

INDICATORS

MONITORING THE HUMAN HEALTH IMPACTS OF CLIMATE CHANGE AND SHIFTING WEATHER PATTERNS FOCUS ON URBAN AREAS

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March 2003

INTRODUCTION

The U.S. National Assessment of the Impacts of Climate Change and Variability (<http://www.usgcrp.gov/usgcrp/nacc/default.htm>) projects that there will be changes in the climate and in weather patterns in every region of the United States in coming decades as a result of increasing atmospheric concentrations of greenhouse gases. These predictions are in keeping with those of the U.N. Intergovernmental Panel on Climate Change for the planet as a whole (Houghton *et al.*, [IPCC] 2001). Changes will involve warming temperatures -- with the largest increases occurring at higher altitudes and latitudes, and during the winter and at night. The warming is also associated with an increase in extreme weather events, with heavy rains (>2"/day) and flooding in some areas and prolonged drought in others.

Accompanying the warming and anomalous weather, major impacts on urban infrastructure are projected, as well as impacts on terrestrial and marine ecosystems; affecting wildlife, forests, agriculture and human health. This brief summary will outline the potential health impacts of climate change and variability and will discuss in more detail three case studies in the U.S. that provide useful models for understanding the relationship of human health to climate and weather.

The following categories of diseases and other health impacts may be affected by climatic conditions and weather. While each one (e.g., heatwaves or emerging infectious diseases) can occur in the absence of climate change, it is projected that climate change and the associated alterations in weather patterns will influence the frequency, intensity and geographic distribution of these health outcomes. Understanding the health/climate/weather connections can

- a) Help generate early warning systems for environmentally-friendly public health interventions; and
- b) Help monitor and understand the short and long-term health consequences of climate change and the associated changes in weather patterns.

Areas Covered

- Heat stroke, dehydration, heat exhaustion and heat waves
- Cardio-respiratory disease and air quality
- Emerging infectious diseases (EIDs) and climate warming and variability
- Traumatic injuries and extreme weather
- Gastro-intestinal infections and water quality

Also to be considered are the morbidity and mortality associated with weather-related impacts on food quality, especially seafood, and the health impacts of sea level rise and storm surges (e.g., from flooding, salt water intrusion of well water, etc.).

HEATWAVES

Recent record-high temperatures in many parts of the United States highlight the need for an awareness of the health hazards posed by global warming. Heat waves can cause dramatic increases in overall morbidity and mortality, and they have increased the number of deaths per day 2 to 3-fold over baseline levels in particularly severe episodes

<http://www.cdc.gov/mmwr/preview/mmwrhtml/00000041.htm>.

From 1979 –1999, excessive heat exposure caused 8,015 deaths in the United States. During this period, more people in this country died from extreme heat than from hurricanes, lightning, tornadoes, floods, and earthquakes combined (<http://www.cdc.gov/nceh/hsb/extremeheat/>). The incidence of heat waves in most U.S. cities is expected to approximately double by the year 2050 by current climate change estimates (Kalkstein, 2000).

The health impacts of heatwaves are a function of average temperatures, nighttime temperatures (minimum), and the heat index (which is a measure of humidity and temperature combined, where high humidity levels interfere with the human body's ability to cool itself by transferring heat, through radiation and evaporation, to its surroundings). Minimum nighttime temperatures have been rising twice as fast as overall warming since 1950 (Karl *et al.*, 1993; Easterling *et al.*, 1997), which is predicted by climate change models. The “heat island effect,” where the heat generated by the cumulative activities of concentrated populations increases the ambient temperature 5-10 degrees F. above that of surrounding, less urban areas, is present in most U.S. urban centers and adds to the intensity of heatwaves. It is, in turn, affected by the presence of urban trees and parks, roof gardens, and heat reflective building colors, particularly on rooftops.

Case Study—The Chicago Heatwave

The Chicago heatwave in the summer of 1995 well illustrates how heat waves influenced by climate change will affect human populations. In this case, there was the lethal combination of high humidity and unusually high nighttime temperatures, so that Chicago residents had little relief at night (CDC, 1995; Whitman *et al.*, 1997). During July 12-16, 1995, Chicago experienced unusually high maximum daily temperatures, ranging from 93 F to 104 F (33.9 C to 40.0 C). On July 13, the heat index peaked at 119 F (48.3 C) -- a record high for the city.

