An Initial Assessment of Winter Climate Change Adaptation Measures for the City of Chicago

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Abstract: There has been little assessment of winter climate changes and their associated urban impacts. Most climate adaptation planning, including the City of Chicago's Climate Action Plan and its Sustainability Action Agenda, focuses on adapting to hotter summers, including more frequent summer heat waves and droughts, greater flood risks from a higher percentage of annual precipitation occurring in the form of more severe storms, and shifts in ranges of flora and fauna (including disease vectors). This Article examines municipal adaptation to some of the impacts of a shorter and warmer winter season in the upper Great Lakes region, using Chicago as a case study. These largely unexamined impacts include a likely greater intensity of winter precipitation events (with a greater percentage of the winter precipitation falling as rain), changes in snowfall density (with more snowfalls possibly in the form of heavy, wet snow), and a possible increase in the frequency of freeze-thaw cycles.

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I. Introduction

As state and federal efforts to reduce greenhouse gas emissions to mitigate global climate change face political constraints and obstructionism, climate initiatives adopted by local governments are emerging as an increasingly important response to political inaction and gridlock. Local officials are embracing a growing number of policies, incentives, and regulations to reduce greenhouse gas emissions and to better address the impacts of future climate changes. The Midwest regional report in the most recent draft National Climate Assessment suggests that the major climate change impacts in urban areas within the Great Lakes region include the increased risks of flooding and erosion, more summer heat waves which pose public health risks for vulnerable populations from both heat stroke and air pollution, and more droughts which impact natural resources, water resources, and crops.[2]

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[2] *See generally* Sara C. Prior & Donald Scavia, *Midwest in* NATIONAL CLIMATE ASSESSMENT AND DEVELOPMENT ADVISORY COMMITTEE DRAFT CLIMATE ASSESSMENT (V. 11. Jan. 2013), *available at* http://ncadac.globalchange.gov/download/NCAJan11-2013-publicreviewdraft-chap18-midwest.pdf.

Warmer average annual temperatures and a greater frequency of more severe storms will also raise health, safety, and ecological concerns because of the consequent shifts in the ranges of disease vectors, changes in habitats, alterations in invasive species, and increased risks of flooding and pollution from urban stormwater runoff.

Communities can do two things to address these issues. First, they can attempt to reduce carbon emissions in order to slow down the rate of climate change (climate change *mitigation*). Second, they can change their policies and programs to better deal with the projected impacts of a changing climate (climate change *adaptation*). Climate change mitigation strategies typically address reducing greenhouse gas emissions through energy conservation by promoting alternate energy resources and encouraging the use of transportation modes (e.g., bicycling, transit, or walking) that minimize the burning of fossil fuels. Climate change adaptation strategies, on the other hand, can involve a wide range of activities and programs to adjust local government practices and services in order to better reduce a community's vulnerability to current and projected future climate change impacts through, for example, rain gardens, reducing impermeable surfaces, or urban cooling centers. A growing number of communities within the Great Lakes region are adopting plans, policies, and programs that promote both climate change mitigation and adaptation by municipalities and their residents. When such plans focus primarily on changing governmental programs and actions, they are known as "Climate Action Plans."

Most of the guidebooks that promote climate change planning and the adoption of local Climate Action Plans focus on the most significant impacts generated by the global climate models employed by the International Panel on Climate Change and the National Oceanic and Atmospheric Administration (NOAA).[3] These assessments have emphasized summer season impacts, especially the impacts of longer and warmer summer seasons on heat wave risks and greenhouse gas emissions since electrical energy generation peaks in the summer months from higher air conditioning loads, producing more greenhouse gases from power plant emissions. Power plant and other emissions also increase urban air pollution during the summer "ozone season," with the associated health risks often exacerbated by heat waves and urban heat island effects. The greater weather variability caused by climate change also leads to more severe storms and their associated impacts – principally increased flood risks and more power blackouts – and, paradoxically, to a higher risk of summer droughts, with their associated impacts on agriculture and water resources. Common adaptation strategies promote greater urban resilience to the societal disruption caused by these extremes in precipitation. For example, flood risks can be mitigated through spatial development policies (e.g., keeping vulnerable development out of high-risk areas), by building codes (e.g., elevating habitable areas), and by reducing peak flood levels by intercepting and infiltrating stormwater runoff with green infrastructure practices before it reaches a waterway or overwhelms a sewer system.

