Wisconsin
Initiative on
Climate
Change
Impacts

Human Health
Working Group Report

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HUMAN HEALTH WORKING GROUP
WISCONSIN INITIATIVE ON CLIMATE CHANGE IMPACTS

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HUMAN HEALTH WORKING GROUP

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Executive Summary

Human health is affected by climate change through many pathways. These include: heat-related morbidity and mortality; flooding and storms with associated trauma and mental health concerns; air pollution, especially from ground-level ozone and potentially from aeroallergens (e.g., pollen and molds); and infectious diseases, particularly those that are water- or vector-borne. Adaptation to climate change health risk, therefore, will involve many different types of interventions.

However, some of the largest gains for public health may stem from a reduction in our dependence on fossil fuels, especially though improved air quality and green design of cities, which would promote a less sedentary lifestyle. The WICCI health task force therefore recommends an integrated approach to risk reduction, whereby the distinction between greenhouse gas mitigation policies and adaptation strategies represent a solid continuum of prevention.

Our panel also recommends that climate change risks not be viewed as an isolated threat. For example, weather-related health risks must be assessed in the context of landcover and other concurrent environmental stressors. The 'urban health island' effect and land cover that alters the rate of rainfall runoff (via impervious surfaces) will modify the intensity of potentially hazardous heat waves and intense precipitation events, respectively.

Health Risks

State or region specific health risks identified by our task force include the following:

- Increase ground-level ozone in the summer months by the end of the current century, translating into an increase in the number of exceedances of the current National Ambient Air Quality Standards (NAAQS) for ozone.
- Uniform increase of future summer temperature associated with more days beyond a threshold temperature (>95th percentile) and therefore more heat-related hospital admissions.

- Heavy rainfall events have increased in frequency considerably in the Midwest. These events will become up to 40% stronger in southern Wisconsin, resulting in greater potential for flooding and water-borne diseases from parasites, bacteria, and/or viruses.
- With regards to vector-borne diseases, warmer temperatures along with drought conditions may increase the number of cases of West Nile virus. However, if dryness dominates future climate scenarios, Lyme disease may be pushed northward into Canada; tick survival is suppressed in the Great Lakes region by the end of this century such that the risk in Madison could fall by over 15%.

Recommendations

In formulating and implementing a state climate change response plan for public health, the task force recommends that:

- The Department of Human Services work closely with the Wisconsin Emergency Management program and other key agencies to incorporate climate change into the planning process and into final mitigation plans.
- The state expands activities of the Wisconsin Environmental Public Health Tracking program to include indicators of climate change.
- Planning should be towards sustainable solutions. For example, in the case of heatwave response plans, consideration should be made on the source of electric power for air conditioning, with a strong preference for renewable source (e.g, wind or solar).

Policy makers (e.g., Public Service Commission of Wisconsin) should carefully weigh the impacts of their infrastructure investment decisions on: a) human health and, b) the state's capacity to adapt to a changing climate. For example, water management facilities should be built to specifications for future intensification of rainfall events rather than simply considering current rainfall/runoff distributions.

The task force encourages greater regional coordination of plans and policies, as well as more effective capacity-building at the local level. We also recommend the development of local and regional plans and policies that create more livable, sustainable, and resilient communities. "Smart Growth" (in contrast to scattered sprawl) has potential benefits for human health, the economy, and the environment. Complementary "green" land use practices (e.g., planting street trees) could adaptively retrofit existing buildings, lots, and neighborhoods. And 'co-benefits' of multimodal transportation planning should be included in any cost benefit analyses of responses to climate change.

Introduction

Many prevalent human diseases are sensitive to climate fluctuations. More direct pathways through which climate change can adversely affect health include: heat-related morbidity and mortality; flooding and storms with associated trauma and mental health concerns; air pollution, especially from ground-level ozone, particular matter (PM) and potentially from aeroallergens (e.g., pollen and molds); and infectious diseases, particularly those that are water- or vector-borne. Land use changes happening alongside climate change can make human health problems worse. For instance, the 'urban heat island effect' could make future heat waves more severe for city-dwellers. One will have to look beyond the human health sector to determine the vulnerabilities for particular locations.

Climate change poses regional and local public health risks in Wisconsin that vary over time and space and that the impact of these risks are dependent upon local level resources for adaptation, including population vulnerability, geographic landscapes, and public health preparedness. This hypothesis is based on past extreme weather events and preliminary results from our team's downscaled global climate models indicating that the most likely types of climate change in Wisconsin will be: (a) reductions in extreme cold; (b) increases in extreme heat; (c) increases in extremely heavy precipitation events; (d) greater precipitation during winter and even more so during spring; and (e) warming in every month/season (Vavrus and Van Dorn 2009).

As for how these future projection impacts upon health, we can only assess future risks to the extent that climate/health mechanisms are understood and quantitative health models are available. Some health issues in Wisconsin may benefit from climate change, such as a reduction in cold-related deaths and, as outlined below, a potential northward shift of Lyme disease into Canada. But, on balance, our task group finds that the adverse health ramifications outweigh potential health benefits. Of course, in addition to future climate projections, varying scenarios of future demographic and economic trends adds uncertainty for assessing human population vulnerability.

This working group report is organized into three sections that cover: current climate sensitivities for the state of Wisconsin; future climate change projections; and current adaptive capacity and public health monitoring to address climate change. Several sections overlap, for example, heatwaves and unhealthy air masses occur simultaneously; such synergistic affects are not discussed. In responding to climate change there are recommendations that apply both to adaptation and mitigation strategies together. Our task group intentionally blurs the separation between actions to be taken to adapt to climate change with actions to mitigate greenhouse gas emissions.

Current Climate Sensitivities and Projected Risks

Heat Waves

It is well known that heat waves can cause a substantial number of deaths. For example, the 1995 upper Midwest heat wave resulted in 700 deaths in Chicago (Semenza et al. 1996). During the same heat wave, 91 deaths and 95 paramedic emergency medical service (EMS) runs in Milwaukee were attributed to heat. During August 2003, a European heat wave killed an estimated 22,000 to 35,000 people (IFRC, 2004; Kovats et al. 2004).

During this ongoing Wisconsin Initiative on Climate Change Impacts (WICCI), we finalized an analysis of heat wave admissions to hospitals in the city of Milwaukee (Li et al, in review). We used a generalized additive model (GAM) to quantify the relationship between morbidity (as measured by hospital admissions) and temperature in Milwaukee. This analysis is coupled with additional information on potential confounders, including relative humidity and the outdoor air pollutants of tropospheric ozone and particulate matters (PM10).

Health data were reported by all of Wisconsin's acute care non-federal hospitals, including General Medical/Surgical, Psychiatric, Alcohol and Drug Abuse (AODA), Rehabilitation, and state institutions for the years 1989-2005. Weather data from

1989-2005 for a single weather station in Milwaukee were obtained from the National Climate Data Center's (NCDC) cooperative daily meteorological data set available at the National Center for Atmospheric Research. Variables obtained included maximum and minimum temperature and maximum and minimum relative humidity (RH) for the time period 1989-2005. We analyzed air pollutant data from two monitor stations located in central Milwaukee, using the maximum 8 hour moving average of ozone and the daily mean concentrations of PM10 in our analysis.

Results

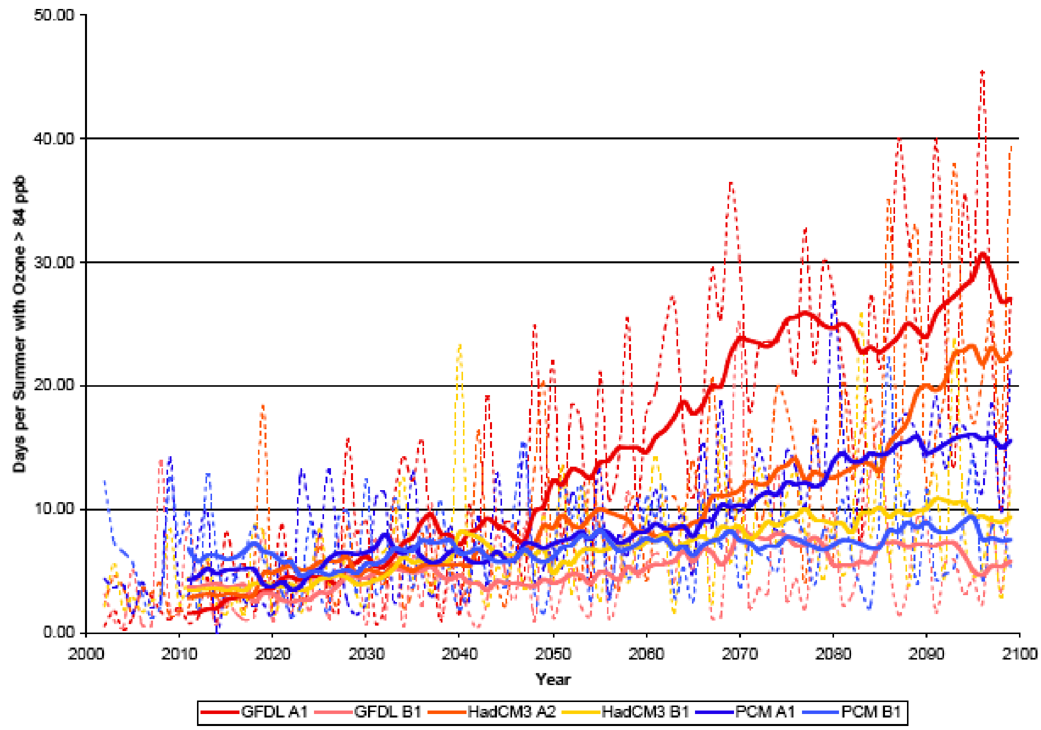
We found an increase in admissions for the following categories of illness: Endocrine, Genitourinary, Respiratory, and Self Harm (e.g, suicide attempts). Several causes of admission are not affected by high temperature, including Cardiovascular, Mental and Nervous System. The relationships for three age groups between 15-84 years old are basically flat, while an obvious increase is seen for children (<5) and the elderly (85+ years). We further identified threshold temperature values (at the 95^{th}percentile) of 27.2°C for Accidents and Self Harm, and 29.5°C for Endocrine, Genitourinary and Renal causes of hospital admissions.

