2002b; Small and Nichols, 2003).

[1] The consumption of plants by animals.

Box 14.1. Accelerating wildfire and ecosystem disturbance dynamics

Since 1980, an average of 22,000 km^2/yr has burned in U.S. wildfires, almost twice the 1920 to 1980 average of 13,000 km^2/yr (Schoennagel et al., 2004). The forested area burned in the western U.S. from 1987 to 2003 is 6.7 times the area burned from 1970 to 1986 (Westerling et al., 2006). In Canada, burned area has exceeded 60,000 km^2/yr three times since 1990, twice the long-term average (Stocks et al., 2002). Wildfire-burned area in the North American boreal region increased from 6,500 km^2/yr in the 1960s to 29,700 km^2/yr in the 1990s (Kasischke and Turetsky, 2006). Human vulnerability to wildfires has also increased, with a rising population in the wildland-urban interface.

A warming climate encourages wildfires through a longer summer period that dries fuels, promoting easier ignition and faster spread (Running, 2006). Westerling et al. (2006) found that in the last three decades the wildfire season in the western U.S. has increased by 78 days, and burn durations of fires >1000 ha in area have increased from 7.5 to 37.1 days, in response to a spring-summer warming of 0.87°C. Earlier spring snowmelt has led to longer growing seasons and drought, especially at higher elevations, where the increase in wildfire activity has been greatest (Westerling et al., 2006). In Canada, warmer May to August temperatures of 0.8°C since 1970 are highly correlated with area burned (Figure 14.1c) (Gillett et al., 2004). In the south-western U.S., fire activity is correlated with El Niño-Southern Oscillation (ENSO) positive phases (Kitzberger et al., 2001; McKenzie et al., 2004), and higher Palmer Drought Severity Indices.

Insects and diseases are a natural part of ecosystems. In forests, periodic insect epidemics kill trees over large regions, providing dead, desiccated fuels for large wildfires. These epidemics are related to aspects of insect life cycles that are climate sensitive (Williams and Liebhold, 2002). Many northern insects have a two-year life cycle, and warmer winter temperatures allow a larger fraction of overwintering larvae to survive. Recently, spruce budworm in Alaska has completed its life cycle in one year, rather than the previous two (Volney and Fleming, 2000). Mountain pine beetle has expanded its range in British Columbia into areas previously too cold (Carroll et al., 2003). Insect outbreaks often have complex causes. Susceptibility of the trees to insects is increased when multi-year droughts degrade the trees' ability to generate defensive chemicals (Logan et al., 2003). Recent dieback of aspen stands in Alberta was caused by light snowpacks and drought in the 1980s, triggering defoliation by tent caterpillars, followed by wood-boring insects and fungal pathogens (Hogg et al., 2002).

Many coastal areas in North America are potentially exposed to storm-surge flooding (Titus and Richman, 2001; Titus, 2005). Some major urban centres on large deltas are below sea level (e.g., New Orleans on the Mississippi; Richmond and Delta on the Fraser), placing large populations at risk. Breaching of New Orleans floodwalls following Hurricane Katrina in 2005 (see Chapter 6, Section 6.4.1.2 and Box 6.4) and storm-wave breaching of a dike in Delta, British Columbia, in 2006 demonstrate the vulnerability. Under El Niño conditions, high water levels combined with changes in winter storms along the Pacific coast have produced severe coastal flooding and storm impacts (Komar et al., 2000; Walker and Barrie, 2006). At San Francisco, 140 years of tide-gauge data suggest an increase in severe winter storms since 1950 (Bromirski et al., 2003) and some studies have detected accelerated coastal erosion (Bernatchez and Dubois, 2004). Some Alaskan villages are threatened and require protection or relocation at projected costs up to US$54 million (Parson et al., 2001a). Recent severe tropical and extra-tropical storms demonstrate that North American urban centres with assumed high adaptive capacity remain vulnerable to extreme events. Recent winters with less ice in the Great Lakes and Gulf of St. Lawrence have increased coastal exposure to damage from winter storms. Winter ice provides seasonal shore protection, but can also damage shorefront homes and infrastructure (Forbes et al., 2002a).

Impacts on coastal communities and ecosystems can be more severe when major storms occur in short succession, limiting the opportunity to rebuild natural resilience (Forbes et al., 2004). Adaptation to coastal hazards under the present climate is often inadequate, and readiness for increased exposure is poor (Clark et al., 1998; Leatherman, 2001; West et al., 2001). Extreme events can add to other stresses on ecological integrity (Scavia et al., 2002; Burkett et al., 2005), including shoreline development and nitrogen eutrophication[2] (Bertness et al., 2002). Already, more than 50% of the original salt marsh habitat in the U.S. has been lost (Kennish, 2001). Impacts from sea-level rise can be amplified by 'coastal squeeze' (see Glossary) and submergence where landward migration is impeded and vertical growth is slower than sea-level rise (see Section 14.4.3) (Kennish, 2001; Scavia et al., 2002; Chmura and Hung, 2004).

14.2.4 Agriculture, forestry and fisheries

Agriculture

Over the last century, yields of major commodity crops in the U.S. have increased consistently, typically at rates of 1 to 2%/yr (Troyer, 2004), but there are significant variations across regions and between years. These yield trends are a result of cumulative changes in multiple factors, including technology, fertiliser use,

[2] Eutrophication is a process whereby water bodies, such as lakes, estuaries, or slow-moving streams receive excess nutrients that stimulate excessive plant growth (e.g., algal blooms and nuisance plants weeds).

seed stocks, and management techniques, plus any changes due to climate; the specific impact from any one factor may be positive or negative. In the Midwestern U.S. from 1970 to 2000, corn yield increased 58% and soybean yields increased 20%, with annual weather fluctuations resulting in year-to-year variability (Hicke and Lobell, 2004). Heavy rainfalls reduced the value of the U.S. corn crop by an average of US$3 billion/yr between 1951 and 1998 (Rosenzweig et al., 2002). In the Corn and Wheat Belt of the U.S., yields of corn and soybeans from 1982 to 1998 were negatively impacted by warm temperatures, decreasing 17% for each 1°C of warm-temperature anomaly (Lobell and Asner, 2003). In California, warmer nights have enhanced the production of high-quality wine grapes (Nemani et al., 2001), but additional warming may not result in similar increases. For twelve major crops in California, climate fluctuations over the last 20 years have not had large effects on yield, though they have been a positive factor for oranges and walnuts and a negative for avocados and cotton (Lobell et al., 2006).

North American agriculture has been exposed to many severe weather events during the past decade. More variable weather, coupled with out-migration from rural areas and economic stresses, has increased the vulnerability of the agricultural sector overall, raising concerns about its future capacity to cope with a more variable climate (Senate of Canada, 2003; Wheaton et al., 2005). North American agriculture is, however, dynamic. Adaptation to multiple stresses and opportunities, including changes in markets and weather, is a normal process for the sector. Crop and enterprise diversification, as well as soil and water conservation, are often used to reduce weather-related risks (Wall and Smit, 2005). Recent adaptations by the agricultural sector in North America, including improved water conservation and conservation tillage, are not typically undertaken as single discrete actions, but evolve as a set of decisions that can span several years in a dynamic and changing environment (Smit and Skinner, 2002) that includes changes in public policy (Goodwin, 2003). While there have been attempts to realistically model the dynamics of adaptation to climate change (Easterling et al., 2003), understanding of agriculture's current sensitivity to climate variability and its capacity to cope with climate change remains limited (Tol, 2002).

Forestry

Forest growth appears to be slowly accelerating (at a rate of less than 1%/decade) in regions where tree growth has historically been limited by low temperatures and short growing seasons (Caspersen et al., 2000; McKenzie et al., 2001; Joos et al., 2002; Boisvenue and Running, 2006). In black spruce at the forest-tundra transition in eastern Canada, height growth has been increasing since the 1970s (Gamache and Payette, 2004). Growth is slowing, however, in areas subject to drought. Radial growth of white spruce on dry south-facing slopes in Alaska has decreased over the last 90 years, due to increased drought stress (Barber et al., 2000). In semi-arid forests of the south-western U.S., growth rates have decreased since 1895, correlated with drought linked to warming temperatures (McKenzie et al., 2001). Relationships between tree-ring growth in sub-alpine forests and climate in the Pacific Northwest from 1895 to 1991 had complex topographic influences (Peterson and Peterson, 2001; Peterson et al., 2002). On high elevation north-facing slopes, growth of sub-alpine fir and mountain hemlock was negatively correlated with spring snowpack depth and positively correlated with summer temperatures, indicating growing-season temperature limitations. On lower elevation sites, however, growth was negatively correlated with summer temperature, suggesting water limitations. In Colorado, aspen have advanced into the more cold-tolerant spruce-fir forests over the past 100 years (Elliott and Baker, 2004). The northern range limit of lodgepole pine is advancing into the zone previously dominated by the more cold-tolerant black spruce in the Yukon (Johnstone and Chapin, 2003). A combination of warmer temperatures and insect infestations has resulted in economically significant losses of the forest resource base to spruce bark beetle in both Alaska and the Yukon (ACIA, 2004).

Freshwater fisheries

Most commercial freshwater fishing in North America occurs in rural or remote areas, with indigenous peoples often taking a major role. Recreational inland fisheries are also significant and increasing (DFO-MPO, 2002; DOI, 2002). Ecological sustainability of fish and fisheries productivity is closely tied to temperature and water supply (flows and lake levels). Climate change and variability increasingly have direct and indirect impacts, both of which interact with other pressures on freshwater fisheries, including human development (Schindler, 2001; Chu et al., 2003; Reed and Czech, 2005; Rose, 2005), habitat loss and alteration (including water pollution), biotic homogenisation due to invasions and introductions (Rahel, 2002), and over-exploitation (Post et al., 2002; Cooke and Cowx, 2004). Cold- and cool-water fisheries, especially Salmonids, have been declining as warmer/drier conditions reduce their habitat. The sea-run[3] salmon stocks are in steep decline throughout much of North America (Gallagher and Wood, 2003). Evidence for impacts of recent climate change is rapidly accumulating. Pacific salmon have been appearing in Arctic rivers (Babaluk et al., 2000). Salmonid species have been affected by warming in U.S. streams (O'Neal, 2002). Lake charr in an Ontario lake suffered recruitment[4] failure due to El Niño-linked warm temperatures (Gunn, 2002). Lake Ontario year-class productivity is strongly linked to temperature, with a shift in the 1990s toward warm-water species (Casselman, 2002). Walleye yield in lakes depends on the amount of cool, turbid habitat (Lester et al., 2004). Recent contraction in habitat for walleye in the Bay of Quinte, Lake Ontario was due in part to warming and lower water levels (Chu et al., 2005). Success of adult spawning and survival of the fry (new-borne) of brook trout is closely linked to cold groundwater seeps, which provide preferred temperature refuges for lake-dwelling populations (Borwick et al., 2006). Rates of fish-egg development and mortality increase with temperature rise within species-specific tolerance ranges (Kamler, 2002).

[3] Sea-run: having the habit of ascending a river from the sea, especially to spawn.

[4] Recruitment: the number of new juvenile fish reaching a size large enough to be caught by commercial fishing methods.

14.2.5 Human health

Many human diseases are sensitive to weather, from cardiovascular and respiratory illnesses due to heatwaves or air pollution, to altered transmission of infectious diseases. Synergistic effects of other activities can exacerbate weather exposures (e.g., via the urban heat island effect), requiring cross-sector risk assessment to determine site-specific vulnerability (Patz et al., 2005).