By addressing only the major summer season impacts of climate change, most local adaptation plans ignore the societal and environmental impacts of warmer and possibly shorter winters. This Article examines some of the winter adaptation policies that can be considered in developing local Climate Action Plans. In developing these winter adaptation measures, specific attention was paid to

[3] *See, e.g.*, KENNETH E. KUNKEL, REGIONAL CLIMATE TRENDS AND SCENARIOS FOR THE U.S. NATIONAL CLIMATE ASSESSMENT, PART 3. CLIMATE OF THE MIDWEST U.S., NOAA Technical Report NESDIS 142-3 (2013).

the 2008 Chicago Climate Action Plan[4] and the Sustainable Chicago 2015 Action Agenda. These City of Chicago initiatives were chosen because of Chicago's status as an early adopter of climate change planning in the Great Lakes region. In fact, Chicago's climate programs are the only ones cited within the Great Lakes region in the Adaptation chapter of the most recent draft National Climate Assessment.[5] Since the city has long been a regional leader in planning for climate mitigation and adaptation, other Great Lakes communities facing similar climate change impacts can learn from Chicago's policies, programs, and outreach efforts.

Chicago's 2008 Climate Action Plan consists of 35 measures set forth in four sections – three of the sections address climate change mitigation (especially the promotion of energy conservation practices to reduce greenhouse gas emissions), with one section devoted to climate change adaptation. Initially administered by the Department of the Environment (DoE), Chicago's climate adaptation strategies focus on managing heat, pursuing innovative cooling, managing stormwater, and promoting green urban design, preserving plants and trees, and engaging the public and businesses. The Chicago Climate Action Plan's specific adaptation tactics include reducing vulnerability to extreme heat and precipitation events; reducing the vulnerability of buildings, infrastructure, and equipment to extreme weather conditions; and reducing Chicago's vulnerability to future ecosystem degradation.[6]

In 2011, after the election of a new mayor, Chicago eliminated its DoE in an administrative reorganization, reallocating many of DoE's staff to other municipal agencies. A Chief Sustainability Officer position was created in the Mayor's Office, which took over the management of the Chicago Climate Action Plan and also instituted a new, shorter-range environmental initiative called the 2015 Sustainable Chicago Action Agenda.[7] The 2015 Sustainable Chicago Action Agenda focuses on economic development and job creation, energy efficiency and clean energy, transportation options, water and wastewater, parks, open space and healthy food, waste and recycling, and climate change. The climate change category contains three goals, two of which address the reduction of carbon emissions and pollutants and the last of which expressly addresses climate change adaptation:

> *GOAL 24. PROTECT THE CITY AND ITS RESIDENTS BY PREPARING FOR CHANGES IN THE CLIMATE*
>
> *Research suggests that Chicago could experience a significant shift in climate and increasing frequency of severe storms. High emissions projections show that by the end of the century, Chicago summers will be similar to those in Baton Rouge today. Chicago will work proactively to*

[4] CITY OF CHICAGO, CHICAGO CLIMATE ACTION PLAN (2008), *available at* http://www.chicagoclimateaction.org/filebin/pdf/finalreport/CCAPREPORTFINALv2.pdf.

[5] *See* Rosina Bierbaum, Arthur Lee & Joel Smith, *Adaptation in* NATIONAL CLIMATE ASSESSMENT AND DEVELOPMENT ADVISORY COMMITTEE DRAFT CLIMATE ASSESSMENT 983, 992-93 (V. 11, January 2013), *available at* http://ncadac.globalchange.gov/download/NCAJan11-2013-publicreviewdraft-chap28-adaptation.pdf.

[6] CITY OF CHICAGO, CHICAGO AREA CLIMATE CHANGE QUICK GUIDE: ADAPTING TO THE PHYSICAL IMPACTS OF CLIMATE CHANGE (Julia Parzen ed. 2008), *available at* http://www.chicagoclimateaction.org/filebin/pdf/ADAPTATION4POST2.pdf.

[7] CITY OF CHICAGO, 2015 SUSTAINABLE CHICAGO ACTION AGENDA (2013), *available at* http://www.cityofchicago.org/city/en/progs/env/sustainable_chicago2015.html.

respond to climate change by advancing policies and solutions to prepare for a changing climate and protect our people, infrastructure and natural resources.