<u>Air pollution risks</u>

Air Quality and Respiratory Disease

As a result of generally-anticipated increases in mean temperature, it follows that the presence of pollutants such as ozone – which is formed more rapidly in the atmosphere at elevated temperatures – will be more prevalent at levels of public health concern. Estimates of the impact of global climate change processes on this front for Chicago, IL (which is 55 miles south of Kenosha, Wisconsin) include projections that the Chicago area will get warmer over the next 100 years, with related changes in circulation, humidity, cloud cover, and precipitation. These meteorological changes alone are expected to increase ground-level ozone by an average of 6.2 ppb (under low-growth scenarios) to 17.0 ppb (under high growth scenarios) in the summer months by the end of the current century, translating into an associated three-fold (low-growth) to eight-fold (high growth) increase in the number of exceedances of the current 84 ppb National Ambient Air Quality Standards (NAAQS) for ozone, as shown in figure 1. (Holloway et al. 2008). As such, changes in air quality and their contribution to increasing respiratory disease burdens are appropriate endpoints for consideration in developing programmatic capacity to address the public health impact of climate change.

Figure 1. Projected increases in ozone in Chicago (Source: Holloway et al. 2008).



Aeroallergens

Another air contaminant that may increase with climate change is pollen. Higher levels of carbon dioxide promote growth and reproduction by many plants, including those that produce allergens. For example, ragweed plants experimentally exposed to high levels of carbon dioxide can increase their pollen production several-fold, perhaps part of the reason for rising ragweed pollen levels in recent decades (Ziska and Caulfield, 2000; Wayne et al., 2002).

<u>Waterborne Diseases</u>

Waterborne disease outbreaks from all causes in the United States have demonstrated a distinct seasonality, a spatial clustering in key watersheds, and an association with heavy precipitation (Curriero, Patz et al. 2001). Certain watersheds, by virtue of the land use patterns and the presence of human and animal fecal contaminants, are at higher risk of surface water contamination after heavy rains, and this has serious implications for drinking water purity. Intense rainfall can also contaminate recreational waters and increase the risk of human illness (Schuster, Ellis, Robertson et al. 2005) through higher bacterial counts. This association is strongest on the beaches closest to rivers (Dwight, Semenza, Baker and Olson, 2002).

Sewage contamination from sewage overflow is a major source of human pathogens and adversely impacts recreational beaches and drinking water sources. Older cities around the northeast and Great lakes regions have combined sewer systems –which handle both sewage and stormwater together in large underground pipes). When these systems become inundated with rainwater following heavy precipitation they can overflow into receiving waters, presenting a health risk from contaminated surface water. The EPA estimates that there are more than 3 trillion liters of un-treated combined sewage released annually (US EPA 2004). Perhaps more alarming is that this only accounts for *reported* sewage overflows; aging infrastructure leading to leaking pipes and illicit cross-connections contribute to unrecognized sewage inputs into surface and groundwater sources. Most water resource managers and civil engineers in urban areas acknowledge unrecognized sewage contamination as a serious problem, but have no idea of the magnitude or the dynamics of how contamination occurs. While there is sewage detectable even under base-flow conditions, precipitation is a major driver of sewage delivery into surface water. Consequently, priority health endpoints of concern from hazardous precipitation events include gastrointestinal illness, allergic reactions, and respiratory effects.

Wisconsin weather events from 2007-2008 and other recent climate trends indicate that the upper Midwest region may already be seeing changing weather patterns. The frequency and intensity of heavy precipitation have been increasing and account for a rising percentage of total precipitation (Ebi 2008). In the Midwest these events have increased in frequency by as much as 100% (Kunkel 2003). Heavy rainfall has been associated with water-borne disease outbreaks – most notably the 1993 *Cryptosporidium* outbreak in Milwaukee WI, exposing an estimated 405,000 people and causing 54 fatalities (Curriero, Patz et al. 2001).

During 2007-2008 Wisconsin experienced very large precipitation events that took their toll on all public health related sectors of society from agriculture, to business, housing and human health. Beginning in early spring and summer 2007, Wisconsin experienced moderate to severe drought, but on August 18, 2007, torrential rainfalls of greater then ten to twelve inches began. The heavy precipitation landed on hardened ground, which led to large-scale flooding in southern Wisconsin. More than 200 homes were flooded, and 5000 residents applied for federal disaster assistance in fourteen counties affected by the rain. The winter 2007-2008 produced record snowfalls for the region, with 101 inches in Madison, WI. As the snows melted into already saturated ground from late fall storms, river levels were higher than they had been for years and floods occurred in 100-500 year flood plains. On June 5, 2008, severe weather including heavy rain, hail, damaging wind, and super-cell thunderstorms began affecting the entire Midwest region impacting already flooded regions across the state. Rains fell at a rate of more than 2 inches per hour, leading to flash flooding, road closures, mudslides and partial washouts and five all-time river cresting records were set.

State emergency and public health response plans were employed. Evacuations were implemented. Over 1000 residents were visited by the US public health services, and 72 environmental health checklists and public health assessments were performed during the initial response to the floods. In total 41,000 households and over 100,000 residents filed for emergency assistance in Southern Wisconsin. Over 2547 water samples were tested by the state lab of hygiene and over 30% of samples tested as unsafe for coliform (29%) or *E. coli* (4.5%) bacteria. Contaminated food supplies led to assistance for over 13,901 households with 37,307 members. Project Recovery, Wisconsin's crisis counseling program, made 8,083 supportive counseling contacts related to these events.