The incidence of infectious diseases transmitted by air varies seasonally and annually, due partly to climate variations. In the early 1990s, California experienced an epidemic of Valley Fever that followed five years of drought (Kolivras and Comrie, 2003). Water-borne disease outbreaks from all causes in the U.S. are distinctly seasonal, clustered in key watersheds, and associated with heavy precipitation (in the U.S. Curriero et al., 2001) or extreme precipitation and warmer temperatures (in Canada, Thomas et al., 2006). Heavy runoff after severe rainfall can also contaminate recreational waters and increase the risk of human illness (Schuster et al., 2005) through higher bacterial counts. This association is strongest at beaches closest to rivers (Dwight et al., 2002).

Food-borne diseases show some relationship with historical temperature trends. In Alberta, ambient temperature is strongly but non-linearly associated with the occurrence of three enteric pathogens, *Salmonella*, *E. coli* and *Campylobacter* (Fleury et al., 2006).

Many zoonotic diseases[5] are sensitive to climate fluctuations (Charron, 2002). The strain of West Nile virus (WNV) that emerged for the first time in North America during the record hot July 1999 requires warmer temperatures than other strains. The greatest WNV transmissions during the epidemic summers of 2002 to 2004 in the U.S. were linked to above-average temperatures (Reisen et al., 2006). Laboratory studies of virus replication in WNV's main *Culex* mosquito vector show high levels of virus at warmer temperatures (Dohm and Turell, 2001; Dohm et al., 2002). Bird migratory pathways and WNV's recent advance westward across the U.S. and Canada are key factors in WNV and must be considered in future assessments of the role of temperature in WNV dynamics. A virus closely related to WNV, Saint Louis encephalitis, tends to appear during hot, dry La Niña years, when conditions facilitate transmission by reducing the extrinsic incubation period[6] (Cayan et al., 2003).

Lyme disease is a prevalent tick-borne disease in North America for which there is new evidence of an association with temperature (Ogden et al., 2004) and precipitation (McCabe and Bunnell, 2004). In the field, temperature and vapour pressure contribute to maintaining populations of the tick *Ixodes scapularis* which, in the U.S., is the micro-organism's secondary host. A monthly average minimum temperature above -7°C is required for tick survival (Brownstein et al., 2003).

Exposure to both extreme hot and cold weather is associated with increased morbidity and mortality, compared to an intermediate 'comfortable' temperature range (Curriero et al., 2002). Across 12 U.S. cities, hot temperatures have been associated with increased hospital admissions for cardiovascular disease (Schwartz et al., 2004a). Emergency hospital admissions have been directly related to extreme heat in Toronto (Dolney and Sheridan, 2006). Heat-response plans and heat early warning systems (EWS) can save lives (Ebi et al., 2004). After the 1995 heatwave, the city of Milwaukee initiated an 'extreme heat conditions plan' that almost halved heat-related morbidity and mortality (Weisskopf et al., 2002). Currently, over two dozen cities worldwide have warning systems focused on monitoring for dangerous air masses (Sheridan and Kalkstein, 2004).

14.2.6 Human settlements

Economic base of resource-dependent communities

Among the most climate-sensitive North American communities are those of indigenous populations dependent on one or a few natural resources. About 1.2 million (60%) of the U.S. tribal members live on or near reservations, and many pursue lifestyles with a mix of traditional subsistence activities and wage labour (Houser et al., 2001). Many reservation economies and budgets of indigenous governments depend heavily on agriculture, forest products and tourism (NAST, 2001). A 1993 hantavirus outbreak related indirectly to heavy rainfall led to a significant reduction in tourist visits to the American South-west (NAST, 2001). Many indigenous communities in northern Canada and Alaska are already experiencing constraints on lifestyles and economic activity from less reliable sea and lake ice (for travelling, hunting, fishing and whaling), loss of forest resources from insect damage, stress on caribou, and more exposed coastal infrastructure from diminishing sea ice (NAST, 2001; CCME, 2003; ACIA, 2005). Many rural settlements in North America, particularly those dependent on a narrow resource base, such as fishing or forestry, have been seriously affected by recent declines in the resource base, caused by a number of factors (CDLI, 1996). However, not all communities have suffered, as some Alaskan fishing communities have benefited from rising regional abundance of selected salmon stocks since the mid-1970s (Eggers, 2006).

Infrastructure and extreme events

About 80% of North Americans live in urban areas (Census Bureau, 2000; Statistics Canada, 2001b). North American cities, while diverse in size, function, climate and other factors, are largely shielded from the natural environment by technical systems. The devastating effects of hurricanes Ivan in 2004 and Katrina, Rita and Wilma in 2005, however, illustrate the vulnerability of North American infrastructure and urban systems that were either not designed or not maintained to adequate safety margins. When protective systems fail, impacts can be widespread and multi-dimensional (see Chapter 7, Boxes 7.2 and 7.4). Disproportionate impacts of Hurricane Katrina on the poor, infirm, elderly, and other dependent populations were amplified by inadequate public sector development and/or

[5] Zoonotic diseases: diseases caused by infectious agents that can be transmitted between (or are shared by) animals and humans.
[6] Extrinsic incubation period: the interval between the acquisition of an infectious agent by a vector and the vector's ability to transmit the agent to other hosts.

execution of evacuation and emergency services plans (Select Bipartisan Committee, 2006).

Costs of weather-related natural disasters in North America rose at the end of the 20th century, mainly as a result of the increasing value of infrastructure at risk (Changnon, 2003, 2005). Key factors in the increase in exposure include rising wealth, demographic shifts to coastal areas, urbanisation in storm-prone areas, and ageing infrastructure, combined with substandard structures and inadequate building codes (Easterling et al., 2000; Balling and Cerveny, 2003; Changnon, 2003, 2005). Trends in the number and intensity of extreme events in North America are variable, with many (e.g., hail events, tornadoes, severe windstorms, winter storms) holding steady or even decreasing (Kunkel et al., 1999; McCabe et al., 2001; Balling and Cerveny, 2003; Changnon, 2003; Trenberth et al., 2007: Section 3.8.4.2).

North America very likely will continue to suffer serious losses of life and property simply due to growth in property values and numbers of people at risk (very high confidence) (Pielke Jr., 2005; Pielke et al., 2005). Of the US$19 trillion value of all insured residential and commercial property in the U.S. states exposed to North Atlantic hurricanes, US$7.2 trillion (41%) is located in coastal counties. This economic value includes 79% of the property in Florida, 63% of the property in New York, and 61% of the property in Connecticut (AIR, 2002). Cumulative decadal hurricane intensity in the U.S. has risen in the last 25 years, following a peak in the mid 20th century and a later decline (Figure 14.1e). North American mortality (deaths and death rates) from hurricanes, tornadoes, floods and lightning have generally declined since the beginning of the 20th century, due largely to improved warning systems (Goklany, 2006). Mortality was dominated by three storms where the warning/evacuation system did not lead to timely evacuation: Galveston in 1900, Okeechobee in 1926, and Katrina in 2005.

Flood hazards are not limited to the coastal zone. River basins with a history of major floods (e.g., the Sacramento (Miller, 2003), the Fraser (Lemmen and Warren, 2004), the Red River (Simonovic and Li, 2004) and the upper Mississippi (Allen et al., 2003)) illustrate the sensitivity of riverine flooding to extreme events and highlight the critical importance of infrastructure design standards, land-use planning and weather/flood forecasts.

14.2.7 Tourism and recreation

The U.S. and Canada rank among the top ten nations for international tourism receipts (US$112 billion and US$16 billion, respectively) with domestic tourism and outdoor recreation markets that are several times larger (World Tourism Organization, 2002; Southwick Associates, 2006). Climate variability affects many segments of this growing economic sector. For example, wildfires in Colorado (2002) and British Columbia (2003) caused tens of millions of dollars in tourism losses by reducing visitation and destroying infrastructure (Associated Press, 2002; Butler, 2002; BC Stats, 2003). Similar economic losses were caused by drought-affected water levels in rivers and reservoirs in the western U.S. and parts of the Great Lakes (Fisheries and Oceans Canada, 2000; Kesmodel, 2002; Allen, 2003). The ten-day closure and clean-up following Hurricane Georges (September 1998) resulted in tourism revenue losses of approximately US$32 million in the Florida Keys (EPA, 1999). While the North American tourism industry acknowledges the important influence of climate, its impacts have not been analysed comprehensively (Scott et al., 2006).

14.2.8 Energy, industry and transportation

North American industry, energy supply and transportation networks are sensitive to weather extremes that exceed their safety margins. Costs of these impacts can be high. For example, power outages in the U.S. cost the economy US$30 billion to 130 billion annually (EPRI, 2003; LaCommare and Eto, 2004). The hurricanes crossing Florida in the summer of 2004 resulted in direct system restoration costs of US$1.4 billion to the four Florida public utilities involved (EEI, 2005). From 1994 to 2004, fourteen U.S. utilities experienced 81 other major storms, which cost an average of US$49 million/storm, with the highest single storm impact of US$890 million (EEI, 2005).

Although it was not triggered specifically by the concurrent hot weather, the 2003 summer outage in north-eastern U.S. and south-eastern Canada illustrates costs to North American society that result from large-scale power interruptions during periods of high demand. Over 50 million people were without power, resulting in US$180 million in insured losses and up to US$10 billion in total losses (Fletcher, 2004). Business interruptions were particularly significant, with costs of over US$250,000/hr incurred by the top quartile of recently surveyed companies (RM, 2003).

The impacts of Hurricanes Katrina, Rita and Wilma in 2005 and Ivan in 2004 demonstrated that the Gulf of Mexico offshore oil and natural gas platforms and pipelines, petroleum refineries, and supporting infrastructure can be seriously harmed by major hurricanes, which can produce national-level impacts, and require recovery times stretching to months or longer (Business Week, 2005; EEA, 2005; EIA, 2005a; Levitan and Associates Inc., 2005; RMS, 2005b; Swiss Re, 2005b, c, d, e).

Hydropower production is known to be sensitive to total runoff, to its timing, and to reservoir levels. For example, during the 1990s, Great Lakes levels fell as a result of a lengthy drought, and in 1999 hydropower production was down significantly both at Niagara and Sault St. Marie (CCME, 2003).

14.3 Assumptions about future trends

14.3.1 Climate

Recent climate model simulations (Ruosteenoja et al., 2003) indicate that by the 2010 to 2039 time slice, year-round temperatures across North America will be outside the range of present-day natural variability, based on 1000 year Atmosphere-Ocean General Circulation Model (AOGCM) simulations with either the CGCM2 or HadCM3 climate models. For most combinations of model, scenario, season and region, warming in the 2010 to 2039 time slice will be in the range of 1 to 3°C.

Late in the century, projected annual warming is likely to be 2 to 3°C across the western, southern, and eastern continental edges, but more than 5°C at high latitudes (Christensen et al., 2007: Section 11.5.3.1). The projected warming is greatest in winter at high latitudes and greatest in the summer in the south-west U.S. Warm extremes across North America are projected to become both more frequent and longer (Christensen et al., 2007: Section 11.5.3.3).