Key Actions:

- *Prepare for the human impacts of climate change by supporting people with information and services, such as cooling centers.*
- *Prepare the natural environment for climate impacts and maintain biodiversity.*
- *Prepare the infrastructure for climate change by reducing the urban heat island effect, managing flooding from high intensity storm events, and strengthening resiliency to extreme weather.*[8]

As with the Chicago Climate Action Plan, Chicago's emphasis on climate adaptation within its sustainability agenda remains focused largely on mitigating summer impacts (e.g., providing cooling centers and reducing heat island effects), although the goals and some of the actions are phrased broadly enough to accommodate many winter climate change impacts as well. The next section examines what these winter impacts are likely to be, a topic that is usually given only brief mention in the climate change adaptation literature.

II. Projected Winter Season Climate Changes

Identifying the potential winter impacts of climate change that can affect Chicago's facilities and operations is important since there has been relatively little attention paid in the climate adaptation literature to either winter climate change or its impacts. For example, the U.S. Global Climate Change Research Program's 2009 national assessment forecasts milder winters, earlier loss of ice cover on waterways and waterbodies, and loss of winter recreational opportunities as possible winter climate change impacts for the Midwest region, but does not discuss how these emerging impacts should be addressed by local officials.[9] The Great Lakes Supplement to NOAA's coastal climate adaptation guidebook notes that "[S]ince 1951, there has been an upward trend in snowfall along the southern and eastern shores of the Great Lakes," and identifies an increased number of nonfatal traffic accidents as an impact of this trend.[10] However, many of these winter impacts are only of limited concern to Chicago since the Chicago Park District does not have any ski resorts and only a few outdoor skating rinks and sledding hills, Chicago's lakefront is largely armored (reducing its storm and erosion susceptibility), and most of Chicago's expressways (except for Lake Shore Drive) and transit facilities are located inland, outside of the lake-effect zone.

Chicago's background report for the Climate Action Plan on forecasted climate change in Chicago examined potential changes and variability in temperatures and precipitation under various emissions

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[8] *Id.* at 35.

[9] *See generally* U.S. GLOBAL CHANGE RESEARCH PROGRAM, GLOBAL CLIMATE CHANGE IMPACTS IN THE UNITED STATES 2009 REPORT (2009), *available at* http://nca2009.globalchange.gov/.

[10] TERRI CRUCE & ERIC YURKOVITCH, NOAA OFFICE OF OCEAN AND COASTAL RESOURCE MANAGEMENT, ADAPTING TO CLIMATE CHANGE: A PLANNING GUIDE FOR STATE COASTAL MANAGERS – A GREAT LAKES SUPPLEMENT 8, 44 (2011), *available at* http://coastalmanagement.noaa.gov/climate/docs/adaptationgreatlakes.pdf.

scenarios in order to frame the municipal policies and actions that could be developed in the 2008 Chicago Climate Action Plan. This climate study's Executive Summary notes that projected impacts from "... substantial increases in annual and seasonal temperatures and extreme heat events, particularly under the higher emissions scenario" included adverse impacts on human health (especially from respiratory diseases that can be triggered or worsened by increased summer air pollution events).[11] The Executive Summary also notes that changes in the frequency of vector- and water-borne disease outbreaks can also pose climate-related health risks. Since the background report stressed summer season climate change trends and impacts, this focus was mirrored in most of the measures proposed within the Chicago Climate Action Plan.

The background report's Executive Summary projects winter and spring precipitation increasing by about 10% by mid-century and 20-30% by the end of the century under both low and high emissions scenarios, with little change in summer precipitation (although higher temperatures may increase evaporation rates, reducing soil moisture) and with increased intensity of heavy precipitation events. Noting that rainfall events of 2.5 inches or more in 24 hours are historically associated with flooding in Chicago, the report predicts a higher frequency of such events in the future. Habitats are also likely to shift northward, with associated impacts on species distributions, pathogen ranges, and water quality. Changes in hydrology and temperatures are also likely to effect the built environment, especially the patterns of energy use and the costs of responding and adapting to natural hazards.

The background report's summary of the projections and impacts of climate change in Chicago makes only a few references to forecasting winter season changes and impacts. These involve both the mortality and morbidity impacts of warmer winters and the impacts of changes in winter snowfalls. With respect to the former issue, the Executive Summary notes that:

> Cold-related morbidity and mortality is more likely than not to decrease as winter temperatures warm. However, most winter mortality is due to the transmission of infectious agents as people are confined indoors for longer periods of time, rather than being caused by individual extreme cold events. For this reason it is difficult to quantify both the relationships between cold weather and health issues as well as how current rates of cold-related illnesses and death might be altered by future climate change.[12]

With respect to forecasting the winter impacts of changing snowfall patterns, the Executive Summary notes a likely decline in winter snow cover within the Chicago metro area:

> Although winter temperatures are very likely to continue to warm, it is more likely than not that only a slight decrease in snowfall occurs under the higher emissions scenario and little change under the lower emissions scenario. This is because the effect of warmer temperatures may be counteracted by increased winter precipitation. Warmer temperatures are likely to reduce snow

[11] KATHARINE HAYHOE & DONALD WUEBBLES, CHICAGO CLIMATE ACTION PLAN, CLIMATE CHANGE AND CHICAGO: PROJECTIONS AND POTENTIAL IMPACTS, EXECUTIVE SUMMARY vii (2008), *available at* http://www.chicagoclimateaction.org/filebin/pdf/report/Chicago_climate_impacts_report_Executive_Summary.pdf.

[12] *Id.* at ix.

cover on the ground, however, with a projected loss of up to 30 days of snow cover under higher emissions and half that under lower emissions by end-of-century.[13]

Updated projected changes in annual and seasonal temperatures and precipitation for the Midwest were recently undertaken by Kunkel et al. for NOAA, as part of the U.S. Global Change Research Program.[14] This study found trends toward warmer seasonal temperatures, especially warmer winter and spring seasons, and a low frequency of cold waves in the Midwest since the mid-1990s. As with the Chicago Climate Action Plan's background study, the more recent analyses have also found that the frequency and intensity of extreme precipitation in the region has increased, with Great Lakes water levels of the combined Lake Michigan-Huron system and ice cover on regional lakes declining. The freeze-free season across the Midwest is also likely to lengthen by 20-30 days, according to climate change modeling. This study also notes that there is a great deal of uncertainty in the modeling of future precipitation changes.

To remedy this relatively brief assessment of winter season climate changes affecting the Chicago area, recent research was undertaken by the Great Lakes Integrated Sciences and Assessments Center (GLISA) at the University of Michigan[15] and by the Midwestern Regional Climate Center (MRCC)[16] on potential winter season impacts affecting northeast Illinois and the larger Great Lakes region. The MRCC assessed winter precipitation changes, snowfall trends, snowfall intensity, snow density, and freeze-thaw events for this research project (with GLISA also contributing an analysis and forecast of freezing rain events) – meteorological factors that are typically ignored in national and regional studies of projected future climate change. Because of their potential to impact municipal facilities and operations, it is useful to examine both historical trends and winter climate change forecasts with respect to these meteorological factors.

A. Winter Temperature Trends

In addition to estimating the historical and projected trends in summer temperatures and heat waves, the MRCC also analyzed winter temperature trends for the Chicago area, especially with respect to extreme cold events. "Very cold" days were those where the minimum temperature was less or equal to 32°F, while "extremely cold" days were defined as days when the minimum temperature was equal or less than 0°F. The MRCC found that Chicago typically has about 128 very cold days and about 9 extremely cold days per year, and that there has been a steady decrease in the number of both per year (see Figure 1). Climate studies project that, as a result of climate change, there will be 22 fewer days per year with a minimum temperature below 32°F by mid-century. MRCC therefore concluded:

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[13] *Id.* at xii.

[14] *See* Kunkel, *supra* note 3.

[15] *See* GREAT LAKES INTEGRATED SCIENCES & ASSESSMENT, FREEZING RAIN IN THE GREAT LAKES (2013), *available at* http://glisaclimate.org/media/Freezing%20Rain%20in%20the%20Great%20Lakes%20%286.7.13%29_0.pdf.

[16] *See* Molly Woloszyn, Chicago Winter Climate Parameters Trends and Projections (2013), *available at* http://glisa.msu.edu/news/Chicago-Winter-Trends-and-Projections.pdf; CHICAGO METROPOLITAN AGENCY FOR PLANNING, CLIMATE ADAPTATION GUIDEBOOK FOR MUNICIPALITIES IN THE CHICAGO REGION, APPENDIX A: PRIMARY IMPACTS OF CLIMATE CHANGE IN THE CHICAGO REGION (2013), *available at* http://www.cmap.illinois.gov/livability/sustainability-climate-change/climate-adaptation-toolkit [hereinafter CMAP APPENDIX A].