During July 11-27 the Cook County Medical Examiner's Office (CCMEO) certified 465 as heat-related, compared with no heat-related deaths during the period of July 4-10. The highest number of heat-related deaths previously certified by the CCMEO was 77 in association with a heat wave in the summer of 1988. During July 13-21 (the period with the most heat-related deaths), a total of 1177 deaths occurred in Chicago -- an 85% increase over the same period in 1994 (637 deaths). A subsequent analysis demonstrated that there were at least 700

excess deaths in Chicago during the heat wave, most of which were heat-related (Semenza et al, 1996). And recent reports have confirmed that there were long-term neurological effects among some of those who had heat stroke but survived (reference to be obtained).

Those at greatest risk of dying from the heat wave were people with chronic medical illnesses. But socioeconomic factors were involved as well; poor and socially isolated people without access to air conditioning were disproportionately affected. Early warning systems are now in place in some U.S. cities (Kalkstein, 2000) and Canada (Smoyer-Tomic *et al.*, 2001), with a program to identify those who live alone, particularly those who are chronically ill medically or psychiatrically. Effective measures for preventing heat-related illness and death include reducing physical activity, drinking nonalcoholic liquids, and spending time in air-conditioned environments.

Severe summer heatwaves, with numerous attributable deaths, have become increasingly common in developing nations as well, notably New Delhi, India.

CARDIO-RESPIRATORY DISEASE AND AIR QUALITY

The following are examples of how climate change can affect cardio-respiratory disease:

- Pollen--pollen release from ragweed and some trees (e.g. birches and poplars) is increased by higher levels of atmospheric CO₂ (in the case of ragweed, with a doubled CO₂ concentration, 60% more pollen is released) (Wayne *et al.*, 2002). Warm winters and the early arrival of spring may exacerbate this effect. Increased pollen levels may explain some of the increased incidence of asthma and respiratory allergies.
- Ground-level ozone or photochemical smog--the reaction of oxides of nitrogen (NO_xs) and volatile organic compounds (VOCs) [both tailpipe emissions] is temperature-dependant; i.e., heat increases smog. Ground-level ozone, which is also increased by higher levels of ultraviolet B radiation from stratospheric ozone depletion, has been shown to cause asthma in children and to trigger attacks (McConnell *et al.*, 2002). Photochemical smog also causes increased morbidity and mortality in those with chronic obstructive pulmonary disease.
- Diesel exhaust particulates (a direct air pollutant from burning fossil fuels)—these particles cause significant illness, especially when they are smaller than 10 microns in diameter and can bypass the lung's defenses. They can:
 1. Clog airways and cause acute, and worsen chronic, cardiovascular and respiratory illness;
 2. Help deliver pollen grains and molds deep into the lung;
 3. Cause lung cancer.

- Heatwaves can result in temperature inversions, leading to trapped masses of unhealthy air contaminated by smog, particulates, and other pollutants.
- Fires—the incidence of forest fires is increased by drought secondary to climate change, and to the lack of spring runoff from reduced winter snows. These fires create smoke and haze which can settle over urban populations causing acute and exacerbating chronic respiratory illness (e.g., the Hayman fire in Colorado, summer 2002). The extensive, severe forest fires in Indonesia in 1997/98 were the result of small fires, started to clear the forests for agriculture, which quickly became out of control due to a severe drought. The resulting plume of smoke settled as haze over large down-wind populations in Southeast Asia, causing widespread respiratory illness.

EMERGING INFECTIOUS DISEASES

Since 1976, the World Health Organization reports there are 30 infectious diseases that are new to medicine. These include Ebola, Legionellas', Lyme disease, Hantavirus Pulmonary Syndrome, a new strain of cholera (*Vibrio cholerae* O139), *E. coli* O157:H7, H.I.V./AIDS, and a host of antibiotic-resistant organisms. In addition, there is a resurgence of some old diseases (malaria, dengue fever, cholera), and a redistribution of others (e.g., West Nile virus) occurring on a global scale. Many emerging diseases are zoonoses, or animal diseases, that spill over to humans, and are responsive to environmental change and climatic variability. For example, “explosions” of rodent populations can follow droughts punctuated by heavy rains, because such weather patterns can result in a decreased population of rodent predators and an increased supply of food (this was the case, for example, with the outbreak of Hantavirus Pulmonary Syndrome in the four corners area of New Mexico in 1993).