Vectorborne infectious diseases

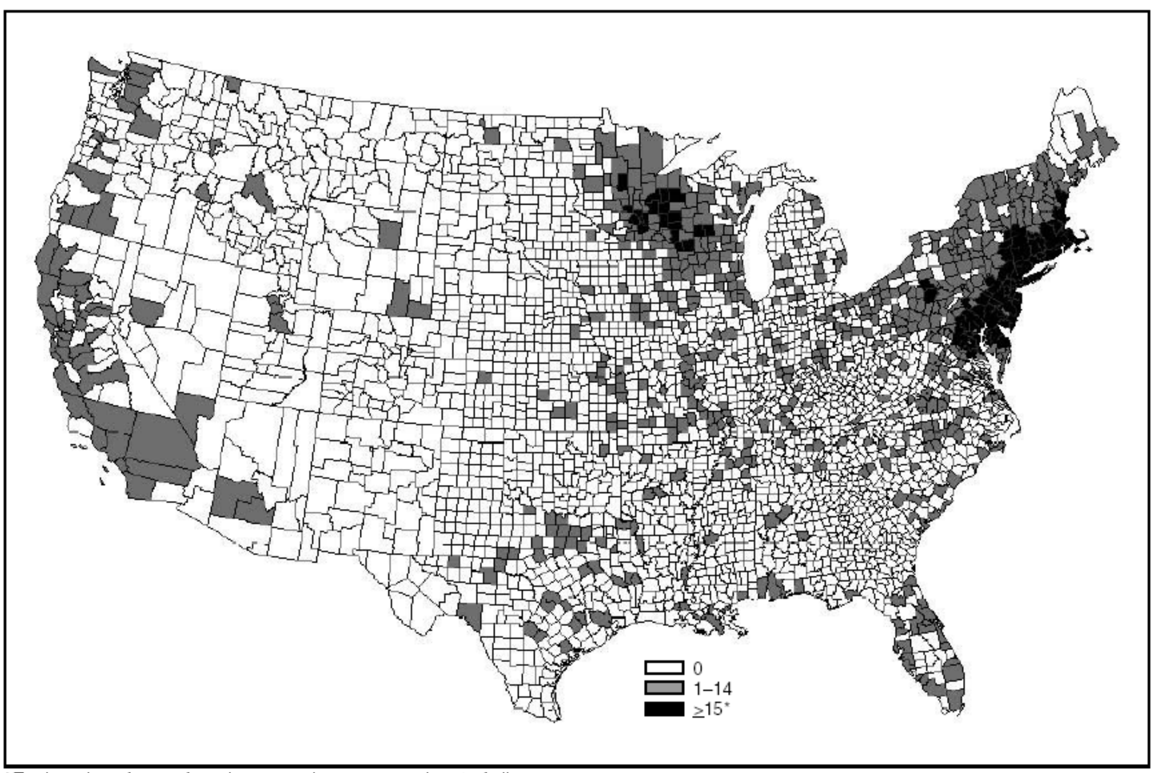
Many zoonotic diseases (natural life cycle being in animals) are sensitive to climate fluctuations such as Saint Louis encephalitis and West Nile virus. West Nile virus (WNV) emerged for the first time in the North America in July 1999. While international travel is suspected as the cause of this event, the unseasonable heatwave that year (as well as in subsequent hot summers in the Midwest and West during peak years of 2002 and 2003 subsequently) raises the question of weather's possible effect on WNV disease ecology and transmission. An outbreak of West Nile encephalomyelitis in horses in the Midwest of the U.S. peaked with high temperatures, and significantly dropped following decreasing ambient temperatures, suggesting a temperature effect (Ward, 2004). Bird migratory pathways and WNV's recent march westward across the U.S. and Canada are key factors as well, and must be considered in future assessment of temperature's role in disease dynamics.

Lyme Disease

Lyme disease is the most prevalent zoonotic disease in the North America for which there is new evidence of an association with temperature (Ogden et al. 2004). Two main foci of disease occur in the Mid-Atlantic region and in western Wisconsin along the Mississippi valley (figure 2). In the field maximum, minimum, and mean temperatures as well as vapor pressure significantly contribute to the abundance this tick, *Ixodes scapularis,* in the U.S. Also, an average monthly minimum temperature threshold above −7°C is required for tick survival (Brownstein, 2003).

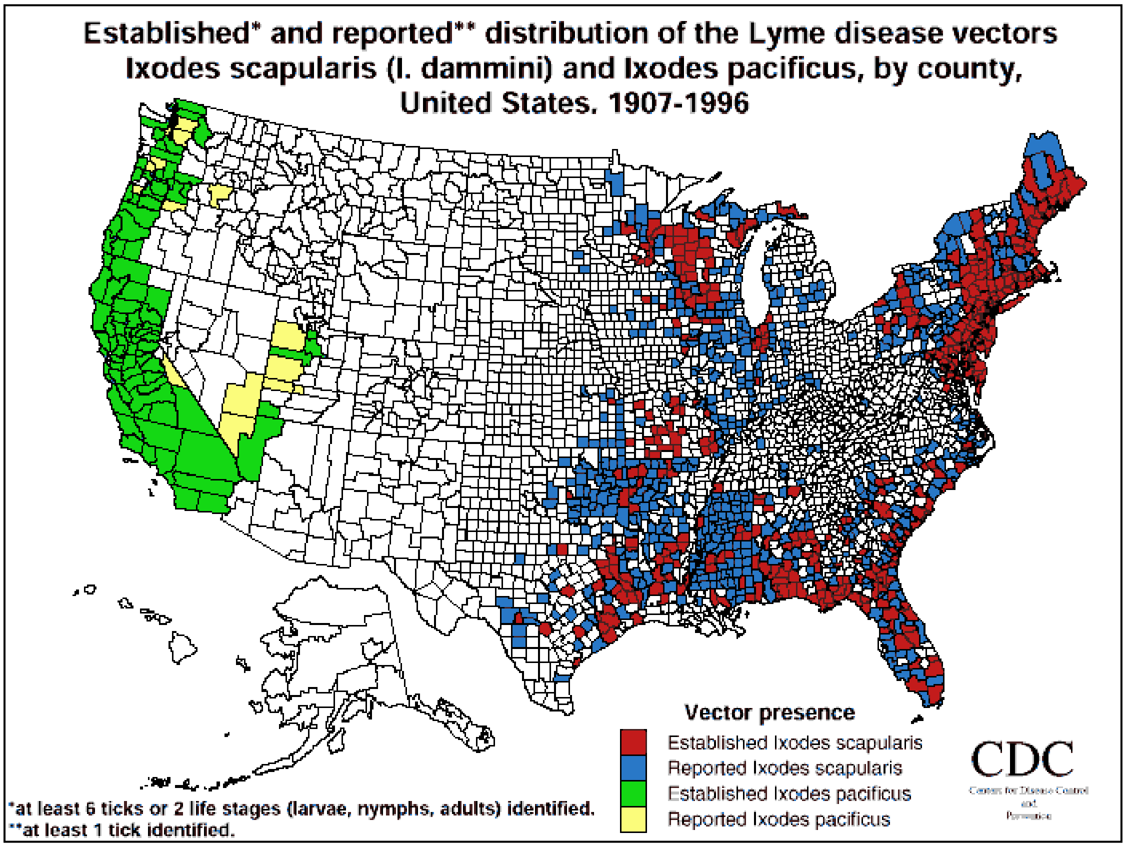
The reported incidence of Lyme disease in Wisconsin has consistently been among the ten highest for states in the U.S. and has doubled over the last decade. The average annual incidence of confirmed Lyme disease infection during the most recent five-year period (2002-2006) was 2.2 times higher than the five years prior to that (1997-2001). Incidence is markedly higher in the western and northwestern parts of the state; six Wisconsin counties reported average annual incidence exceeding 100 cases per 100,000 persons during 2002-2006. Statewide incidence in 2006 was 25.9 cases per 100,000 persons and rose to 32.7 cases per 100,000 in 2007. Of the 1,839 cases of Lyme disease reported to the Wisconsin Division of Public Health (WDPH) in 2007, annual incidence of at least 100 cases per 100,000 persons (3.6 times higher then the five previous years) was reported in 22 counties.

Figure 2a. The most recent distribution map of human cases from CDC (below).[i]



*Total number of cases from these counties represented 90% of all 2000 cases.

Figure 2b. [1] CDC. Lyme Disease—United States, 2000. MMWR 2002; 51 (No. 2)29-31.



Future Climate Projections for Wisconsin

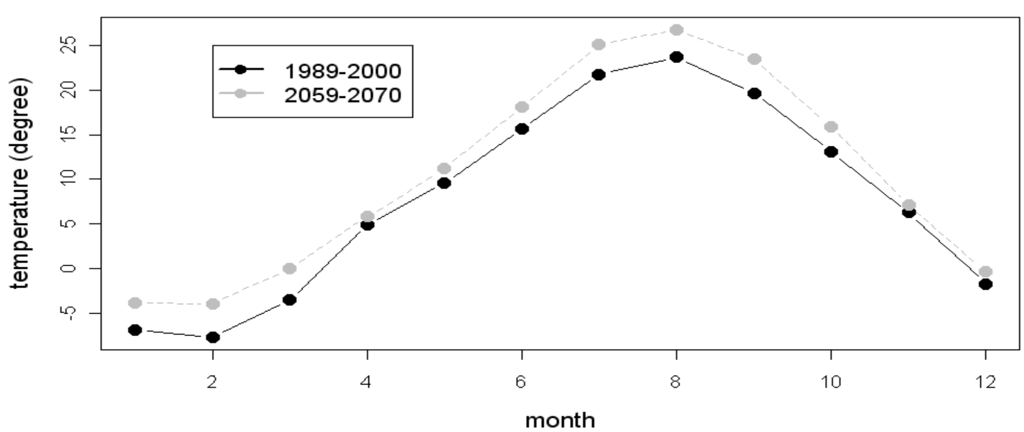
Heat waves

For assessing future climate trends we downscaled climate results from the North American Regional Climate Change Assessment Program (NARCCAP, Mearns et al., 2009). The projections are for the period, 2041-2070, and at a spatial resolution of 50 km. (These data are available at: http://www.gfdl.noaa.gov/~bw/narccap/).

The monthly mean temperature difference (future minus current period) from the time-slice experiments is applied to our actual temperature data set for 1989-2005 to project the future temperature in 2059-2075. This gives the mean-adjusted future temperature projection. Furthermore, the variance of the future temperature is also expected to change; thus, in addition to mean adjustment, we can adjust the variance of the past temperature as well in our projected monthly temperatures.