A composite of global climate models indicate that by the end of the century, the United States will experience a 90% reduction in the frequency of extreme cold-air outbreaks, with the decline possibly even greater in the Great Lakes region. For Chicago, the simulated occurrence of extremely cold days declines by 50% under a low emissions scenario and by 90% (meaning only about one day per year) under a high emission scenario by the end of the 21st century.[17]

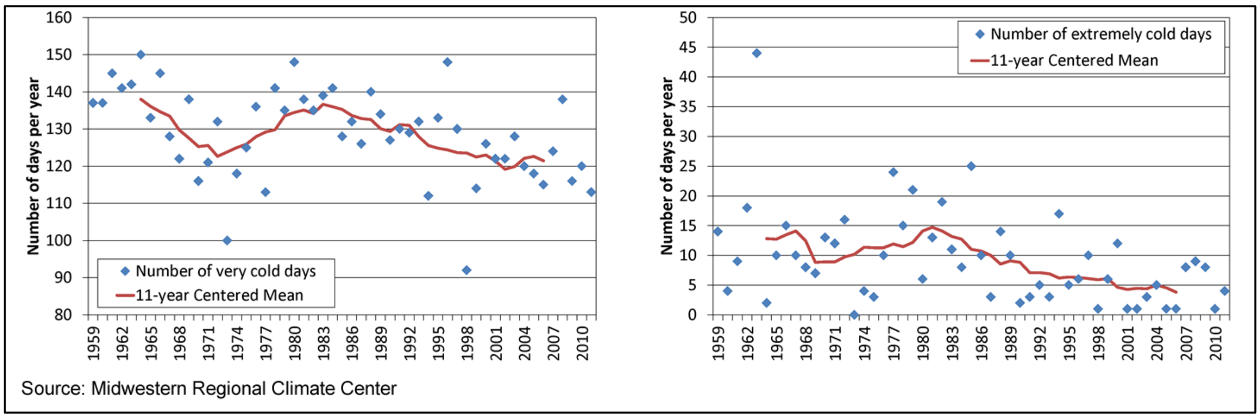

Figure 1. The number of very cold days (left) and extreme cold days (right) per year at Chicago O'Hare. The blue dots represent the number of days per year and the red line shows the 11-year centered mean.

In order to better assess the impacts of these trends on energy use, the MRCC calculated historical trends for heating and cooling needs, expressed as heating and cooling degree days, for Chicago.[18] A cooling degree day is a measurement designed to reflect the demand for energy needed to cool a building, and a heating degree day reflects the demand for energy needed to heat a building. The number of cooling degree days for a given day is calculated by subtracting a base temperature of 65°F from the average daily temperature, while the number of heating degree days for a given day is calculated by subtracting the average daily temperature from a base temperature of 65°F. The MRCC found that the number of heating degree days has declined since the early 1980s, indicating a lower demand for energy needed to heat buildings during the colder months. At the same time, the number of cooling degree days during the warmer months has remained fairly steady since the late 1950s until the last decade, when it began to show an increase (see Figure 2). For the future, climate studies predict that the changes in cooling degree days are anticipated to be larger than the changes in heating degree days, with heating degree days decreasing by 15% across the Midwest region (according to the mean of multiple climate change models) because of warmer winters. Because of warmer summers, climate studies anticipate that by 2041-2070 there will be a 66% increase in cooling degree days when averaged across the Midwest.[19]

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[17] CMAP APPENDIX A, *supra* note 16, at 13.
[18] *Id.* at 13-14.
[19] *Id.* at 14.