Moreover, climate (especially winter [minimum] temperatures) can restrict the geographic range of some infectious diseases by altitude and by latitude (in the case of vector-borne infectious diseases, for example, by being too cold above a certain altitude or latitude for a vector, host, or infectious agent to survive) (Epstein *et al.*, 1998), while weather can affect the timing, intensity, and location of outbreaks. Rising minimum (winter) temperatures are particularly important in allowing the over-wintering of some diseases vectors (e.g., ticks or mosquitoes), and in increasing the number of reproductive generations (e.g., rodents). In addition, extreme weather events (especially droughts and floods) often precipitate clusters of rodent-, mosquito- and water-borne diseases (Epstein, 1999).

Case Study—West Nile Virus

Summary

West Nile virus (WNV) was first reported in Uganda in 1937. WNV is a zoonosis, with “spill-over” to humans, which also poses significant risks for wildlife, zoo and domestic animal populations. While it is not known how West Nile virus (WNV) entered the New World in 1999, anomalous weather conditions may have helped amplify this *Flavivirus* that circulates among urban mosquitoes, birds and mammals. Analysis of weather patterns coincident with a series of U.S. urban outbreaks of St. Louis encephalitis (SLE), (a disease with a similar life cycle), and four recent large outbreaks of WNV, revealed that drought was a common feature. *Culex pipiens*, the primary mosquito vector (carrier) for WN, thrives in city storm drains and catch basins, especially in the organically rich water that forms during drought and the accompany warm temperatures. As the potential risks from pesticides for disease control must be weighed against the health risks of the disease, an early warning system of conditions conducive to amplification of the enzootic cycle could help initiate timely preventive measures, and potentially limit chemical interventions.

Background on WNV

West Nile virus, first reported in Uganda in 1937, entered the Western Hemisphere in 1999, most likely via migratory or imported birds from Europe. But, while the precise means of introduction is not known, experience with a similar virus -- St. Louis encephalitis (SLE) -- as well as the European outbreaks of WNV during the 1990s -- suggests that certain climatic conditions are conducive to outbreaks of this disease. Evidence suggests that mild winters, coupled with prolonged droughts and heat waves, are the conditions that amplify these two diseases that cycle among urban mosquitoes (*Culex pipiens*), birds and humans.

SLE and WNV are transmitted by mosquitoes to birds and other animals, with occasional "spillover" to humans. *Culex pipiens* typically breed in organically rich standing water in city drains and catch basins (as well as unused pools and tires). During a drought, those pools become even richer in the organic material that *Culex spp.* needs to thrive. Excessive rainfall flushes the drains and dilutes the pools. Drought conditions may also lead to a decline in the number of mosquito predators, such as amphibians and dragonflies, and encourage birds to congregate around shrinking water sites -- where the virus can circulate more easily. In addition, high temperatures accelerate the extrinsic incubation period (period of maturation) of viruses (and parasites) within mosquito carriers. Thus higher temperatures enhance the potential for transmission and dissemination. Together these factors increase the possibility that infectious virus levels will build up in birds and mosquitoes living in close proximity to human beings.

Outbreaks of St. Louis encephalitis in the U.S.

SLE first emerged in the city of St. Louis in 1933, during the dust bowl era. Since 1933 there have been 24 urban outbreaks of SLE in the US. SLE as an appropriate surrogate for study because of its similarity to WNV, and because of the significant number of SLE outbreaks in the U.S. along with accurate weather data. For the US outbreaks we examined meteorological data, using the Palmer Severity Drought Index (PSDI); a measure of dryness that is a function of precipitation and soil moisture compared with 30 years of data in the same location. The PSDI ranges from -4 (dry) to +4 (wet) -- (National Climatic Data Center, National Oceanographic and Atmospheric Administration, U.S. Dept of Commerce, www.ncdc.noaa.gov). The examination revealed that from 1933 to the mid-1970s 10 of the 12 urban SLE outbreaks -- regionally clustered in Kentucky, Colorado, Texas, Indiana, Tennessee and Illinois -- were associated with 2 months of drought (one of the other 2 with one month of drought). After the mid-1970s the relationship shifts and outbreaks are associated with anomalous conditions that include droughts and heavy rains.