Figure 3 shows the monthly average temperature for both the past (1989-2000) and future (2059-2070) based on the General Fluid Dynamics Laboratory climate model data. Uniform increase of future temperature is observed across seasons, and in particular, the amount of increase is pronounced in July, August, and Septmeber. The temperature projections for both adjusted mean and variance is associated with more days beyond a threshold temperature (>95th percentile) and more hospital admissions. These results assess the sensitivity of hospital admissions to temperature change since we assumed the pollution level and other meteorological variables remain the same as in the past.

Figure 3. Monthly average temperature over 1989-2000 and 2059-2070 from time-slice experiments at Geophysical Fluid Dynamics Laboratory (GFDL). Source: Li et al. (in review).

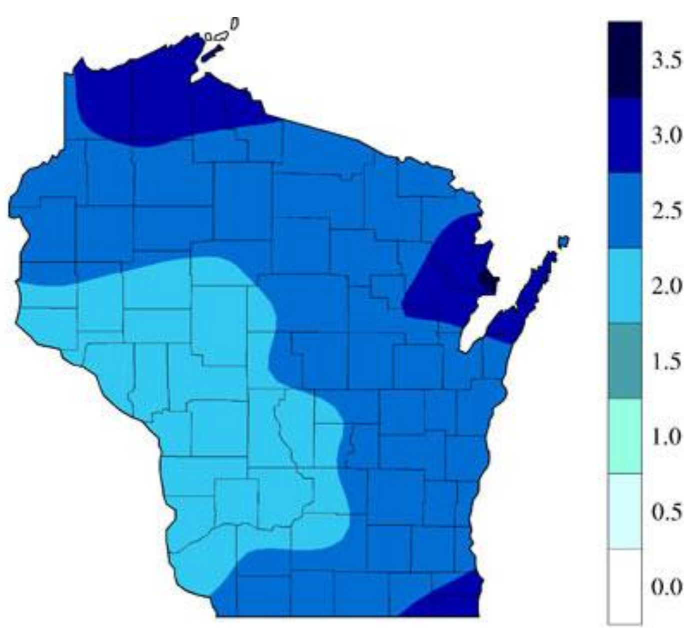


<u>Rainfall and Health</u>

Marked variability in the hydrologic cycle will accompany climate change, in addition to hotter temperatures; this translates both to more droughts and floods (from a more dynamic water cycle). We focused on rainfall and flooding as a risk to water quality. Our preliminary finding since the startup of WICCI stems from our research under an EPA STAR grant and from a Center for Disease Control and Prevention (CDC) grant to conduct a health impact assessment of climate change for the state of Wisconsin.

For the Great Lakes region of the U.S., contamination events typically occur when daily rainfall levels exceed a threshold approximating 2 to 2.5 inches (Hayhoe et al, 2007; McLellan et al, 2007). Given that heavy rainfalls are expressions of climate, there is heightened concern as to how this type of event may change in a warmer future climate. The WICCI Climate Working Group have projections of 2-inch rainfall events for mid-century (figure 4).

Figure 4. Projected Change in the Frequency of 2" Precipitation Events (days/decade) from 1980 to 2055 based on downscaled climate models (http://www.wicci.wisc.edu)



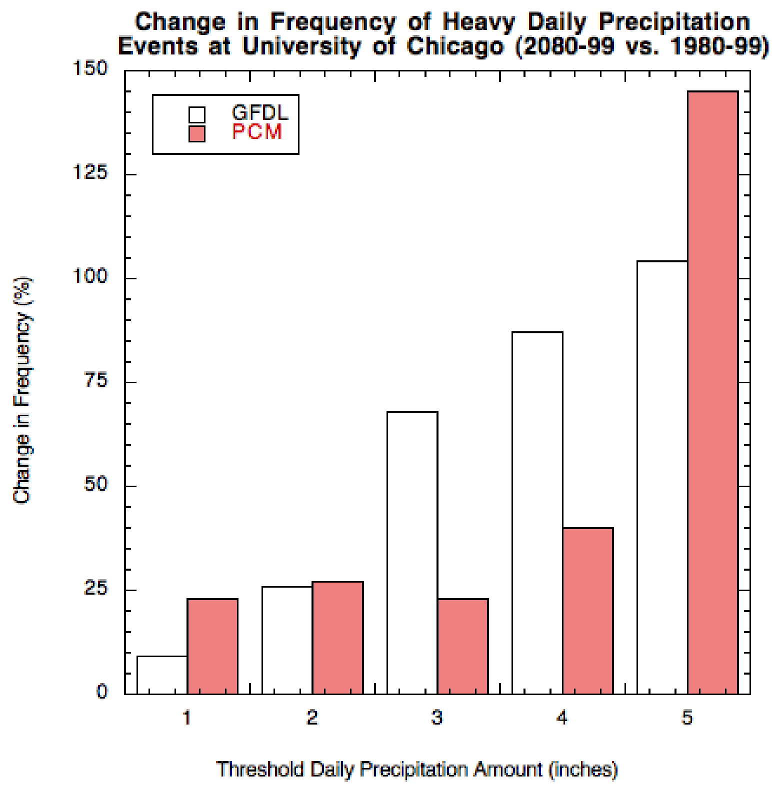
Precipitation intensity (total precipitation divided by the number of wet days) is projected to increase almost everywhere, particularly in middle and high latitudes where mean precipitation is also expected to increase (Tebaldi, 2006). Most of the Great Lakes region is projected to experience a rise in mean and intense precipitation events (IPCC, 2007; Diffenbaugh et al, 2005).

These anticipated future changes are consistent with recent trends over the United States, including the Great Lakes area. Major storms have been occurring with greater frequency during the 20th century, and the total precipitation increase over this interval has resulted disproportionately from the increase in heavy events (Changnon and Kunkel, 1995; Karl and Knight, 1998; Karl, Knight and Plummer, 1995). This secular trend has been accentuated by the increase in heavy events toward the end of the century, the time of most pronounced global warming (Groisman et al, 2004; Kunkel et al, 2003).

Analysis of downscaled Global Climate Models (GCM) predict with high certainty that climate change will lead to increases in heavy precipitation with greater winter and spring precipitation (Vavrus and Van Dorn 2009). Vavrus and colleagues have tailored these large-scale findings to the Wisconsin-Chicago region, where we are conducting research on the health impacts of rainfall events. In one example, we computed the recent and future simulated precipitation rate of the ten wettest days for the Madison, WI, area from seven global climate models used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report

(Fig.5). For each ranking (10th wettest day to the very wettest day), the precipitation rate of these very heavy events increases in the future, and the enhancements are most pronounced for the most intense events (wettest and second wettest days). Overall, the models project that these extremely heavy precipitation events will become 10 to 40% stronger in southern Wisconsin, resulting in greater potential for flooding and water-borne diseases that often accompany high discharge into Lake Michigan (Patz et al, 2008).

Figure 5.



The expected changes in the hydrological cycle, including increases in heavy precipitation events, should have a direct bearing on waterborne diseases in the Great Lakes. For example, the 1993 cryptosporidiosis outbreak in Milwaukee was preceded by the heaviest rainfall in fifty years in the associated watersheds

(Curriero, Patz et al, 2001). Summertime bacteria concentrations in an inland lake in Wisconsin (Lake Geneva) exhibit positive, statistically significant correlations not only with mean summertime rainfall but also with the duration between rainfall events, a variable that is expected to increase in the future (Allen and Ingram, 2002). The combination of future thermal and hydrological changes may affect the usability of recreational beaches. Chicago beach closures are dependent on the magnitude of recent (<24-hour) precipitation, lake temperature, and lake stage (Olyphant and Whitman, 2004). Projected increases in heavy rainfall, warmer lake waters, and lowered lake levels (Kunkel et al, 2007) would all be expected to enhance beach contamination in the future. Although more intense rainfalls would seem to contradict the projection of lower lake levels, the latter expectation stems from a large anticipated increase in evaporation at the lake surface (which can offset the precipitation gain) and a higher proportion of future precipitation falling as heavy events, even if the total precipitation amount does not rise.

<u>Ongoing Health Impact Assessment of Rainfall Variability and Waterborne Diseases</u>

Under a grant from the CDC we will draw upon several recent and ongoing studies to define “hazardous” weather occurrences and examine relationships between these patterns and pathogen occurrence and health outcomes. Figures 6 a&b show our framework to assess environmental health impacts of hazardous rainfall (e.g., changes in precipitation) events in Wisconsin. The model is based on the premise that climate predictions indicate increased precipitation in the upper Midwest. For example, sewage overflow events and subsequent viral contamination of surface and ground waters have been found to be exacerbated if these events have been preceded by previous heavy rainfall or drought conditions (Borchardt 2003, 2004, 2006, 2007; Ebi 2008). Flooding also impacts indoor air quality by increasing the potential for mold to grow, mortality (from drowning), injuries (from clean up and hazardous conditions), and long term mental health issues (from displacement) (Greenough et al. 2001; Keim 2008).