Annual-mean precipitation is projected to decrease in the south-west of the U.S. but increase over the rest of the continent (Christensen et al., 2007: Section 11.5.3.2). Increases in precipitation in Canada are projected to be in the range of +20% for the annual mean and +30% for the winter. Some studies project widespread increases in extreme precipitation (Christensen et al., 2007: Section 11.5.3.3), with greater risks of not only flooding from intense precipitation, but also droughts from greater temporal variability in precipitation. In general, projected changes in precipitation extremes are larger than changes in mean precipitation (Meehl et al., 2007: Section 10.3.6.1)

Future trends in hurricane frequency and intensity remain very uncertain. Experiments with climate models with sufficient resolution to depict some aspects of individual hurricanes tend to project some increases in both peak wind speeds and precipitation intensities (Meehl et al., 2007: Section 10.3.6.3). The pattern is clearer for extra-tropical storms, which are likely to become more intense, but perhaps less frequent, leading to increased extreme wave heights in the mid-latitudes (Meehl et al., 2007: Section 10.3.6.4).

El Niño events are associated with increased precipitation and severe storms in some regions, such as the south-east U.S., and higher precipitation in the Great Basin of the western U.S., but warmer temperatures and decreased precipitation in other areas such as the Pacific Northwest, western Canada, and parts of Alaska (Ropelewski and Halpert, 1986; Shabbar et al., 1997). Recent analyses indicate no consistent future trends in El Niño amplitude or frequency (Meehl et al., 2007: Section 10.3.5.4).

14.3.2 Social, economic and institutional context

Canada and the U.S. have developed economies with per capita gross domestic product (GDP) in 2005 of US$31,572 and US$37,371, respectively (UNECE, 2005a,b). Future population growth is likely to be dominated by immigration (Campbell, 1996). Interests of indigenous peoples are important in both Canada and the U.S., especially in relation to questions of land management. With ageing populations, the costs of health care are likely to climb over several decades (Burleton, 2002).

Major parts of the economies of Canada and the U.S. are directly sensitive to climate, including the massive agricultural (2005 value US$316 billion) (Economic Research Service, 2006; Statistics Canada, 2006), transportation (2004 value US$510 billion) (Bureau of Transportation Statistics, 2006; Industry Canada, 2006) and tourism sectors (see Section 14.2.4, 14.2.7 and 14.2.8). Although many activities have limited direct sensitivity to climate (Nordhaus, 2006), the potential realm of climate-sensitive activities expands with increasing evidence that storms, floods, or droughts increase in frequency or intensity with climate change (Christensen et al., 2007: Section 11.5.3.3 and Meehl et al., 2007: Sections 10.3.6.1 and 10.3.6.2).

The economies of Canada and the U.S. have large private and public sectors, with strong emphasis on free market mechanisms and the philosophy of private ownership. If strong trends toward globalisation in the last several decades continue through the 21st century, it is likely that the means of production, markets, and ownership will be predominantly international, with policies and governance increasingly designed for the international marketplace (Stiglitz, 2002).

14.4 Key future impacts and vulnerabilities

14.4.1 Freshwater resources

Freshwater resources will be affected by climate change across Canada and the U.S., but the nature of the vulnerabilities varies from region to region (NAST, 2001; Environment Canada, 2004; Lemmen and Warren, 2004). In certain regions including the Colorado River, Columbia River and Ogallala Aquifer, surface and/or groundwater resources are intensively used for often competing agricultural, municipal, industrial and ecological needs, increasing potential vulnerability to future changes in timing and availability of water (see Box 14.2).

Surface water

Simulated annual water yield in basins varies by region, General Circulation Model (GCM) or Regional Climate Model (RCM) scenario (Stonefelt et al., 2000; Fontaine et al., 2001; Stone et al., 2001; Rosenberg et al., 2003; Jha et al., 2004; Shushama et al., 2006), and the resolution of the climate model (Stone et al., 2003). Higher evaporation related to warming tends to offset the effects of more precipitation, while magnifying the effects of less precipitation (Stonefelt et al., 2000; Fontaine et al., 2001).

Warming, and changes in the form, timing and amount of precipitation, will very likely lead to earlier melting and significant reductions in snowpack in the western mountains by the middle of the 21st century (high confidence) (Loukas et al., 2002; Leung and Qian, 2003; Miller et al., 2003; Mote et al., 2003; Hayhoe et al., 2004). In projections for mountain snowmelt-dominated watersheds, snowmelt runoff advances, winter and early spring flows increase (raising flooding potential), and summer flows decrease substantially (Kim et al., 2002; Loukas et al., 2002; Snyder et al., 2002; Leung and Qian, 2003; Miller et al., 2003; Mote et al., 2003; Christensen et al., 2004; Merritt et al., 2005). Over-allocated water systems of the western U.S. and Canada, such as the Columbia River, that rely on capturing snowmelt runoff, will be especially vulnerable (see Box 14.2).

Lower water levels in the Great Lakes are likely to influence many sectors, with multi-dimensional, interacting impacts (Figure 14.2) (high confidence). Many, but not all, assessments project lower net basin supplies and water levels for the Great Lakes – St. Lawrence Basin (Mortsch et al., 2000; Quinn and Lofgren, 2000; Lofgren et al., 2002; Croley, 2003). In addition

Box 14.2. Climate change adds challenges to managing the Columbia River system

Current management of water in the Columbia River basin involves balancing complex, often competing, demands for hydropower, navigation, flood control, irrigation, municipal uses, and maintenance of several populations of threatened and endangered species (e.g., salmon). Current and projected needs for these uses over-commit existing supplies. Water management in the basin operates in a complex institutional setting, involving two sovereign nations (Columbia River Treaty, ratified in 1964), aboriginal populations with defined treaty rights ('Boldt decision' in U.S. *vs.* Washington in 1974), and numerous federal, state, provincial and local government agencies (Miles et al., 2000; Hamlet, 2003). Pollution (mainly non-point source) is an important issue in many tributaries. The first-in-time first-in-right provisions of western water law in the U.S. portion of the basin complicate management and reduce water available to junior water users (Gray, 1999; Scott et al., 2004). Complexities extend to different jurisdictional responsibilities when flows are high and when they are low, or when protected species are in tributaries, the main stem or ocean (Miles et al., 2000; Mote et al., 2003).

With climate change, projected annual Columbia River flow changes relatively little, but seasonal flows shift markedly toward larger winter and spring flows and smaller summer and autumn flows (Hamlet and Lettenmaier, 1999; Mote et al., 1999). These changes in flows will likely coincide with increased water demand, principally from regional growth but also induced by climate change. Loss of water availability in summer would exacerbate conflicts, already apparent in low-flow years, over water (Miles et al. 2000). Climate change is also projected to impact urban water supplies within the basin. For example, a 2°C warming projected for the 2040s would increase demand for water in Portland, Oregon by 5.7 million m^3/yr with an additional demand of 20.8 million m^3/yr due to population growth, while decreasing supply by 4.9 million m^3/yr (Mote et al., 2003). Long-lead climate forecasts are increasingly considered in the management of the river but in a limited way (Hamlet et al., 2002; Lettenmaier and Hamlet, 2003; Gamble et al., 2004; Payne et al., 2004). Each of 43 sub-basins of the system has its own sub-basin management plan for fish and wildlife, none of which comprehensively addresses reduced summertime flows under climate change (ISRP/ISAB, 2004).

The challenges of managing water in the Columbia River basin will likely expand with climate change due to changes in snowpack and seasonal flows (Miles et al., 2000; Parson et al., 2001b; Cohen et al., 2003). The ability of managers to meet operating goals (reliability) will likely drop substantially under climate change (as projected by the HadCM2 and ECHAM4/OPYC3 AOGCMs under the IPCC IS92a emissions scenario for the 2020s and 2090s) (Hamlet and Lettenmaier, 1999). Reliability losses are projected to reach 25% by the end of the 21st century (Mote et al., 1999) and interact with operational rule requirements. For example, 'fish-first' rules would reduce firm power reliability by 10% under present climate and 17% in years during the warm phase of the Pacific Decadal Oscillation. Adaptive measures have the potential to moderate the impact of the decrease in April snowpack, but lead to 10 to 20% losses of firm hydropower and lower than current summer flows for fish (Payne et al., 2004). Integration of climate change adaptation into regional planning processes is in the early stages of development (Cohen et al., 2006).

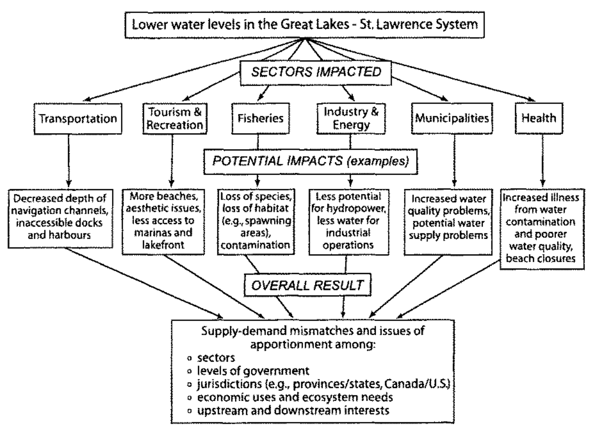

Figure 14.2. *Interconnected impacts of lower water levels in the Great Lakes - St Lawrence system (modified from Lemmen and Warren, 2004).*

to differences due to climate scenarios, uncertainties include atmosphere-lake interactions (Wetherald and Manabe, 2002; Kutzbach et al., 2005). Adapting infrastructure and dredging to cope with altered water levels would entail a range of costs (Changnon, 1993; Schwartz et al., 2004b). Adaptations sufficient to maintain commercial navigation on the St. Lawrence River could range from minimal adjustments to costly, extensive structural changes (St. Lawrence River-Lake Ontario Plan of Study Team, 1999; D'Arcy et al., 2005). There have been controversies in the Great Lakes region over diversions of water, particularly at Chicago, to address water quality, navigation, water demand and drought mitigation outside the region. Climate change will exacerbate these issues and create new challenges for bi-national co-operation (very high confidence) (Changnon and Glantz, 1996; Koshida et al., 2005).

Groundwater

With climate change, availability of groundwater is likely to be influenced by withdrawals (reflecting development, demand and availability of other sources) and recharge (determined by temperature, timing and amount of precipitation, and surface water interactions) (medium confidence) (Rivera et al., 2004). Simulated annual groundwater base flows and aquifer levels respond to temperature, precipitation and pumping – decreasing in scenarios that are drier or have higher pumping and increasing in a wetter scenario. In some cases there are base flow shifts - increasing in winter and decreasing in spring and early summer (Kirshen, 2002; Croley and Luukkonen, 2003; Piggott et al., 2003). For aquifers in alluvial valleys of south-central British Columbia, temperature and precipitation scenarios have less impact on groundwater recharge and levels than do projected changes in river stage[7] (Allen et al., 2004a,b).

Heavily utilised groundwater-based systems in the southwest U.S. are likely to experience additional stress from climate change that leads to decreased recharge (high confidence). Simulations of the Edwards aquifer in Texas under average recharge project lower or ceased flows from springs, water shortages, and considerable negative environmental impacts (Loáiciga, 2000; Loáiciga et al., 2000). Regional welfare losses associated with projected flow reductions (10 to 24%) range from US$2.2 million to 6.8 million/yr, with decreased net agricultural income as a consequence of water allocation shifting to municipal and industrial uses (Chen et al., 2001). In the Ogallala aquifer region, projected natural groundwater recharge decreases more than 20% in all simulations with warming of 2.5°C or greater (based on outputs from the GISS, UKTR and BMRC AOGCMs, with three atmospheric concentrations of CO_2: 365, 560 and 750 ppm) (Rosenberg et al., 1999).