Note: Outbreaks of SLE during the 1974-76 period and after show a variable pattern in relation to weather (occurring with drought or, alternatively, after anomalous rains). Once established in a region, summer rains may boost populations of *Aedes japonicus* and other *Aedes spp.* that can function as “bridge vectors,” efficiently carrying virus from birds to humans. The roles of “maintenance” (primarily bird-biting mosquitoes) and bridge vectors in WNV transmission are under study.

Outbreaks of WNV

Romania 1996: A significant European outbreak of WNV occurred in 1996 in Romania, in the Danube Valley and in Bucharest. This episode, with hundreds experiencing neurological disease and 17 fatalities, occurred between July and October and coincided with a prolonged drought (May through October) and excessive heat (May through July). Human cases in Bucharest were concentrated in blockhouses situated over an aging sewage system where *C. pipiens* were breeding in abundance.

Russia 1999: A third large outbreak of WNV occurred in Russia in the summer of 1999, following a drought. Hospitals in the Volgograd Region admitted 826 patients; 84 with meningoencephalitis, of which 40 died.

Israel 2000: WNV was first reported in Israel in 1951, and sporadic outbreaks followed. Israel, a major stopover for migrating birds, usually receives little precipitation from May to October. In 2000, the region was especially dry, as drought conditions prevailed across southern Europe and the Middle East, from Spain to Afghanistan. Between August 1 and October 31, 2000, 417 cases of

serologically confirmed WNV were diagnosed in Israel with 35 deaths. *C. pipiens* was identified as a vector.

US 1999: In the spring and summer of 1999, a severe drought (following a mild winter), affected the Northeastern and Mid-Atlantic States. The prolonged drought culminated in a three-week July heat wave that enveloped the Northeast. Then the pendulum swung in the opposite direction, bringing torrential end-of-August rains (and, later, Hurricane Floyd to the mid-Atlantic states). *Culex spp.* thrived in the drought months; *Aedes spp.* bred in the late summer floodwaters. In the NY outbreak seven people died and of the 62 people who suffered neurological symptoms and survived, most report chronic disabilities, such as extreme muscle weakness and fatigue.

US 2002: In the summer of 2002 much of the West and Midwest of the U.S. experienced severe spring and summer drought. Lack of snowpack in the Rockies (warming winters leading to more winter precipitation falling as rain) contributed. Forest fires burned over 6.1 million acres, and haze and respiratory disease affected several Colorado cities. There was also an explosion of WNV cases (see chart below), with humans or animal WNV being documented in 43 states and the District of Columbia, reaching to California. Drought conditions were present in June in Louisiana in June, the first epicenter of WNV in 2002. Widespread drought conditions and heatwaves may have amplified WNV and contributed to its rapid spread throughout the continental U.S. (Health officials have also become convinced that WNV can be transmitted via organ transplant and blood transfusion.)

WNV is primarily a disease of wildlife and there is also evidence of infection in birds (120 species) and other animals, primarily horses. Raptors (owls, kestrels) have been particularly affected; West Nile virus likely caused thousands of birds of prey to die in Ohio and other states in July 2002. Some zoo animals have died (e.g., 8 Humboldt penguins in the Milwaukee Zoo and macaques.)

Note: The population impacts on wildlife and biodiversity have not been adequately evaluated. The impacts of declines in birds of prey could ripple through ecological systems and food chains, and could in itself contribute to the emergence of disease.