Figure 6a.

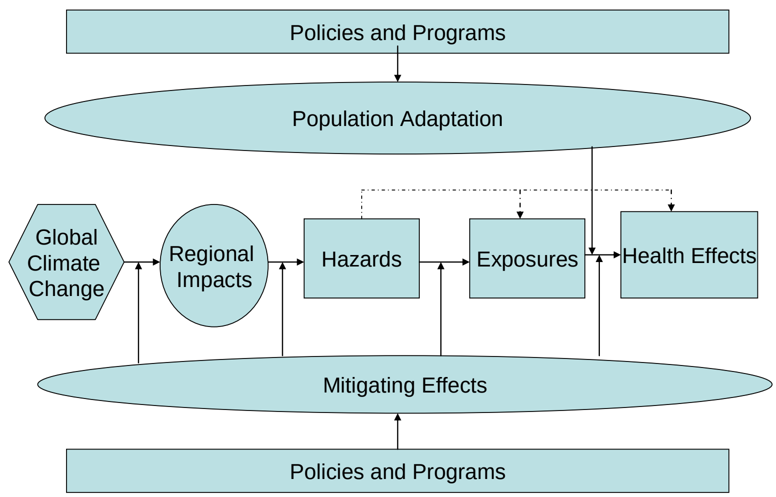
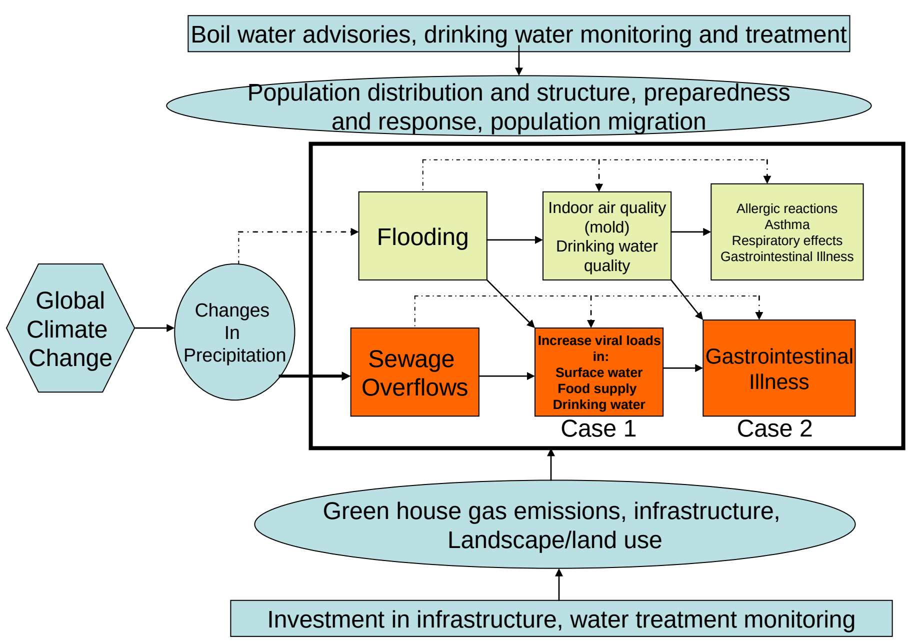


Figure 6b.



Precipitation and pathogens in surface water.

Previous research in the Milwaukee River Watershed has indicated that pathogen presence in surface water is, to a large degree, driven by precipitation-runoff events. Results of one study indicated that cryptosporidium concentrations during runoff events were greater than during low-flow periods in an urban and a rural sub-watershed (Corsi et al. 2003). Similarly, preliminary results from a recent study of enteric viruses in the Milwaukee area indicated that human-specific viruses were present in 63% of precipitation-runoff samples with an average of 76 viral genomic copies/L compared to just 20% of samples collected during low-flow that had an average concentration of 13 genomic copies/L. The study is focusing on viruses, wastewater indicators, and microbial indicators of human influence in surface water as they relate to stream flow, water quality, and other environmental variables.

*Precipitation and pathogens in groundwater***.**

Not nearly as obvious as its effects on rivers, precipitation also may affect the sanitary quality of groundwater. In a study funded by the Wisconsin Department of Natural Resources, Mark Borchardt and his collaborators at the Wisconsin Geological Survey and the U.S. Geological Survey have been relating groundwater recharge to levels of human viruses in six municipal wells in Madison, WI. Beginning in 2006, well water samples for viruses have been collected on an approximately monthly basis. Samples are also collected from local lakes and from untreated sewage. There is a strong temporal correlation between viral serotypes found in sewage, lakes, and groundwater suggesting very rapid transport from the source(s) to wells. Water isotope analyses showed surface water to be an unlikely source of viruses; thus, the most likely source of the viruses in the wells is leakage of untreated sewage from the Madison sewer system. While the study is ongoing and any conclusions are preliminary, on two notable hydrologic events, heavy snowfall followed by rapid melting in January 2007 and 10 inches of rainfall over three days in June 2008, monitoring wells in Madison showed rapid groundwater recharge and at the same time virus levels in all six municipal wells increased substantially.

Linking Climate Change and Gastrointestinal Illness

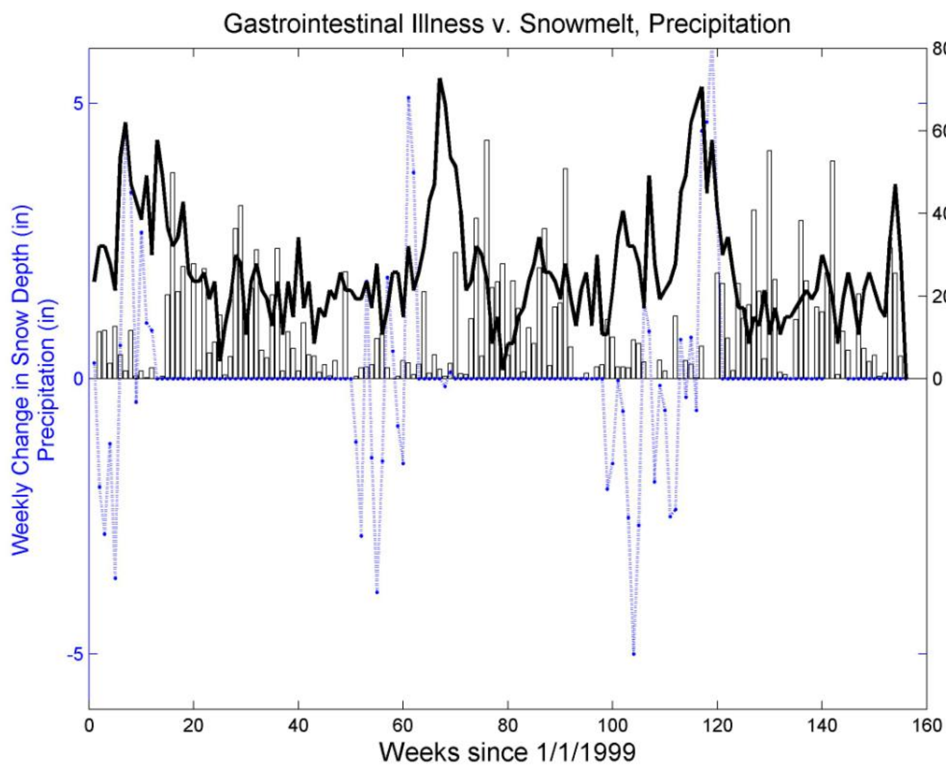
*Sewer overflows and gastroenteritis***.** Other scientists collaborating with our WICCI team on the CDC grant have also examined the association between pediatric gastroenteritis and secondary sewage bypass (Redman, Nenn, Eastwood, and Gorelick 2007). This practice, also known as sewage blending, occurs when part of the sewage treatment process is bypassed in response to sewage flow exceeding treatment capacity due to heavy precipitation, resulting in the release of partially-treated sewage. Using three years of data (2002-2004) from a large children's hospital emergency department (ED) in Milwaukee, researchers employed an autoregressive integrated moving average (ARIMA) time series model to determine the impact of sewage bypass events on ED visits for acute gastroenteritis. After adjusting for potential confounders (including rainfall and season), a significant spike in visits (50% relative increase) was seen 3-7 days after the 2 largest of 6 bypass events. This increase was seen only for children residing in zip codes served by Lake Michigan drinking water, and not from those residing in zip codes with groundwater sources. These data suggest a potentially harmful effect of such sewage bypass, and also that large rainfall events may have an adverse health impact by increasing the frequency of such events.