Water quality

Simulated future surface and bottom water temperatures of lakes, reservoirs, rivers, and estuaries throughout North America consistently increase from 2 to 7°C (based on $2\times CO_2$ and IS92a scenarios) (Fang and Stefan, 1999; Hostetler and Small, 1999; Nicholls, 1999; Stefan and Fang, 1999; Lehman, 2002; Gooseff et al., 2005), with summer surface temperatures exceeding 30°C in Midwestern and southern lakes and reservoirs (Hostetler and Small, 1999). Warming is likely to extend and intensify summer thermal stratification, contributing to oxygen depletion. A shorter ice-cover period in shallow northern lakes could reduce winter fish kills caused by low oxygen (Fang and Stefan, 1999; Stefan and Fang, 1999; Lehman, 2002). Higher stream temperatures affect fish access, survival and spawning (e.g., west coast salmon) (Morrison et al., 2002).

Climate change is likely to make it more difficult to achieve existing water quality goals (high confidence). For the Midwest, simulated low flows used to develop pollutant discharge limits (Total Maximum Daily Loads) decrease over 60% with a 25% decrease in mean precipitation, reaching up to 100% with the incorporation of irrigation demands (Eheart et al., 1999). Restoration of beneficial uses (e.g., to address habitat loss, eutrophication, beach closures) under the Great Lakes Water Quality agreement will likely be vulnerable to declines in water levels, warmer water temperatures, and more intense precipitation (Mortsch et al., 2003). Based on simulations, phosphorus remediation targets for the Bay of Quinte (Lake Ontario) and surrounding watershed could be compromised as 3 to 4°C warmer water temperatures contribute to 77 to 98% increases in summer phosphorus concentrations in the bay (Nicholls, 1999), and as changes in precipitation, streamflow and erosion lead to increases in average phosphorus concentrations in streams of 25 to 35% (Walker, 2001). Decreases in snow cover and more winter rain on bare soil are likely to lengthen the erosion season and enhance erosion, increasing the potential for water quality impacts in agricultural areas (Atkinson et al., 1999; Walker, 2001; Soil and Water Conservation Society, 2003). Soil management practices (e.g., crop residue, no-till) in the Cornbelt may not provide sufficient erosion protection against future intense precipitation and associated runoff (Hatfield and Pruger, 2004; Nearing et al., 2004).

14.4.2 Ecosystems

Several simulations (Cox et al., 2000; Berthelot et al., 2002; Fung et al., 2005) indicate that, over the 21st century, warming will lengthen growing seasons, sustaining forest carbon sinks in North America despite some decreased sink strength resulting from greater water limitations in western forests and higher respiration in the tropics (medium confidence). Impacts on ecosystem structure and function may be amplified by changes in extreme meteorological events and increased disturbance frequencies. Ecosystem disturbances, caused either by humans or by natural events, accelerate both loss of native species and invasion of exotics (Sala et al., 2000).

Primary production

At high latitudes, several models simulate increased NPP as a result of expansion of forests into the tundra and longer growing seasons (Berthelot et al., 2002). In the mid-latitudes, simulated changes in NPP are variable, depending on whether there is sufficient enhancement of precipitation to offset

[7] River stage: water height relative to a set point.

increased evapotranspiration in a warmer climate (Bachelet et al., 2001; Berthelot et al., 2002; Gerber et al., 2004; Woodward and Lomas, 2004). Bachelet et al. (2001) project the areal extent of drought-limited ecosystems to increase by 11%/°C warming in the continental U.S. By the end of the 21st century, ecosystems in the north-east and south-east U.S. will likely become carbon sources, while the western U.S. remains a carbon sink (Bachelet et al., 2004).

Overall forest growth in North America will likely increase modestly (10-20%) as a result of extended growing seasons and elevated CO_2 over the next century (Morgan et al., 2001), but with important spatial and temporal variations (medium confidence). Growth of white spruce in Québec will be enhanced by a 1°C temperature increase but depressed with a 4°C increase (Andalo et al., 2005). A 2°C temperature increase in the Olympic Mountains (U.S.) would cause dominant tree species to shift upward in elevation by 300 to 600m, causing temperate species to replace sub-alpine species over 300 to 500 years (Zolbrod and Peterson, 1999). For widespread species such as lodgepole pine, a 3°C temperature increase would increase growth in the northern part of its range, decrease growth in the middle, and decimate southern forests (Rehfeldt et al., 2001).

Population and community dynamics

For many amphibians, whose production of eggs and migration to breeding ponds is intimately tied to temperature and moisture, mismatches between breeding phenology and pond drying can lead to reproductive failure (Beebee, 1995). Differential responses among species in arrival or persistence in ponds will likely lead to changes in community composition and nutrient flow in ponds (Wilbur, 1997). Changes in plant species composition in response to climate change can facilitate other disturbances, including fire (Smith et al., 2000) and biological invasion (Zavaleta and Hulvey, 2004). Bioclimate modelling based on output from five GCMs suggests that, over the next century, vertebrate and tree species richness will decrease in most parts of the conterminous U.S., even though long-term trends (over millennia) ultimately favour increased richness in some taxa and locations (Currie, 2001). Based on relationships between habitat area and biodiversity, 15 to 37% of plant and animal species in a global sample are likely to be 'committed to extinction' by 2050, although actual extinctions will be strongly influenced by human forces and could take centuries (Thomas et al., 2004).

14.4.3 Coastal regions

Added stress from rapid coastal development, including an additional 25 million people in the coastal U.S. over the next 25 years, will reduce the effectiveness of natural protective features, leading to impaired resilience. As property values and investment continue to rise, coastal vulnerability tends to increase on a broad scale (Pielke Jr. and Landsea, 1999; Heinz Center, 2000), with a sensitivity that depends on the commitment to and flexibility of adaptation measures. Disproportionate impacts due to socio-economic status are likely to be exacerbated by rising sea levels and storm severity (Wu et al., 2002; Kleinosky et al., 2006).

Sea-level rise has accelerated in eastern North America since the late 19th century (Donnelly et al., 2004) and further acceleration is expected (high confidence). For The IPCC Special Report on Emissions Scenarios (SRES, Nakićenović and Swart, 2000) scenario A1B, global mean sea level is projected to rise by 0.35 ± 0.12 m from the 1980 to 1999 period to the 2090 to 2099 period (Meehl et al., 2007: Section 10.6.5). Spatial variability of sea-level rise has become better defined since the TAR (Church et al., 2004) and the ensemble mean for A1B shows values close to the global mean along most North American coasts, with slightly higher rates in eastern Canada and western Alaska, and stronger positive anomalies in the Arctic (Meehl et al., 2007: Figure 10.32). Vertical land motion will decrease (uplift) or increase (subsidence) the relative sea-level rise at any site (Douglas and Peltier, 2002).

Superimposed on accelerated sea-level rise, the present storm and wave climatology and storm-surge frequency distributions lead to forecasts of more severe coastal flooding and erosion hazards. The water-level probability distribution is shifted upward, giving higher potential flood levels and more frequent flooding at levels rarely experienced today (very high confidence) (Zhang et al., 2000; Forbes et al., 2004). If coastal systems, including sediment supply, remain otherwise unchanged, higher sea levels are likely to be correlated with accelerated coastal erosion (Hansom, 2001; Cowell et al., 2003).

Up to 21% of the remaining coastal wetlands in the U.S. mid-Atlantic region are potentially at risk of inundation between 2000 and 2100 (IS92a emissions scenario) (Najjar et al., 2000). Rates of coastal wetland loss, in Chesapeake Bay and elsewhere (Kennish, 2002), will increase with accelerated sea-level rise, in part due to 'coastal squeeze' (high confidence). Salt-marsh biodiversity is likely to be diminished in north-eastern marshes through expansion of cordgrass (*Spartina alterniflora*) at the expense of high-marsh species (Donnelly and Bertness, 2001). Many salt marshes in less developed areas have some potential to keep pace with sea-level rise (to some limit) through vertical accretion (Morris et al., 2002; Chmura et al., 2003; Chmura and Hung, 2004). Where rapid subsidence increases rates of relative sea-level rise, however, as in the Mississippi Delta, even heavy sediment loads cannot compensate for inundation losses (Rybczyk and Cahoon, 2002).

Potentially more intense storms and possible changes in El Niño (Meehl et al., 2007: Sections 10.3.5.4 and 10.3.6.3) are likely to result in more coastal instability (medium confidence) (see Section 14.3.1) (Scavia et al., 2002; Forbes et al., 2004; Emanuel, 2005). Damage costs from coastal storm events (storm surge, waves, wind, ice encroachment) and other factors (such as freeze-thaw) have increased substantially in recent decades (Zhang et al., 2000; Bernatchez and Dubois, 2004) and are expected to continue rising (high confidence). Higher sea levels in combination with storm surges will cause widespread problems for transportation along the Gulf and Atlantic coasts (Titus, 2002). More winters with reduced sea ice in the Gulf of St. Lawrence, resulting in more open water during the winter storm season, will lead to an increase in the average number of storm-wave events per year, further accelerating coastal erosion (medium confidence) (Forbes et al., 2004).

14.4.4 Agriculture, forestry and fisheries

Agriculture

Research since the TAR supports the conclusion that moderate climate change will likely increase yields of North American rain-fed agriculture, but with smaller increases and more spatial variability than in earlier estimates (high confidence) (Reilly, 2002). Most studies project likely climate-related yield increases of 5 to 20% over the first decades of the century, with the overall positive effects of climate persisting through much or all of the 21st century. This pattern emerges from recent assessments for corn, rice, sorghum, soybean, wheat, common forages, cotton and some fruits (Adams et al., 2003; Polsky et al., 2003; Rosenberg et al., 2003; Tsvetsinskaya et al., 2003; Antle et al., 2004; Thomson et al., 2005b), including irrigated grains (Thomson et al., 2005b). Increased climate sensitivity is anticipated in the south-eastern U.S. and in the U.S. Cornbelt (Carbone et al., 2003), but not in the Great Plains (Mearns et al., 2003). Crops that are currently near climate thresholds (e.g., wine grapes in California) are likely to suffer decreases in yields, quality, or both, with even modest warming (medium confidence) (Hayhoe et al., 2004; White et al., 2006).

Recent integrated assessment model studies explored the interacting impacts of climate and economic factors on agriculture, water resources and biome boundaries in the conterminous U.S. (Edmonds and Rosenberg, 2005; Izaurralde et al., 2005; Rosenberg and Edmonds, 2005; Sands and Edmonds, 2005; Smith et al., 2005; Thomson et al., 2005a,b,c,d), concluding that scenarios with decreased precipitation create important challenges, restricting the availability of water for irrigation and at the same time increasing water demand for irrigated agriculture and urban and ecological uses.

The critical importance of specific agro-climatic events (e.g., last frost) introduces uncertainty in future projections (Mearns et al., 2003), as does continued debate about the CO_2 sensitivity of crop growth (Long et al., 2005). Climate change is expected to improve the climate for fruit production in the Great Lakes region and eastern Canada but with risks of early season frost and damaging winter thaws (Bélanger et al., 2002; Winkler et al., 2002). For U.S. soybean yield, adjusting the planting date can reduce the negative effects of late season heat stress and can more than compensate for direct effects of climate change (Southworth et al., 2002).