As of March 12, 2003, the Centers for Disease Control and Prevention (CDC) reports:

Laboratory confirmed human cases nationally: 4,161

Deaths associated with the virus: 277

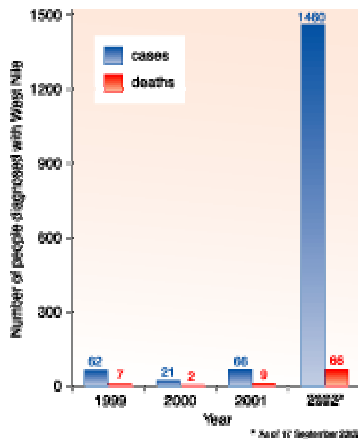
Deaths in Illinois, the leading state for cases: 54

Deaths in Michigan, the second leading state for cases: 46

Deaths in Ohio, the third leading state for cases: 31

Equine cases were 14,045 in 38 states, reported to USDA APHIS by state health officials as of 26 Nov 2002. WNV has now been associated with illness and death in several other mammal species, including squirrel, wolf, and dog in Illinois (which leads the country in number of human cases), and mountain goat and sheep in Nebraska, which leads the country in numbers of equine cases.

Moreover, because of the bird and mammal reservoirs for WNV, there is the potential for outbreaks in all Eastern and Gulf States of the US and into Canada in the coming years.



Science 2002:297:1988

Conclusions and Discussion

Multi-month drought, especially in spring and early summer, was found to be associated with urban SLE outbreaks from its initial appearance in 1933 through 1973 and with recent severe urban outbreaks of WNV in Europe and the U.S. Other factors, such as inadequate sanitation, sluggish urban waterways and abandoned tires, may increase vulnerability to urban arbovirus outbreaks. Each new outbreak requires introduction or reintroduction of the virus, primarily via birds or wildlife – so there have been seasons without SLE outbreaks despite multi-month drought. Spread of WNV and sporadic cases may occur, even in the absence of conditions amplifying the enzootic cycling. In Bayesian parlance, drought increases the “prior probability” of a significant outbreak once the virus becomes established in a region, other factors, such as rains that increase populations of bridge vectors, may affect transmission dynamics.

Further investigation and modeling are needed to determine the role of meteorological factors, and identify reservoirs, overwintering patterns, and the susceptibility of different species associated with WNV. The migration path of many eastern U.S. birds extends from Canada across the Gulf of Mexico to South America (<http://www.npwrc.usgs.gov/resource/othrdata/migratio/prince.htm>).

Public Health Implications

Factors other than weather and climate contribute to outbreaks of these two diseases. Antiquated urban drainage systems leave more fetid pools in which mosquitoes can breed, and stagnant rivers and streams do not adequately support healthy fish populations that consume mosquito larvae in isolated standing pools. Such environmental "vulnerabilities" present opportunities for environmentally based public health interventions following early warnings of conducive meteorological conditions.

State plans to prevent the spread and contain WNV have three components:

1. Mosquito surveillance and monitoring of dead birds. Community communications and media outreach;
2. Source (breeding site) reduction through larviciding (*Bacillus sphaericus* and Altocid (methiprine)) and neighborhood clean-ups; and
3. Pesticide (synthetic pyrethrins) spraying, when deemed necessary.

The information on predisposing climatic conditions and predictions of them may be most applicable for areas that have not yet experienced WNV, but lie in the flyway from Canada to the Gulf of Mexico. Projections of droughts (e.g., for Northeast Brazil during an El Niño event) could help focus attention on those areas, enhancing surveillance efforts (including active bird surveillance), public communication and environmentally-friendly, public health interventions. They may also help to set the stage for earlier chemical interventions once circulating virus is detected.

Finally, in terms of the public perception and concerns over the risks of chemical interventions: understanding the links of WNV to climatic factors and mobilizing public agency departments, such as water and sewage services, to address a public health threat may prove helpful in garnering public support for the combined set of activities needed to protect public health.

TRAUMATIC INJURIES AND EXTREME WEATHER EVENTS

Anomalous weather and extreme events have increased in intensity, and they are projected to increase in frequency, as climate changes (IPCC, 2001). Some events, like heat waves, have already become more common; droughts have become more prolonged, and heavy rain events (>2"/day) have increased over the past century (Karl *et al.*, 1995; Easterling *et al.*, 2000). Storms can effect populations directly, but they can also do so indirectly, as they can increase the number of breeding sites for disease vectors; and drive nutrients, microorganisms and toxic chemicals into waterways and water supplies, affecting both the food and water supply. Fog, avalanches, ice, wind and hail storms are all potentially

affected by changes in ambient temperatures and alteration of the hydrological cycle.