*Rainfall and gastrointestinal illness***.** A recent study by two of our investigators examined the association between pediatric gastroenteritis and rainfall. Using a similar data source (Children's Hospital of Wisconsin ED visits for gastroenteritis, 2002-2007), an ARIMA time series was conducted, with rainfall as the primary covariate, lagged 1-7 days. Potential confounders included season and combined sewer overflows. Rainfall 4 days prior to the visit was significantly associated with the number of visits, with an adjusted 10.8% increase in visits (95% confidence interval: 2.0, 20.0) for each 1 inch of rainfall increment. Results were similar when stratified by water source (surface vs. ground).

*Drinking water transmission of infectious diarrhea***.** A study led by Mark Borchardt at the Marshfield Clinic Research Foundation and funded by the US EPA STAR Program is examining drinking water transmission of infectious diarrhea. One of the primary study objectives is to relate virus levels in the tap water of 14 Wisconsin communities to the incidence of acute gastrointestinal illness (AGI). The study team found AGI incidence was significantly associated with enteric viruses, particularly

G1 norovirus, in community drinking water. Insofar as heavy precipitation events increase virus levels in municipal drinking water wells, as suggested by the Madison well study described previously, residents of communities that use non-disinfected groundwater for their drinking water source are at increased risk for AGI when there is a precipitation event. For the Marshfield Clinic catchment area, preliminary data also shows a strong correlation between AGI and rainfall in the spring, and with snow melt during winter (Figure 7).

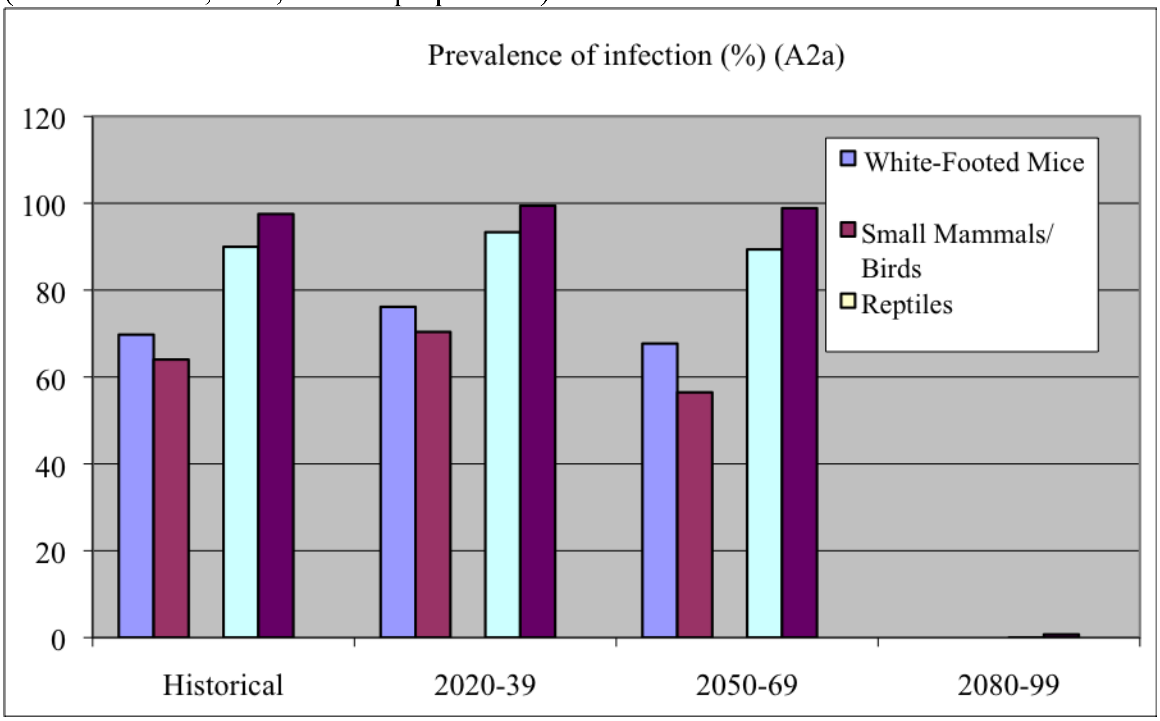
Figure 7: Incident cases (weekly) of non-specific gastrointestinal illness (solid line) are strongly associated with snowmelt (dotted blue line) in the winter and precipitation (bars) in the other seasons in Marshfield, WI.



Lyme Disease and Future Climate Projections

Preliminary analysis of climate change effects on Lyme disease in the region show a northern migration of disease (Focks, Patz, et al, in preparation). Daily output from the Hadley Climate Centre's coupled ocean/atmosphere general circulation model (HadCM3) was used to assess Lyme disease risk in the U.S. and Canada under two greenhouse emissions scenarios, SRES A2a and B2a. Seasonal dynamics of *Ixodes scapularis*, and the prevalence of Lyme bacteria, *Borrelia burgdorferi*, are influenced by weather (precipitation, maximum and minimum temperatures, and saturation deficit), soil type, vegetative cover, and host types, day length, and densities. A discrete life-history simulation model of Lyme disease and the dynamics of hosts and vectors (LymSiM) was used to integrate these factors. In the Great Lakes region, we looked at Madison, WI, and Minneapolis, MN, as well as areas in Canada. We found that warmer conditions promote tick abundance, assuming adequate moisture. But increased dryness lowers tick survival such that tick abundance is suppressed in the Great Lakes region by the end of this century. For Minneapolis and Madison, risk of human Lyme disease decreased by 35%, and 17% respectively (Figure 8). However, Canadian regions currently too cool to permit the establishment of *I. scapularis*, warmed sufficiently with adequate moisture to allow Lyme disease to spread northerly into receptive areas in the southern third of the provinces of Alberta and Saskatchewan where favorable soil types and mixed and/or hardwood forests occur (Focks, Patz, et al, in preparation). These preliminary studies show how sensitive the simulation is to moisture projections, and can now benefit from the downscaled climate scenarios emerging from WICCI. Our current plan is to rerun LymSiM with the new results from WICCI.

Figure 8. Lyme Disease Risk for Madison, WI, derived from the USDA LymSiM model. Future climate scenarios were generated from the Hadley Climate Centre's coupled ocean/atmosphere general circulation model (HadCM3), SRES A2a emissions scenario (Source: Focks, Patz, et al. in preparation).



Current Adaptive Capacity

Heat waves

Air conditioning is one adaptation to heat waves, and increasing trends in air conditioning market saturation and may substantially offset direct risks of more frequent heat waves (Sailor and Pavlova, 2003). However, use will increase the demand for electrical power and subsequent production of pollution and greenhouse gases – potentially an unsustainable adaptation, unless demand for electricity can by generated by renewable sources (e.g, wind and solar).

Heat response plans and heat early warning systems (EWS) can save lives. For example, in the wake of the 1995 heat wave, the city of Milwaukee initiated an "extreme heat conditions plan" that almost halved heat-related morbidity and mortality –see figure 9 (Weisskopf et al. 2002). As for EWS, currently, over two-dozen cities worldwide have a "synoptic-based" weather watch-warning system, which focuses monitoring on dangerous air masses (Sheridan and Kalkstein, 2004). However, variability in predictability between cities suggests that systems must be location specific, requiring the input of considerable amounts of health-related and meteorological data for each locale at considerable costs.

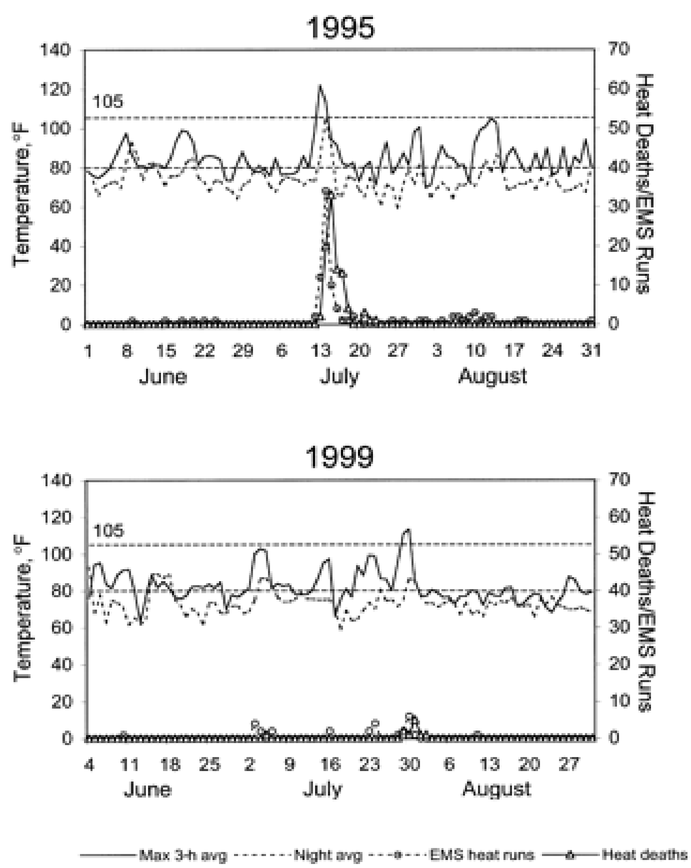


Figure 9: Summer daily heat-index measures, heat-related mortality, and heat-related emergency medical service (EMS) runs: Milwaukee, WI, 1995 and 1999

Current EWS for infectious diseases have not yet demonstrated their utility, and are only likely to improve if predictive accuracy through incorporation of both climatic and non-climatic determinants is achieved.