Vulnerability of North American agriculture to climatic change is multi-dimensional and is determined by interactions among pre-existing conditions, indirect stresses stemming from climate change (e.g., changes in pest competition, water availability), and the sector's capacity to cope with multiple, interacting factors, including economic competition from other regions as well as advances in crop cultivars and farm management (Parson et al., 2003). Water access is the major factor limiting agriculture in south-east Arizona, but farmers in the region perceive that technologies and adaptations such as crop insurance have recently decreased vulnerability (Vasquez-Leon et al., 2002). Areas with marginal financial and resource endowments (e.g., the U.S. northern plains) are especially vulnerable to climate change (Antle et al., 2004). Unsustainable land-use practices will tend to increase the vulnerability of agriculture in the U.S. Great Plains to climate change (Polsky and Easterling, 2001).

Forestry

Across North America, impacts of climate change on commercial forestry potential are likely to be sensitive to changes in disturbances (Dale et al., 2001) from insects (Gan, 2004), diseases (Woods et al., 2005) and wildfires (high confidence) (see Box 14.1). Warmer summer temperatures are projected to extend the annual window of high fire ignition risk by 10-30%, and could result in increased area burned of 74-118% in Canada by 2100 (Brown et al., 2004; Flannigan et al., 2004). In the absence of dramatic increases in disturbance, effects of climate change on the potential for commercial harvest in one study for the 2040s ranged from mixed for a low emissions scenario (the EPPA LLH emissions scenario) to positive for a high emissions scenario (the EPPA HHL emissions scenario) (Perez-Garcia et al., 2002). Scenarios with increased harvests tend to lead to lower prices and, as a consequence, reduced harvests, especially in Canada (Perez-Garcia et al., 2002; Sohngen and Sedjo, 2005). The tendency for North American producers to suffer losses increases if climate change is accompanied by increased disturbance, with simulated losses averaging US$1 billion to 2 billion/yr over the 21st century (Sohngen and Sedjo, 2005). Increased tropospheric ozone could cause further decreases in tree growth (Karnosky et al., 2005). Risks of losses from Southern pine beetle likely depend on the seasonality of warming, with winter and spring warming leading to the greatest damage (Gan, 2004).

Warmer winters with more sporadic freezing and thawing are likely to increase erosion and landslides on forest roads, and reduce access for winter harvesting (Spittlehouse and Stewart, 2003).

Freshwater fisheries

Cold-water fisheries will likely be negatively affected by climate change; warm-water fisheries will generally gain; and the results for cool-water fisheries will be mixed, with gains in the northern and losses in the southern portions of ranges (high confidence) (Stefan et al., 2001; Rahel, 2002; Shuter et al., 2002; Mohseni et al., 2003; Fang et al., 2004). Salmonids, which prefer cold, clear water, are likely to experience the most negative impacts (Gallagher and Wood, 2003). Arctic freshwaters will likely be most affected, as they will experience the greatest warming (Wrona et al., 2005). Many warm-water and cool-water species will shift their ranges northward or to higher altitudes (Clark et al., 2001; Mohseni et al., 2003). In the continental U.S., cold-water species will likely disappear from all but the deeper lakes, cool-water species will be lost mainly from shallow lakes, and warm-water species will thrive except in the far south, where temperatures in shallow lakes will exceed survival thresholds (see Section 14.4.1) (Stefan et al., 2001). Species already listed as threatened will face increased risk of extinction (Chu et al., 2005), with pressures from climate exacerbated by the expansion of predatory species like smallmouth bass (Jackson and Mandrak, 2002). In Lake Erie, larval recruitment of river-spawning walleye will depend on temperature and flow changes, but lake-spawning stocks will likely decline due to the effects of warming and lower lake levels (Jones et al., 2006). Thermal habitat suitable for yellow perch will expand, while that for lake trout will contract (Jansen and Hesslein, 2004). While temperature increases may favour warm-water fishes like smallmouth bass, changes in water supply and flow regimes seem likely to have negative effects (Peterson and Kwak, 1999).

14.4.5 Human health

Risks from climate change to human health will be strongly modulated by changes in health care infrastructure, technology, and accessibility as well as ageing of the population, and patterns of immigration and/or emigration (UNPD, 2005). Across North America, the population over the age of 65 will increase slowly to 2010, and then grow dramatically as the Baby Boomers join the ranks of the elderly – the segment of the population most at risk of dying in heatwaves.

Heatwaves and health

Severe heatwaves, characterised by stagnant, warm air masses and consecutive nights with high minimum temperatures, will intensify in magnitude and duration over the portions of the U.S. and Canada where they already occur (high confidence) (Cheng et al., 2005). Late in the century, Chicago is projected to experience 25% more frequent heatwaves annually (using the PCM AOGCM with a business-as-usual emissions scenario, for the period 2080 to 2099) (Meehl and Tebaldi, 2004), and the projected number of heatwave days in Los Angeles increases from 12 to 44-95 (based on PCM and HadCM3 for the A1FI and B1 scenarios, for the 2070 to 2099 period) (Hayhoe et al., 2004).

Air pollution

Surface ozone concentration may increase with a warmer climate. Ozone damages lung tissue, causing particular problems for people with asthma and other lung diseases. Even modest exposure to ozone may encourage the development of asthma in children (McConnell et al., 2002; Gent et al., 2003). Ozone and non-volatile secondary particulate matter generally increase at higher temperatures, due to increased gas-phase reaction rates (Aw and Kleeman, 2002). Many species of trees emit volatile organic compounds (VOC) such as isoprene, a precursor of ozone (Lerdau and Keller, 1998), at rates that increase rapidly with temperature (Guenther, 2002).

For the 2050s, daily average ozone levels are projected to increase by 3.7 ppb across the eastern U.S. (based on the GISS/MM5 AOGCM and the SRES A2 emissions scenario), with the cities most polluted today experiencing the greatest increase in ozone pollution (Hogrefe et al., 2004). One-hour maximum ozone follows a similar pattern, with the number of summer days exceeding the 8-hour regulatory U.S. standard projected to increase by 68% (Bell et al., 2007). Assuming constant population and dose-response characteristics, ozone-related deaths from climate change increase by approximately 4.5% from the 1990s to the 2050s (Knowlton et al., 2004; Bell et al., 2007). The large potential population exposed to outdoor air pollution translates this small relative risk into a substantial attributable health risk.

Pollen

Pollen, another air contaminant, is likely to increase with elevated temperature and atmospheric CO_2 concentrations. A doubling of the atmospheric CO_2 concentration stimulated ragweed-pollen production by over 50% (Wayne et al., 2002). Ragweed grew faster, flowered earlier and produced significantly greater above-ground biomass and pollen at urban than at rural locations (Ziska et al., 2003).

Lyme disease

The northern boundary of tick-borne Lyme disease is limited by cold temperature effects on the tick, *Ixodes scapularis*. The northern range limit for this tick could shift north by 200 km by the 2020s, and 1000 km by the 2080s (based on projections from the CGCM2 and HadCM3 AOGCMs under the SRES A2 emissions scenario) (Ogden et al., 2006).

14.4.6 Human settlements

Economic base

The economies of resource-dependent communities and indigenous communities in North America are particularly sensitive to climate change, with likely winners and losers controlled by impacts on important local resources (see Sections 14.4.1, 14.4.4 and 14.4.7). Residents of northern Canada and Alaska are likely to experience the most disruptive impacts of climate change, including shifts in the range or abundance of wild species crucial to the livelihoods and well-being of indigenous peoples (high confidence) (see Chapter 15 Sections 15.4.2.4 and 15.5) (Houser et al., 2001; NAST, 2001; Parson et al., 2001a; ACIA, 2005).

Infrastructure, climate trends and extreme events

Many of the impacts of climate change on infrastructure in North America depend on future changes in variability of precipitation and extreme events, which are likely to increase but with substantial uncertainty (Meehl et al., 2007: Section 10.5.1; Christensen et al., 2007: Section 11.5.3). Infrastructure in Alaska and northern Canada is known to be vulnerable to warming. Among the most sensitive areas are those affected by coastal erosion and thawing of ice-rich permafrost (see Chapter 15 Section 15.7.1) (NAST, 2001; Arctic Research Commission, 2003; ACIA, 2005). Building, designing, and maintaining foundations, pipelines and road and railway embankments will become more expensive due to permafrost thaw (ACIA, 2005). Examples where infrastructure is projected to be at 'moderate to high hazard' in the mid-21st century include Shishmaref, Nome and Barrow in Alaska, Tuktoyaktuk in the Northwest Territories, the Dalton Highway in Alaska, the Dempster Highway in the Yukon, airfields in the Hudson Bay region, and the Alaska Railroad (based on the ECHAM1-A, GFDL89 and UKTR climate models) (Nelson et al., 2002; Instanes et al., 2005).

Since the TAR, a few studies have projected increasing vulnerability of infrastructure to extreme weather related to climate warming unless adaptation is effective (high confidence). Examples include the New York Metropolitan Region (Rosenzweig and Solecki, 2001) (see Box 14.3), the mid-Atlantic Region (Fisher, 2000; Barron, 2001; Wu et al.,

Box 14.3. North American cities integrate impacts across multiple scales and sectors

Impacts of climate change in the metropolitan regions of North America will be similar in many respects. Los Angeles, New York and Vancouver are used to illustrate some of the affected sectors, including infrastructure, energy and water supply. Adaptation will need to be multi-decadal and multi-dimensional, and is already beginning (see Section 14.5).

Infrastructure

Since most large North American cities are on tidewater, rivers or both, effects of climate change will likely include sea-level rise (SLR) and/or riverine flooding. The largest impacts are expected when SLR, heavy river flows, high tides and storms coincide (California Regional Assessment Group, 2002). In New York, flooding from the combination of SLR and storm surge could be several metres deep (Gornitz and Couch, 2001; Gornitz et al., 2001). By the 2090s under a strong warming scenario (the CGCM climate model with the CCGG emissions scenario), today's 100-year flood level could have a return period of 3 to 4 years, and today's 500-year flood could be a 1-in-50-year event, putting much of the region's infrastructure at increased risk (Jacob et al., 2001; Major and Goldberg, 2001).

Energy supply and demand

Climate change will likely lead to substantial increases in electricity demand for summer cooling in most North American cities (see Section 14.4.8). This creates a number of conflicts, both locally and at a distance. In southern California, additional summer electricity demand will intensify inherent conflicts between state-wide hydropower and flood-control objectives (California Regional Assessment Group, 2002). Operating the Columbia River dams that supply 90% of Vancouver's power would be complicated by lower flows and environmental requirements (see Box 14.2). In New York, supplying summer electricity demand could increase air pollutant levels (e.g., ozone) (Hill and Goldberg, 2001; Kinney et al., 2001; Knowlton et al., 2004) and health impacts could be further exacerbated by climate change interacting with urban heat island effects (Rosenzweig et al., 2005). Unreliable electric power, as in minority neighbourhoods during the New York heatwave of 1999, can amplify concerns about health and environmental justice (Wilgoren and Roane, 1999).

Water supply systems

North American city water supply systems often draw water from considerable distances, so climate impacts need not be local to affect cities. By the 2020s, 41% of the supply to southern California is likely to be vulnerable to warming from loss of Sierra Nevada and Colorado River basin snowpack (see Section 14.4.1). Similarly, less mountain snowpack and summer runoff could require that Vancouver undertakes additional conservation and water restrictions, expands reservoirs, and develops additional water sources (Schertzer et al., 2004). The New York area will likely experience greater water supply variability (Solecki and Rosenzweig, 2007). The New York system can likely accommodate this, but the region's smaller systems may be vulnerable, leading to a need for enhanced regional water distribution protocols (Hansler and Major, 1999).