While there continues to be debate about whether greenhouse warming and climate change leads to an increased frequency of severe storms and hurricanes, there is broad consensus that the amount of water dumped by such storms has been increased. There are two reasons for this. With warming, there is both an increased evaporation of water from land and from the oceans, and an increased capacity of the atmosphere to hold water. As a result, there is increased cloud formation and when it does rain, the rains can be torrential. This has been observed in recent hurricanes in the U.S. (e.g., Hurricane Floyd, drenching the Mid-Atlantic states in September 1999), and in Hurricane Mitch in Central America in November 1998 in Honduras (with six feet or rain over 3 days). The enormous amounts of precipitation have led to massive flooding, mudslides, the wash out of roads and bridges, and the resulting injuries and deaths from drownings, car accidents, and the collapse of homes and other buildings. The freezing rain and ice storms seen in winter are also the result of warming temperatures, leading to driving and pedestrian hazards.

Ice storm traffic deaths and power outages, such as those occurring in December 2002 in Arkansas and North Carolina, are examples of the potential impacts of early storms and anomalous weather.

GASTRO-INTESTINAL INFECTIONS AND WATER QUALITY

Water quality and quantity are affected by climate and weather. Some parts of the US are experiencing chronic shortages of precipitation (e.g., the West and Midwest), while others are experiencing an excess (e.g., the Northwest). [Water withdrawals and competing uses are contributing to water problems in many parts of the U.S., and changes in precipitation patterns are exacerbating the issues of shortages in some parts and excess in others.]

Case Study—the Milwaukee *Cryptosporidium* Outbreak

In addition, floods are related to water-borne diseases. The torrential rains in 1993 (that led to the flooding of the Mississippi River valley) resulted in the largest waterborne disease outbreak in U.S. history in Milwaukee, Wisconsin. The rains washed a protozoan called *Cryptosporidium* from farm lots (it is present in the stools of livestock) into surface waters that supply Milwaukee with drinking water. An estimated 403,000 persons contracted *Cryptosporidiosis*, a gastrointestinal infection of varying severity in different populations. This constituted an incidence rate of 52% among all those served by the South Milwaukee water works plant (MacKenzie *et al.*, 1994). In most people exposed, the infection was mild and self-limited and did not cause serious illness. In others, especially in those with compromised immune systems (e.g. those with HIV/AIDS infections or those being given chemotherapy for cancer), the situation was very different. In this group, there were over 100 deaths (Vakill *et al.*, 1996).

An extensive study of water-borne disease outbreaks for the U.S. demonstrates the strong association with heavy rain events and flooding (Curriero *et al.*, 2001) (Also see review of climate and disease: Patz *et al.*, 2001).

FOOD QUALITY

Food quality can be affected by heat. Episodes of bacterial food contamination in Japan are highest during the summer, and notable outbreaks have accompanied prolonged summer heatwaves (McMichael *et al.*, 1996).

Seafood contamination with biotoxins (biological toxins) is associated with “red tides,” or harmful algal blooms (HABs). Excess nutrients and the loss of filtering wetlands, combined with warm, stagnant seas can lead to red tides and outbreaks of shellfish contamination (paralytic, neurological, amnesic and diarrheic shellfish poisoning). In addition, heavy rains can flush nutrients into estuaries and coastal zones, triggering HABs (Epstein *et al.*, 1998; Harvell *et al.*, 1999).

SEA LEVEL RISE AND STORM SURGES

Sea level rise (SLR) presents a longer-term threat to infrastructure and human health. SLR can lead to salination of underground water, with implications for hypertension and the availability of potable water. SLR can also increase the frequency of storm surges and associated damage to infrastructure and sanitation systems, contamination of ground and surface water with farm animal wastes, and the overflow of Combined Sewer systems.

CONCLUSIONS

Climate change and increased variability of weather pose numerous threats to public health. The issues range from heatwaves, synergies with air pollution, infrastructure damages, and water quality to WNV. Some issues will be most felt in urban settings; others more rural. Monitoring those conditions that are affected by climate and weather can be integrated into the practices of public health departments. Such integration can provide early warnings and guidance for prioritizing interventions and involvement of public health departments in long-range prevention.

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