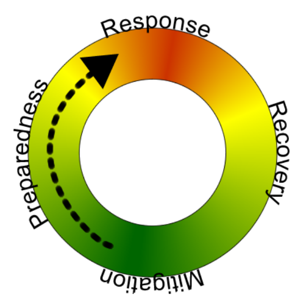
Wisconsin Emergency Management.

As the chief state agency responsible for coordinating state and local responses to a range of emergency situations, Wisconsin Emergency Management (WEM) is an important partner for Department of Human Services (DHS) in assessing and responding to emergencies related to a large number of factors. WEM also has six regional offices that work closely with tribal and local emergency management programs. Following a natural or man-made disaster, local officials work through their county emergency management director to contact WEM's 24-hour duty officer system.

Emergency management involves preparing for disasters before they occur, responding to and providing support during events, and assisting the recovery of a community's social infrastructure after a natural or human-made disaster. WEM acts in each of four phases of emergency management: mitigation, preparedness, response and recovery.

- *Mitigation* focuses on long-term measures for reducing or eliminating risk to life and property in future disasters.
- *Preparedness* plans, trains, and executes exercises to provide first responders, volunteers, elected officials, emergency managers and others

a chance to develop the skills necessary to protect lives and property during a catastrophic event.



- *Response* occurs the second that a disaster happens. The first response to a disaster is the job of the local government's emergency services with support from nearby municipalities, the state and volunteer agencies.
- *Recovery* assists individuals, businesses and communities to recover quickly, safely and with more resistance to disasters.

Recommendations

1) In formulating and implementing a state climate change response plan for public health, the Department of Human Services should work with Wisconsin Emergency Management program and other key agencies to incorporate climate change into the planning process, and into final mitigation plans. DHS can work with local and state agencies and groups like WICCI to develop analyses and mitigation strategies on climate change and its potential impact in Wisconsin and its communities. The State Hazard Mitigation plan is updated every three years with the next update due in 2011. In the subsequent updates, WEM will work towards incorporating an analysis and mitigation strategy for climate change into the state's hazard mitigation plan. Existing hazard mitigation plans will be used in tandem with output from the WICCI process and other existing and emerging plans to broaden the depth and breadth of Wisconsin's developing climate change response plan for public health.

2) For heatwave response plans, consideration should be made on the source of electric power for air conditioning, with a strong preference for renewable source (e.g, wind or solar).

Air Pollution

The Wisconsin Environmental Public Health Tracking (WI EPHT) program has a significant role in projects related to the epidemiology of ambient air quality and human health effects. As part of the program's Public Health Air Surveillance Evaluation (PHASE) project, a set of methods for identifying cases of asthma and acute myocardial infarctions, modeling air quality related to ozone and fine particulate matter ($PM_{2.5}$), estimating human exposure to the contaminants and calculating the relationship between exposure and health outcomes was developed and assessed. Epidemiologists from three different states worked to combine their health data and partnered with topic experts from CDC and the US EPA to link the health data with air quality data.

At the state level, the WI EPHT program has worked closely with Wisconsin Department of Natural Resources (WI DNR) since 2002. Support from the EPHT program was instrumental in the production of an interactive website providing real-time data from the state's ozone and $PM_{2.5}$ monitors (http://dnrmaps.wisconsin.gov/imf/imf.jsp?site=wisards). The site also provides a query application that allows a search of all historical data from monitors for criteria air pollutants.

The program has also partnered with WI DNR for developing measures related to air emissions. The current EPHT portal contains data for criteria air pollutant emissions for 2000-2006 and is updated annually. With regards to toxic air emissions, air quality modeling experts at the DNR are working with state-of-the-art techniques using the Regional Air Impact Modeling Initiative methods to estimate cumulative cancer risks from exposure to multiple compounds. This model provides improved characterization of human health impacts in comparison to traditional methods where toxicity of compounds is considered individually.

Co-benefits of Alternative Transportation Scenarios

While the transportation sector produces one-third of U.S. greenhouse gas emissions contributing to global climate change, automobile exhaust also contains precursors to fine particulate matter ($PM_{2.5}$) and ozone (O_3), posing public health risks. Therefore, adopting a greener transportation system (e.g, fewer automobiles) could have immediate health “co-benefits” via improved air quality. Researchers at The Nelson Institute Center for Sustainability and the Global Environment (SAGE) have used census tract-level mobile emissions estimates to examine the effects on $PM_{2.5}$ and ozone air concentration by removing automobile trips shorter than five miles, for the 11 largest metropolitan areas in the midwestern U.S. Annual average $PM_{2.5}$ fell significantly and summer peak O_3 increases slightly in large cities but dropped regionally. Net annual mortality and morbidity in the region was substantially reduced with health care cost savings ranging in the billions of dollars (Grabow et al, in preparation).

Recommendations

1) The state should expand activities of the Wisconsin Environmental Public Health Tracking to include indicators of air pollution conditions linked to climate variability and change.

2) Health Co-benefits of "green" transportation planning should be included in any cost benefit analyses of responses to climate change.

3) More broadly, policy makers (e.g., Public Service Commission of Wisconsin) should carefully weigh the impacts of their infrastructure investment decisions on: a) human health and, b) the state's capacity to adapt to a changing climate. For example, water management facilities should be built to specifications for future intensification of rainfall events rather than simply considering current rainfall/runoff distributions.

Monitoring Health Risks of Climate Change in Wisconsin

Funded since 2002, the Wisconsin Environmental Public Health Tracking program creates an environmental health tracking system by centralizing and streamlining Wisconsin's environmental, agricultural, and health data. Wisconsin is one of over 20 states that joined with representatives from CDC and academic partners to develop Nationally Consistent Data and Measures (NCDMs) for relevant topics as part of the national EPHT program. Data and information for these topics are included in web-based portals that make them available to the public, as well as in secure environments for approved users. Current core data topics include asthma, ambient air quality, cancer, and public drinking water quality. However, more recently, the national program has formed a team to develop NCDMs related to climate change, and representatives from Wisconsin are active participants on this team. The WI EPHT program provides publicly accessible and secure environments to target the needs of local public health department professionals. In this way, the WI EPHT network provides a platform for disseminating timely and relevant data to local officials as well as the general public to inform decision-making and prioritization of activities.

Tables 1 and 2 outline direct and indirect impacts of hazardous precipitation events along with other key climate related scenarios contributing to public health impacts in the state. Table 3 describes the range of health outcome datasets potentially available for data linkages and routine surveillance within the state. These tables were generated by staff from the WI EPHT program to demonstrate the strength, expertise and knowledge base within DHS for addressing complex environmental health problems.

Table 1: Indirect Impacts of Climate Change on Public Health Case Study – Extreme Precipitation

Regional Impacts	**Hazards**	**Environmental Impacts/Exposures**	**Health Effects/ Outcomes**	**Vulnerable Subpopulations**	**DHS Health Effect Datasets**
Increases in Heavy Precipitation	**Flooding**	Microbial/viral increases in surface water, drinking water	Waterborne and Illness (i.e., gastrointestinal illness)	Immunocompromised, children Elderly, specific to virus of concern	WEDDS Census ED Visit data Physician office visits Vital statistics
		Mold/indoor air quality	Respiratory illness Allergic reactions Asthma Mortality	Children, pre-existing heart of lung disease, chronic conditions, urban and rural poor	Indoor air quality calls Hospitalization ED Visit Census Vital statistics
		Hazardous roads and vulnerable infrastructure, loss of property, population displacement	Injuries Mortality Mental well-being/psychosocial stress	Elderly, children, existing mental health conditions, chronic conditions, urban and rural poor	Hospitalization ED Visit Census Vital statistics Census HSEES Physician office visits
		Contaminated food supply	Food-borne illness		

	Sewage overflows	Microbial/viral increases in surface water, drinking water	Waterborne and Illness (i.e. gastrointestinal illness)	Immunocompromised, children Elderly, specific to virus of concern	WEDDS Census ED Visit data Physician office visits Vital statistics
	Droughts	Extreme drought leads to variability and effects of extreme precipitation and flash flooding (see above)			