Adaptation

Many cities in North America have initiated 'no regrets' actions based on historical experience. In the Los Angeles area, incentive and information programmes of local water districts encourage water conservation (MWD, 2005). A population increase of over 35% (nearly one million people) since 1970 has increased water use in Los Angeles by only 7% (California Regional Assessment Group, 2002). New York has reduced total water consumption by 27% and per capita consumption by 34% since the early 1980s (City of New York, 2005). Vancouver's 'CitiesPLUS' 100-year plan will upgrade the drainage system by connecting natural areas and waterways, developing locally resilient, smaller systems, and upgrading key sections of pipe during routine maintenance (Denault et al., 2002).

2002; Rygel et al., 2006) and the urban transportation network of the Boston metropolitan area (Suarez et al., 2005). For Boston, projections of a gradual increase (0.31%/yr) in the probability of the 100-year storm surge, as well as sea-level rise of 3 mm/yr, leads to urban riverine and coastal flooding (based on the CGCM1 climate model), but the projected economic damages do not justify the cost of adapting the transportation infrastructure to climate change.

Less reliable supplies of water are likely to create challenges for managing urban water systems as well as for industries that depend on large volumes of water (see Sections 14.2.1, 14.4.1). U.S. water managers anticipate local, regional or state-wide water shortages during the next ten years (GAO, 2003). Threats to reliable supply are complicated by the high population growth rates in western states where many water resources are at or approaching full utilisation (GAO, 2003) (see Section 14.4.1). Potential increases in heavy precipitation, with expanding impervious surfaces, could increase urban flood risks and create additional design challenges and costs for stormwater management (Kije Sipi Ltd., 2001).

14.4.7 Tourism and recreation

Although coastal zones are among the most important recreation resources in North America, the vulnerability of key tourism areas to sea-level rise has not been comprehensively assessed. The cost to protect Florida beaches from a 0.5 m rise in sea level, with sand replenishment, was estimated at US$1.7 billion to 8.8 billion (EPA, 1999).

Nature-based tourism is a major market segment, with over 900 million visitor-days in national/provincial/state parks in 2001. Visits to Canada's national parks system are projected to increase by 9 to 25% (2050s) and 10 to 40% (2080s) as a result of a lengthened warm-weather tourism season (based on the PCM GCM and the SRES B2 emissions scenario, and the CCSR GCM with A1) (Jones and Scott, 2006). This would have economic benefits for park agencies and nearby communities, but could exacerbate visitor-related ecological pressures in some parks. Climate-induced environmental changes (e.g., loss of glaciers, altered biodiversity, fire- or insect-impacted forests) would also affect park tourism, although uncertainty is higher regarding the regional specifics and magnitude of these impacts (Richardson and Loomis, 2004; Scott et al., 2007a).

Early studies of the impact of climate change on the ski industry did not account for snowmaking, which substantially lowers the vulnerability of ski areas in eastern North America for modest (B2 emissions scenario) but not severe (A1) warming (based on 5 GCMs for the 2050s) (Scott et al., 2003; Scott et al., 2007b). Without snowmaking, the ski season in western North America will likely shorten substantially, with projected losses of 3 to 6 weeks (by the 2050s) and 7 to 15 weeks (2080s) in the Sierra Nevada of California (based on PCM and HadCM3 GCMs for the B1 and A1FI scenarios), and 7 to 10 weeks at lower elevations and 2 to 14 weeks at higher elevations at Banff, Alberta (based on the PCM GCM with the B2 emissions scenario, and the CCSR GCM with A1, for the 2050s) (Hayhoe et al., 2004; Scott and Jones, 2005). With advanced snowmaking, the ski season in Banff shortens at low but not at high altitudes. The North American snowmobiling industry (valued at US$27 billion) (ISMA, 2006) is more vulnerable to climate change because it relies on natural snowfall. By the 2050s, a reliable snowmobile season disappears from most regions of eastern North America that currently have developed trail networks (based on the CGCM1 and HadCM3 GCMs with IS92a emissions, the PCM GCM with B2 emissions and the CCSR GCM with A1 emissions) (Scott, 2006; Scott and Jones, 2006).

14.4.8 Energy, industry and transportation

Energy demand

Recent North American studies generally confirm earlier work showing a small net change (increase or decrease, depending on methods, scenarios and location) in the net demand for energy in buildings but a significant increase in demand for electricity for space cooling, with further increases caused by additional market penetration of air conditioning (high confidence) (Sailor and Muñoz, 1997; Mendelsohn and Schlesinger, 1999; Morrison and Mendelsohn, 1999; Mendelsohn, 2001; Sailor, 2001; Sailor and Pavlova, 2003; Scott et al., 2005; Hadley et al., 2006). Ruth and Amato (2002) projected a 6.6% decline in annual heating fuel consumption for Massachusetts in 2020 (linked to an 8.7% decrease in heating degree-days) and a 1.9% increase in summer electricity consumption (12% increase in annual cooling degree-days). In Québec, net energy demand for heating and air conditioning across all sectors could fall by 9.4% of 2001 levels by 2100 (based on the CGCM1 GCM and the IS92a emissions scenario), with residential heating falling by 10 to 15% and air conditioning increasing two- to four-fold. Peak electricity demand is likely to decline in the winter peaking system of Quebec, while summer peak demand is likely to increase 7 to 17% in the New York metropolitan region (Ouranos, 2004).

Energy supply

Since the TAR, there have been regional but not national-level assessments of the effects of climate change on future hydropower resources in North America. For a 2 to 3°C warming in the Columbia River Basin and British Columbia Hydro service areas, the hydroelectric supply under worst-case water conditions for winter peak demand will likely increase (high confidence). However, generating power in summer will likely conflict with summer instream flow targets and salmon restoration goals established under the Endangered Species Act (Payne et al., 2004). This conclusion is supported by accumulating evidence of a changing hydrologic regime in the western U.S. and Canada (see Sections 14.2.1, 14.4.1, Box 14.2). Similarly, Colorado River hydropower yields will likely decrease significantly (medium confidence) (Christensen et al., 2004), as will Great Lakes hydropower (Moulton and Cuthbert, 2000; Lofgren et al., 2002; Mirza, 2004). James Bay hydropower will likely increase (Mercier, 1998; Filion, 2000). Lower Great Lake water levels could lead to large economic losses (Canadian $437 million to 660 million/yr), with increased water levels leading to small gains (Canadian $28 million to 42 million/yr) (Buttle et al., 2004; Ouranos, 2004). Northern Québec hydropower production would likely benefit from greater precipitation and more open-water conditions, but hydro plants in southern Québec would likely be affected by lower water levels. Consequences of changes in seasonal distribution of flows and in the timing of ice formation are uncertain (Ouranos, 2004).

Wind and solar resources are about as likely as not to increase (medium confidence). The viability of wind resources depends on both wind speed and reliability. Studies to date project wind resources that are unchanged by climate change (based on the HadGCM2 CGSa4 experiment) or reduced by 0 to 40% (based on CGCM1 and the SRES A1 scenario, and HadCM2 and RegCM2 and a 1%/yr CO_2 increase) (Segal et al., 2001; Breslow and Sailor, 2002). Future changes in cloudiness could slightly increase the potential for solar energy in North America south of 60°N (using many models, the A1B scenario and for 2080 to 2099 *vs.* 1980 to 1999) (Meehl et al., 2007: Figure 10.10). However, Pan et al. (2004) projected the opposite: that increased cloudiness will likely decrease the potential output of photovoltaics by 0 to 20% (based on HadCM2 and RegCM2 and a 1%/yr CO_2 increase for the 2040s).

Bioenergy potential is climate-sensitive through direct impacts on crop growth and availability of irrigation water. Bioenergy crops are projected to compete successfully for agricultural acreage at a price of US$33/Mg, or about US$1.83/10^9 joules (Walsh et al., 2003). Warming and precipitation increases are expected to allow the bioenergy crop switchgrass to compete effectively with traditional crops in the central U.S. (based on RegCM2 and a 2×CO_2 scenario) (Brown et al., 2000).

Construction

As projected in the TAR, the construction season in Canada and the northern U.S. will likely lengthen with warming (see Section 14.3.1 and Christensen et al., 2007 Section 11.5.3). In permafrost areas in Canada and Alaska, increasing depth of the 'active layer' or loss of permafrost can lead to substantial decreases in soil strength (ACIA, 2004). In areas currently underlain by permafrost, construction methods are likely to require changes (Cole et al., 1998), potentially increasing construction and maintenance costs (high confidence) (see Chapter 15 Section 15.7.1) (ACIA, 2005).

Transportation

Warmer or less snowy winters will likely reduce delays, improve ground and air transportation reliability, and decrease the need for winter road maintenance (Pisano et al., 2002). More intense winter storms could, however, increase risks for traveller safety (Andrey and Mills, 2003) and require increased snow removal. Continuation of the declining fog trend in at least some parts of North America (Muraca et al., 2001; Hanesiak and Wang, 2005) should benefit transport. Improvements in technology and information systems will likely modulate vulnerability to climate change (Andrey and Mills, 2004).

Negative impacts of climate change on transportation will very likely result from coastal and riverine flooding and landslides (Burkett, 2002). Although offset to some degree by fewer ice threats to navigation, reduced water depth in the Great Lakes would lead to the need for 'light loading' and, hence, adverse economic impacts (see Section 14.4.1) (du Vair et al., 2002; Quinn, 2002; Millerd, 2005). Adaptive measures, such as deepening channels for navigation, would need to address both institutional and environmental challenges (Lemmen and Warren, 2004).

Warming will likely adversely affect infrastructure for surface transport at high northern latitudes (Nelson et al., 2002). Permafrost degradation reduces surface load-bearing capacity and potentially triggers landslides (Smith and Levasseur, 2002; Beaulac and Doré, 2005). While the season for transport by barge is likely to be extended, the season for ice roads will likely be compressed (Lonergan et al., 1993; Lemmen and Warren, 2004; Welch, 2006). Other types of roads are likely to incur costly improvements in design and construction (Stiger, 2001; McBeath, 2003; Greening, 2004) (see Chapter 15 Section 15.7.1).

An increase in the frequency, intensity or duration of heat spells could cause railroad track to buckle or kink (Rosetti, 2002), and affect roads through softening and traffic-related rutting (Zimmerman, 2002). Some problems associated with warming can be ameliorated with altered road design, construction and management, including changes in the asphalt mix and the timing of spring load restrictions (Clayton et al., 2005; Mills et al., 2006).

14.4.9 Interacting impacts

Impacts of climate change on North America will not occur in isolation, but in the context of technological, economic (Nakićenović and Swart, 2000; Edmonds, 2004), social (Lebel, 2004; Reid et al., 2005) and ecological changes (Sala et al., 2000). In addition, challenges from climate change will not appear as isolated effects on a single sector, region, or group. They will occur in concert, creating the possibility of a suite of local, as well as long-distance, interactions, involving both impacts of climate change and other societal and ecosystem trends (NAST, 2001; Reid et al., 2005). In some cases, these interactions may reduce impacts or decrease vulnerability, but in others they may amplify impacts or increase vulnerability.