Table 2: Direct Impacts of Climate Change on Public Health Case Study – Case Study - Extreme Heat and Cold

Regional Impacts	**Hazards**	**Environmental Impacts/Exposures**	**Health Effects/ Outcomes**	**Vulnerable Subpopulations**	**DHS Health Effect Datasets**
Extreme Heat	Heat waves, urban heat islands (increase in nighttime heat temp over extended periods of time)	Heat related morbidity and mortality Hyperthermia	Heat related mortality Heat related morbidity	Children, pre-existimg heart of lung disease, chronic conditions, urban poor, those living without air conditioning, mentally ill	Hospitalization ED Visit Census Vital statistics Physician office visits
Extreme Cold	Extremely Cold Temperatures	Cold related morbidity and mortality Hypothermia	Cold related mortality Cold related morbidity (hypothermia and injuries)	Children, pre-existing chronic conditions, disabilities, urban and rural poor, mentally ill	Hospitalization ED Visit Census Vital statistics Physician office visits

Table 3: Health-outcome datasets available for geo-spatial and time series analysis linking outcomes to downscaled GCM modeling

<table>
<tr><th colspan="2">Data source</th><th>Population</th><th>Spatial resolution</th><th>Temporal resolution</th><th>Health outcome variables</th></tr>
<tr><td colspan="2">Vital Statistics (mortality)</td><td>All WI residents</td><td>geocoded</td><td>annual; 6-12 mouth lag</td><td>ICD 10 codes</td></tr>
<tr><td colspan="2">Inpatient Hospitalizations</td><td>All Wisconsin acute care, non federal hospitals</td><td>Zip code</td><td>Annual; previous year is available in July of the following year
1989-2007</td><td>ICD 9 codes
001-009.9 Specified Gastrointestinal Infections
558.9 Unspecified Gastroenteritis
787.91 Diarrhea</td></tr>
<tr><td colspan="2">Emergency department visit</td><td>All Wisconsin acute care, non federal hospitals</td><td>Zip code</td><td>Annual; previous year is available in July of the following year
2002-2007</td><td>ICD 9 codes
001-009.9 Specified Gastrointestinal Infections
558.9 Unspecified Gastroenteritis
787.91 Diarrhea</td></tr>
<tr><td colspan="2">Administrative claims data (Wisconsin Health Information Organization)</td><td>8 health care insurance payors and Medicaid</td><td>County</td><td>Refreshed every 6 months with a rolling 27 months</td><td>Data grouped into episodes based on ICD 9 codes</td></tr>
<tr><td colspan="2">Medicaid</td><td>All Wisconsin residents qualifying for coverage; low-income, disabled, children</td><td>County</td><td>Annual</td><td>ICD 9 codes
001-009.9 Specified Gastrointestinal Infections
558.9 Unspecified Gastroenteritis
787.91 Diarrhea</td></tr>
<tr><td rowspan="3">Electronic medical record data</td><td>University of Wisconsin Family Medicine</td><td>28 clinics</td><td>?</td><td>Annual; ?
1989-?</td><td>ICD 9 codes</td></tr>
<tr><td>Federally Qualified Health Centers</td><td>17 clinics</td><td>?</td><td>Annual; ?</td><td>ICD 9 codes</td></tr>
<tr><td>Marshfield Epidemiologic Study Area (MESA)</td><td>24 clinics
(95% of the 50,000 residents)</td><td>14 zip codes</td><td>Can extract the data at anytime in the year; short lag, but not real time data.</td><td>ICD 9 codes</td></tr>
<tr><td colspan="2">Emergency room registration data (Wisconsin Health Information Exchange)</td><td>Milwaukee County</td><td>?</td><td>Real time</td><td>Chief complaint</td></tr>
</table>

Air Quality Monitoring

WI DNR has developed a statewide air quality notification system. DNR uses weather forecasts and data from air monitoring sites to forecast air quality in the state, and notifies interested residents when pollutants reach unhealthy levels. An *air quality watch* is issued when conditions are favorable for air pollutants to reach unhealthy levels, and an *air quality advisory* is issued when air pollutants have reached unhealthy levels. Weather parameters such as temperature, humidity, wind speed, and wind direction affect the concentrations of air pollutants. Particularly hot and humid summer days with stagnant air often result in high ozone concentrations, and wintertime increases in fine particle pollution can occur when warmer air masses move slowly over snow-covered ground and form local inversions. Both may be expected to occur increasingly as a result of climatic changes.

Residents are notified about an air quality watch or advisory through Wisconsin's Air Quality Notices system (http://dnr.wi.gov/air/aq/health/status.asp) or through media coverage in partnership with the National Weather Service. WI DNR's air quality notices system posts notices on the WI DNR website, updates a toll-free air quality hotline and e-mails notices to a listserve with over 3300 subscribers. Population groups, which are sensitive to ozone and fine particle pollution, include children and elderly residents and individuals with respiratory or cardiovascular disease. Air quality notices are based on the national Air Quality Index, which was developed to define the health significance of air pollutants at different levels. Targeted outreach to county and city public health departments, school nurses, daycare centers, summer camps, nursing homes and other facilities would provide valuable public health education and notification to help address anticipated increases in air quality watches and warnings as climatic changes in Wisconsin occur.

Vectorborne Disease Surveillance Program

As a part of the DHS Bureau of Communicable Diseases and Emergency Response, the state's vectorborne disease surveillance program (VDSP) conducts statewide human case surveillance for all mosquito-borne and tickborne arbovirus infections, including Lyme Disease, West Nile Virus, La Crosse/California encephalitis, St. Louis encephalitis, Eastern Equine encephalitis, and Western Equine encephalitis. Cases are managed, analyzed and interpreted using the Wisconsin Electronic Data Surveillance System and are reported to CDC through National Electronic Disease Surveillance System and the CDC ArboNet reporting system where appropriate.

The surveillance program is specifically involved in data quality assurance, assisting in generating statistical reports including yearly incidence maps, number of cases by county, cases by month and age, and other requested epidemiological reports.

The VDSP also participates in tick surveillance studies conducted in Wisconsin and assists in the collection of ticks for species identification. Other activities include coordinating the West Nile Virus Wisconsin Working Group, which includes 15-20 local health departments, WI State Laboratory of Hygiene, WI

Veterinary Diagnostic Laboratory, University of Wisconsin-Madison, Department of Entomology, WI DNR, and USDA-Wildlife. The VDSP also participates in CDC- and CSTE-sponsored teleconferences and conferences regarding arboviral activities, responds to public, media, and legislative inquiries, and produces and distributes educational materials such as fact sheets, brochures, and pocket cards to local health departments, other state agencies and the public.

Harmful Algal Blooms Surveillance Program

Wisconsin has received CDC funding since 2008 to conduct surveillance of human and animal health outcomes related to harmful algal blooms. During the 2009 season, WI DHS reported 35 human exposure cases and two animal exposure cases to CDC for inclusion in its Harmful Algal Bloom Integrated Surveillance System. Because of the likelihood that increasing mean atmospheric and surface water temperatures in Wisconsin will contribute to increased freshwater algal bloom activity, this program will serve as a valuable data collection resource and surveillance partner for efforts aimed at delineating the ways in which climate change processes may increase the occurrence of human and animal exposures to harmful algal blooms.

Conclusion

It is clear that some communities in Wisconsin will be disproportionately affected by the public health sequelae of climate change. As such, it will be necessary to tailor vulnerability assessments and strategic adaptation or mitigation response plans to the anticipated impacts in individual communities. Building on the successes of WI DHS and UW-Madison programs on climate change research, vectorborne disease surveillance, HIA/built environment, environmental public health tracking, and harmful algal blooms, Wisconsin is a state that has already begun to consider climate change in its public health planning and preparedness.

The task force, therefore, encourages greater regional coordination of plans and policies, as well as more effective capacity-building at the local level. We also recommend the development of local and regional plans and policies that create more livable, sustainable, and resilient communities. "Smart Growth" (in contrast to scattered sprawl) has potential benefits for human health, the economy, and the environment (see resources listed below). Complementary "green" land use practices (e.g., planting street trees) could adaptively retrofit existing buildings, lots, and neighborhoods (see http://www.milliontreesnyc.org/). Additional resources can be found at: http://www.smartgrowth.org/; http://www.epa.gov/dced/topics/eb.htm; http://coastalsmartgrowth.noaa.gov/

The University of Wisconsin could play an important role in raising awareness statewide, and in educating local and regional decision-makers about the benefits of sustainable development (and redevelopment). Two models of how this could be implemented include: http://uacdc.uark.edu/ and http://www.rrcdc.org/.

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