Effects of climate change on ecosystems do not occur in isolation. They co-occur with numerous other factors, including effects of land-use change (Foley et al., 2005), air pollution (Karnosky et al., 2005), wildfires (see Box 14.1), changing biodiversity (Chapin et al., 2000) and competition with invasives (Mooney et al., 2005). The strong dependence of ecosystem function on moisture balance (Baldocchi and Valentini, 2004), coupled with the greater uncertainty about future precipitation than about future temperature (Christensen et al., 2007: Section 11.5.3), further expands the range of possible futures for North American ecosystems.

People also experience climate change in a context that is strongly conditioned by changes in other sectors and their adaptive capacity. Interactions with changes in material wealth (Ikeme, 2003), the vitality of local communities (Hutton, 2001; Wall et al., 2005), the integrity of key infrastructure (Jacob et al., 2001), the status of emergency facilities and preparedness and planning (Murphy et al. 2005), the sophistication of the public health system (Kinney et al., 2001), and exposure to conflict (Barnett, 2003), all have the potential to either exacerbate or ameliorate vulnerability to climate change. Among the unexpected consequences of the population displacement caused by Hurricane Katrina in 2005 is the strikingly poorer health of storm evacuees, many of whom lost jobs, health insurance, and stable relationships with medical professionals (Columbia University Mailman School of Public Health, 2006).

Little of the literature reviewed in this chapter addresses interactions among sectors that are all impacted by climate change, especially in the context of other changes in economic activity, land use, human population, and changing personal and political priorities. Similarly, knowledge of the indirect impacts on North America of climate change in other geographical regions is very limited.

14.5 Adaptation: practices, options and constraints

The U.S. and Canada are developed economies with extensive infrastructure and mature institutions, with important regional and socio-economic variations (NAST, 2000; Lemmen and Warren, 2004). These capabilities have led to adaptation and coping strategies across a wide range of historic conditions, with both successes and failures. Most studies on adaptive strategies consider implementation based on past experiences (Paavola and Adger, 2002). Examples of adaptation based on future projections are rare (Smit and Wall, 2003; Devon, 2005). Expanding beyond reactive adaptation to proactive, anticipatory adaptive strategies presents many challenges. Progress toward meeting these challenges is just beginning in North America.

14.5.1 Practices and options

Canada and the U.S. emphasise market-based economies. Governments often play a role implementing large-scale adaptive measures, and in providing information and incentives to support development of adaptive capacity by private decision makers (UNDP, 2001; Michel-Kerjan, 2006). In practice, this means that individuals, businesses and community leaders act on perceived self interest, based on their knowledge of adaptive options. Despite many examples of adaptive practices in North America, under-investment in adaptation is evident in the recent rapid increase in property damage due to climate extremes (Burton and Lim, 2005; Epstein and Mills, 2005) and illustrates the current adaptation deficit.

Adaptation by individuals and private businesses

Research on adaptive behaviour for coping with projected climate change is minimal, though several studies address adaptations to historic variation in the weather. About 70% of businesses face some weather risk. The impact of weather on businesses in the U.S. is an estimated US$200 billion/yr (Lettre, 2000). Climate change may also create business opportunities. For example, spending on storm-worthiness and construction of disaster-resilient homes (Koppe et al., 2004; Kovacs, 2005b; Kunreuther, 2006) increased substantially after the 2004 and 2005 Atlantic hurricanes, as did the use of catastrophe bonds (CERES, 2004; Byers et al., 2005; Dlugolecki, 2005; Guy Carpenter, 2006).

Businesses in Canada and the U.S. are investing in climate-relevant adaptations, though few of these appear to be based on projections of future climate change. For example:

- Insurance companies are introducing incentives for homeowners and businesses that invest in loss prevention strategies (Kim, 2004; Kovacs, 2005b).
- Insurance companies are investing in research to prevent future hazard damage to insured property, and to adjust pricing models (Munich Re., 2004; Mills and Lecomte, 2006).
- Ski resort operators are investing in lifts to reach higher altitudes and in snow-making equipment (Elsasser et al., 2003; Census Bureau, 2004; Scott, 2005; Jones and Scott, 2006; Scott et al., 2007a).
- With highly detailed information on weather conditions, farmers are adjusting crop and variety selection, irrigation strategies and pesticide application (Smit and Wall, 2003).
- The forest resources sector is investing in improved varieties, forest protection, forest regeneration, silvicultural management and forest operations (Loehle et al., 2002; Spittlehouse and Stewart, 2003).

Adaptation by governments and communities

Many North American adaptations to climate-related risks are implemented at the community level. These include efforts to minimise damage from heatwaves, droughts, floods, wildfires or tornados. These actions may entail land-use planning, building code enforcement, community education and investments in critical infrastructure (Burton et al., 2002; Multihazard Mitigation Council, 2005).

Flooding and drought present recurring challenges for many North American communities (Duguid, 2002). When the City of Peterborough, Canada, experienced two 100-year flood events within three years, it responded by flushing the drainage systems and replacing the trunk sewer systems to meet more extreme 5-year flood criteria (Hunt, 2005). Recent droughts in six major U.S. cities, including New York and Los Angeles, led to adaptive measures involving investments in water conservation systems and new water supply-distribution facilities (Changnon and Changnon, 2000). To cope with a 15% increase in heavy precipitation, Burlington and Ottawa, Ontario, employed both structural and non-structural measures, including directing downspouts to lawns to encourage infiltration and increasing depression and street detention storage (Waters et al., 2003).

Some large cities (e.g., New Orleans) and important infrastructure (e.g., the only highway and rail link between Nova Scotia and the rest of Canada) are located on or behind dykes that will provide progressively less protection unless raised on an ongoing basis. Some potential damages may be averted through redesigning structures, raising the grade, or relocating (Titus, 2002). Following the 1996 Saguenay flood and 1998 ice storm, the province of Québec modified the Civil Protection Act and now requires municipalities to develop comprehensive emergency management plans that include adaptation strategies (McBean and Henstra, 2003). More communities are expected to re-examine their hazard management systems following the catastrophic damage in New Orleans from Hurricane Katrina (Kunreuther et al., 2006).

Rapid development and population growth are occurring in many coastal areas that are sensitive to storm impacts (Moser, 2005). While past extreme events have motivated some aggressive adaptation measures (e.g., in Galveston, Texas) (Bixel and Turner, 2000), the passage of time, new residents, and high demand for waterfront property are pushing coastal development into vulnerable areas.

Climate change will likely increase risks of wildfire (see Box 14.1). FireWise and FireSmart are programmes promoting wildfire safety in the U.S. and Canada, respectively (FireSmart, 2005; FireWise, 2005). Individual homeowners and businesses can participate, but the greatest reduction in risk will occur in communities that take a comprehensive approach, managing forests with controlled burns and thinning, promoting or enforcing appropriate roofing materials, and maintaining defensible space around each building (McGee et al., 2000).

Public institutions are responsible for adapting their own legislation, programmes and practices to appropriately anticipate climate changes. The recent Québec provincial plan, for example, integrates climate change science into public policy. Public institutions can also use incentives to encourage or to overcome disincentives to investment by private decision makers (Moser, 2006). Options, including tax assistance, loan guarantees and grants, can improve resilience to extremes and reduce government costs for disaster management (Moser, 2005). The U.S. National Flood Insurance Program is changing its policy to reduce the risk of multiple flood claims, which cost the programme more than US$200 million/yr (Howard, 2000). Households with two flood-related claims are now required to elevate their structure 2.5 cm above the 100-year flood level, or relocate. To complement this, a 5-year, US$1 billion programme to update and digitise flood maps was initiated in 2003 (FEMA, 2006). However, delays in implementing appropriate zoning can encourage accelerated, maladapted development in coastal communities and flood plains.

14.5.2 Mainstreaming adaptation

One of the greatest challenges in adapting North America to climate change is that individuals often resist and delay change (Bacal, 2000). Good decisions about adapting to climate change depend on relevant experience (Slovic, 2000), socio-economic factors (Conference Board of Canada, 2006), and political and institutional considerations (Yarnal et al., 2006; Dow et al., 2007). Adaptation is a complex concept (Smit et al., 2000; Dolan and Walker, 2006), that includes wealth and several other dimensions.

Experience and knowledge

The behaviour of people and systems in North America largely reflects historic climate experience (Schipper et al., 2003), which has been institutionalised through building codes, flood management infrastructure, water systems and a variety of other programmes. Canadian and U.S. citizens have invested in buildings, infrastructure, water and flood management systems designed for acceptable performance under historical conditions (Bruce, 1999; Co-operative Programme on Water and Climate, 2005; UMA Engineering, 2005; Dow et al., 2007). Decisions by community water managers (Rayner et al., 2005; Dow et al., 2007) and set-back regulations in coastal areas (Moser, 2005) also account for historic experience but rarely incorporate information about climate change or sea-level rise. In general, decision makers lack the tools and perspectives to integrate future climate, particularly events that exceed historic norms (UNDP, 2001).

Examples of adaptive behaviour influenced exclusively or predominantly by projections of climate change are largely absent from the literature, but some early steps toward planned adaptation have been taken by the engineering community, insurance companies, water managers, public health officials, forest managers and hydroelectric producers. Some initiatives integrate consideration of climate change into the environmental impact assessment process. Philadelphia, Toronto and a few other communities have introduced warning programmes to manage the health threat of heatwaves (Kalkstein, 2002). The introduction of Toronto's heat/health warning programme was influenced by both climate projections and fatalities from past heatwaves (Koppe et al., 2004; Ligeti, 2006).

Weather extremes can reveal a community's vulnerability or resilience (RMS, 2005a) and provide insights into potential adaptive responses to future events. Since the 1998 ice storm, Canada's two most populous provinces, Ontario and Québec, have strengthened emergency preparedness and response capacity. Included are comprehensive hazard-reduction measures and loss-prevention strategies to reduce vulnerability to extreme events. These strategies may include both public information programmes and long-term strategies to invest in safety infrastructure (McBean and Henstra, 2003). Adaptive behaviour is typically greater in the communities that recently experienced a natural disaster (Murphy et al., 2005). But the near absence of any personal preparedness following the 2003 blackout in eastern North America demonstrated that adaptive actions do not always follow significant emergencies (Murphy, 2004).

Socio-economic factors

Wealthier societies tend to have greater access to technology, information, developed infrastructure, and stable institutions (Easterling et al., 2004), which build capacity for individual and collective action to adapt to climate change. But average economic status is not a sufficient determinant of adaptive capacity (Moss et al., 2001). The poor and marginalised in Canada and the U.S. have historically been most at risk from weather shocks (Turner et al., 2003), with vulnerability directly related to income inequality (Yohe and Tol, 2002). Differences in individual capacity to cope with extreme weather were evident in New Orleans during and after Hurricane Katrina (Kunreuther et al., 2006), when the large majority of those requiring evacuation assistance were either poor or in groups with limited mobility, including elderly, hospitalised and disabled citizens (Murphy et al., 2005; Kumagi et al., 2006; Tierney, 2006).

Political and institutional capacity for autonomous adaptation

Public officials in Canada and the U.S. typically provide early and extensive assistance in emergencies. Nevertheless, emergency response systems in the U.S. and Canada are based on the philosophy that households and businesses should be capable of addressing their own basic needs for up to 72 hours after a disaster (Kovacs and Kunreuther, 2001). The residents' vulnerability depends on their own resources, plus those provided by public service organisations, private firms and others (Fischhoff, 2006). When a household is overwhelmed by an extreme event, household members often rely on friends, family and other social networks for physical and emotional support (Cutter et al., 2000; Enarson, 2002; Murphy, 2004). When a North American community responds to weather extremes, non-governmental organisations often coordinate support for community-based efforts (National Voluntary Organizations Active in Disaster, 2006).

An active dialogue among stakeholders and political institutions has the potential to clarify the opportunities for adaptation to changing climate. However, public discussion about adaptation is at an early stage in the U.S. and Canada (Natural Resources Canada, 2000), largely because national governments have focused public discussion on mitigation, with less attention to adaptation (Moser, 2005). Some public funds have been directed to research on impacts and adaptation, and both countries have undertaken national assessments with a synthesis of the adaptation literature, but neither country has a formal adaptation strategy (Conference Board of Canada, 2006). Integrating perspectives on climate change into legislation and regulations has the potential to promote or constrain adaptive behaviour (Natural Resources Canada, 2000). North American examples of public policies that influence adaptive behaviour include water allocation law in the western U.S. (Scheraga, 2001), farm subsidies (Goklany, 2007), public flood insurance in the U.S. (Crichton, 2003), guidance on preservation of wetlands and emergency management.

14.5.3 Constraints and opportunities

Social and cultural barriers

High adaptive capacity, as in most of North America, should be an asset for coping with or benefiting from climate change. Capacity, however, does not ensure positive action or any action at all. Societal values, perceptions and levels of cognition shape adaptive behaviour (Schneider, 2004). In North America, information about climate change is usually not 'mainstreamed' or explicitly considered (Dougherty and Osaman Elasha, 2004) in the overall decision-making process (Slovic, 2000; Leiss, 2001). This can lead to actions that are maladapted, for example, development near floodplains or coastal areas known to be vulnerable to climate change. Water managers are unlikely to use climate forecasts, even when they recognise the vulnerability, unless the forecast information can fit directly into their everyday management decisions (Dow et al., 2007).

Informational and technological barriers

Uncertainty about the local impacts of climate change is a barrier to action (NRC, 2004). Incomplete knowledge of disaster safety options (Murphy, 2004; Murphy et al., 2005) further constrains adaptive behaviour. Climate change information must be available in a form that fits the needs of decision-makers. For example, insurance companies use climate models with outputs specifically designed to support decisions related to the risk of insolvency, pricing and deductibles, regulatory and rating agency considerations, and reinsurance (Swiss Re, 2005a). Some electrical utilities have begun to integrate climate model output into planning and management of hydropower production (Ouranos, 2004).

A major challenge is the need for efficient technology and knowledge transfer. In general, questions about responsibility for funding research, involving stakeholders, and linking communities, government and markets have not been answered (Ouranos, 2004). Another constraint is resistance to new technologies (e.g., genetically modified crops), so that some promising adaptations in the agricultural, water resource management and forestry sectors are unlikely to be realised (Goklany, 2000, 2001).

Financial and market barriers

In the U.S., recent spending on adaptation to extremes has been a sound investment, contributing to reduced fatalities, injuries and significant economic benefits. The Multihazard Mitigation Council (2005) found that US$3.5 billion in spending between 1993 and 2003 on programmes to reduce future damages from flooding, severe wind and earthquakes contributed US$14 billion in societal benefits. The greatest savings were in flood (5-fold) and wind (4-fold) damage reduction. Adaptation also benefited government as each dollar of spending resulted in US$3.65 in savings or increased tax revenue. This is consistent with earlier case studies; the Canadian $65 million invested in 1968 to create the Manitoba Floodway has prevented several billion dollars in flood damage (Duguid, 2002).

Economic issues are frequently the dominant factors influencing adaptive decisions. This includes community response to coastal erosion (Moser, 2000), investments to enhance water resource systems (Report of the Water Strategy Expert Panel, 2005), protective retrofits to residences (Simmons et al., 2002; Kunreuther, 2006), and changes in insurance practices (Kovacs, 2005a). The cost and availability of economic resources clearly influence choices (WHO, 2003), as does the private versus public identity of the beneficiaries (Moser, 2000).

Sometimes, financial barriers interact with the slow turnover of existing infrastructure (Figure 14.3). Extensive property damage in Florida during Hurricane Andrew in 1992 led to significant revisions to the building code. If all properties in southern Florida met this updated code in 1992, then property damage from Hurricane Andrew would have been lower by nearly 45% (AIR, 2002). Florida will, however, still experience extensive damage from hurricanes through damage to the large number of older homes and businesses. Other financial barriers come from the challenge property owners face in recovering the costs of protecting themselves. Hidden adaptations tend to be undervalued, relative to obvious ones. For example, homes with storm shutters sell for more than homes without this visible adaptation, while less visible retrofits, such as tie-down straps to hold the roof in high winds, add less to the resale value of the home, relative to their cost (Simmons et al., 2002).

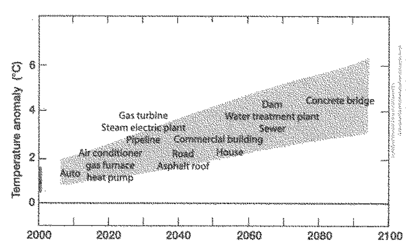

Figure 14.3. *Typical infrastructure lifetimes in North America (data from Lewis, 1987; Bettigole, 1990; EIA, 1999, 2001; Statistics Canada, 2001a; BEA, 2003), in relation to projected North American warming for 2000 to 2100 (relative to 1901-1950) for the A1B scenario, from the IPCC AR4 Multi-Model Dataset (yellow envelope). Measured and modelled anomalies for 2000 are shown with black and orange bars, respectively. Projected warming for 2091 to 2100 for the B1, A1B and A2 scenarios are indicated by the blue, yellow and red bars, respectively at the right (data from Christensen et al., 2007: Box 11.1 Figure 1).*

14.6 Case studies

Many of the topics discussed in this chapter have important dimensions, including interactions with other sectors, regions and processes, that make them difficult to assess from the perspective of a single sector. This chapter develops multi-sector case studies on three topics of special importance to North America – forest disturbances (see Box 14.1), water resources (using the Columbia River as an example) (see Box 14.2) and coastal cities (see Box 14.3).

14.7 Conclusions: implications for sustainable development

Climate change creates a broad range of difficult challenges that influence the attainment of sustainability goals. Several of the most difficult emerge from the long time-scale over which the changes occur (see Section 14.3) and the possible need for action well before the magnitude (and certainty) of the impacts is clear (see Section 14.5). Other difficult problems arise from the intrinsic global scale of climate change (EIA, 2005b). Because the drivers of climate change are truly global, even dedicated action at the regional scale has limited prospects for ameliorating regional-scale impacts. These two sets of challenges, those related to time-scale and those related to the global nature of climate change, are not in the classes that have traditionally yielded to the free-market mechanisms and political decision making that historically characterise Canada and the U.S. (see Section 14.5). Yet, the magnitude of the climate change challenge calls for proactive adaptation and technological and social innovation, areas where Canada and the U.S. have abundant capacity. An important key to success will be developing the capacity to incorporate climate change information into adaptation in the context of other important technological, social, economic and ecological trends.

The preceding sections describe current knowledge concerning the recent climate experience of North America, the impacts of the changes that have already occurred, and the potential for future changes. They also describe historical experience with and future prospects for dealing with climate impacts. The key points are:

- North America has experienced substantial social, cultural, economic and ecological disruption from recent climate-related extremes, especially storms, heatwaves and wildfires [14.2].
- Continuing infrastructure development, especially in vulnerable zones, will likely lead to continuing increases in economic damage from extreme weather [14.2.6, 14.4.6].
- The vulnerability of North America depends on the effectiveness of adaptation and the distribution of coping capacity, both of which are currently uneven and have not always protected vulnerable groups from adverse impacts of climate variability and extreme weather events [14.5].
- A key prerequisite for sustainability is 'mainstreaming' climate issues into decision making [14.5].
- Climate change will exacerbate stresses on diverse sectors in North America, including, but not limited to, urban centres, coastal communities, human health, water resources and managed and unmanaged ecosystems [14.4].
- Indigenous peoples of North America and those who are socially and economically disadvantaged are disproportionately vulnerable to climate change [14.2.6, 14.4.6].

14.8 Key uncertainties and research priorities

The major limits in understanding of climate change impacts on North America, and on the ability of its people, economies and ecosystems to adapt to these changes, can be grouped into seven areas.

- Projections of climate changes still have important uncertainties; especially on a regional scale (Christensen et al., 2007: Section 11.5.3). For North America, the greater uncertainty about future precipitation than about future temperature substantially expands the uncertainty of a broad range of impacts on ecosystems (see Section 14.4.2), hydrology and water resources (see Sections 14.4.1, 14.4.7), and on industries (see Sections 14.4.6, 14.4.7).
- North American people, economies and ecosystems tend to be much more sensitive to extremes than to average conditions [14.2]. Incomplete understanding of the relationship between changes in the average climate and extremes (Meehl et al., 2007: Section 10.3.6; Christensen et al., 2007: Section 11.5.3.3) limits our ability to connect future conditions with future impacts and the options for adaptation. There is a need for improved understanding of the relationship between changes in average climate and those extreme events with the greatest potential impact on North America, including hurricanes, other severe storms, heatwaves, floods, and prolonged droughts.
- For most impacts of climate change, we have at least some tools for estimating gradual change (see Section 14.4), but we have few tools for assessing the conditions that lead to tipping points, where a system changes or deteriorates rapidly, perhaps without further forcing.
- Most of the past research has addressed impacts on a single sector (e.g., health, transportation, unmanaged ecosystems). Few studies address the interacting responses of diverse sectors impacted by climate change, making it very difficult to evaluate the extent to which multi-sector responses limit options or push situations toward tipping points (see Section 14.4.9).
- Very little past research addresses impacts of climate change in a context of other trends with the potential to exacerbate impacts of climate change or to limit the range of response options (see Section 14.4.9) (but see Reid et al., 2005 for an important exception). A few North American examples of trends likely to complicate the development of strategies for dealing with climate change include continuing development in coastal areas (see Section 14.2.3), increasing demand on

freshwater resources (see Section 14.4.1), the accumulation of fuel in forest ecosystems susceptible to wildfire (see Box 14.1), and continued introductions of invasive species with the potential to disrupt agriculture and ecosystem processes (see Section 14.2.2, 14.2.4). In the sectors that are the subject of the most intense human management (e.g., health, agriculture, settlements, industry), it is possible that changes in technology or organisation could exacerbate or ameliorate impacts of climate change (see Section 14.4.9).

- Indirect impacts of climate change are poorly understood. In a world of ever-increasing globalisation, the future of North American people, economies and ecosystems is connected to the rest of the world through a dense network of cultural exchanges, trade, mixing of ecosystems, human migration and, regrettably, conflict (see Section 14.3). In this interconnected world, it is possible that profoundly important impacts of climate change on North America will be indirect consequences of climate change impacts on other regions, especially where people, economies or ecosystems are unusually vulnerable.
- Examples of North American adaptations to climate-related impacts are abundant, but understanding of the options for proactive adaptation to conditions outside the range of historical experience is limited (see Section 14.5).

All of these areas potentially interact, with impacts that are unevenly distributed among regions, industries, and communities. Progress in research and management is occurring in all these areas. Yet stakeholders and decision makers need information immediately, placing a high priority on strategies for providing useful decision support in the context of current knowledge, conditioned by an appreciation of the limits of that knowledge.

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