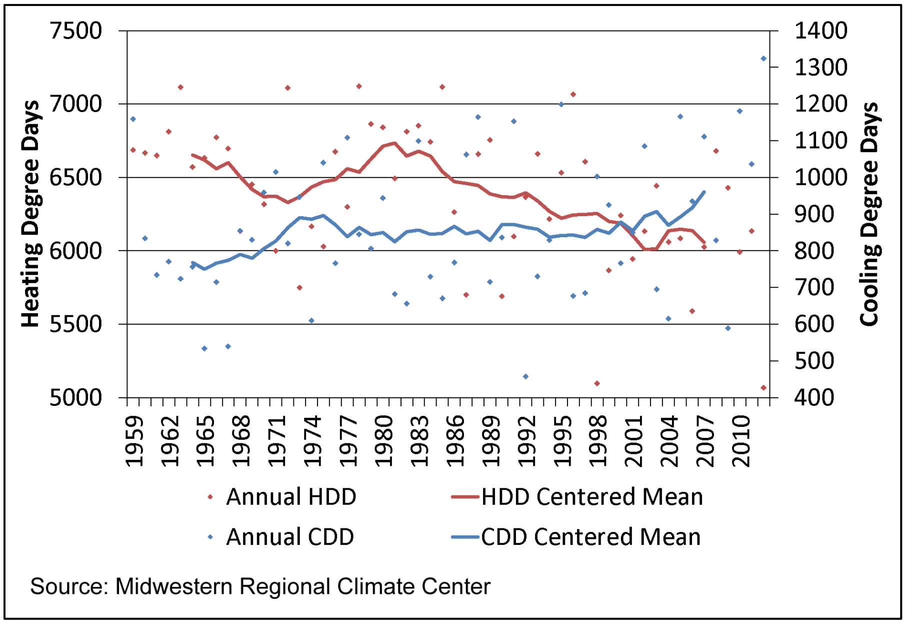

Figure 2. The number of heating degree days (left axis) and cooling degree days (right axis) per year at Chicago O'Hare. The dots represent annual values, while the lines represent the 11-year centered mean.

Longer term annual, seasonal, and even monthly temperature trends tell only part of the story, however. One type of temperature change event that may occur on a daily or even hourly scale is a freeze-thaw cycle – a relatively rapid shift in ambient conditions from a below-freezing to an above-freezing temperature. Using a definition of a "freeze-thaw event" as one where the minimum daily air temperature is at least 26°F and the maximum daily air temperature is at least 43°F, the MRCC notes that, historically, there are about 7.5 such freeze-thaw cycles per year in Chicago.[20]

The MRCC found a statistically significant downward trend in the average number of freeze-thaw events occurring in Chicago each year and also noted a decrease in year-to-year variability, meaning less variability in the number of events from one year to the next (see Figure 3).[21] The MRCC, however, concluded that it was not clear how climate warming may affect the frequency of freeze-thaw cycles. Climate studies hypothesize that less snowy winters might contribute to an increased frequency of soil freeze-thaw cycles. The MRCC also cited a Canadian study of freeze-thaw trends in several Ontario communities, with one community – Harrow, Ontario – located at roughly the same latitude as Chicago. Harrow also experienced 6-7 annual freeze-thaw cycles (comparable to Chicago) and modeling suggests that it may experience as many as 11-12 such cycles annually by 2050.[22]

[20] Woloszyn, *supra* note 16, at 29.
[21] *Id.*
[22] *See* Hugh A. L. Henry, *Climate Change and Soil Freezing Dynamics: Historical Trends and Projected Changes*, 87 CLIMATE CHANGE 421-434 (2008).

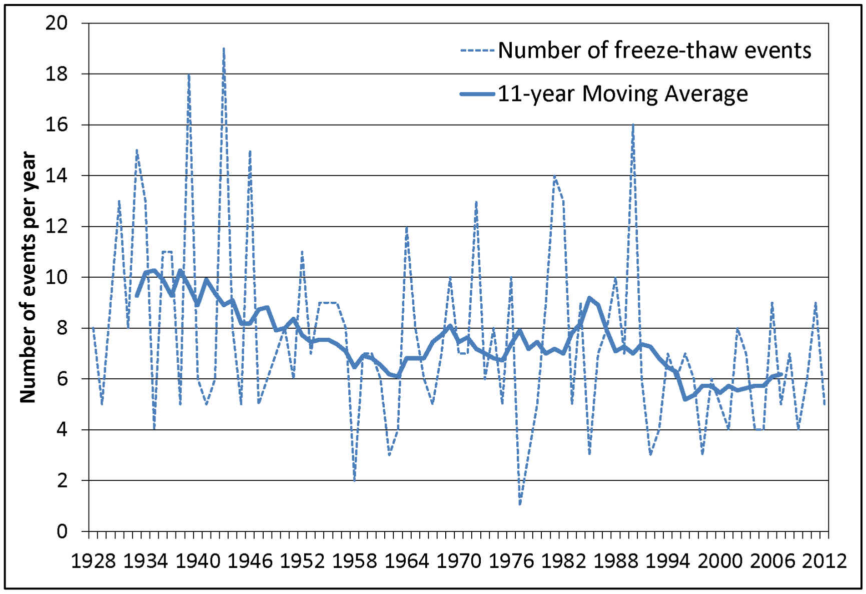

Figure 3. The number of freeze-thaw events at Chicago Midway per year (dotted blue line). The solid blue line shows the 11-year moving average.

If the projected future trends in freeze-thaw cycles in Harrow, Ontario are indeed comparable to Chicago's, then a doubling of such events by 2050 might have significant impacts on Chicago's municipal operations and facilities. Thaws can melt snow and warmer winter temperatures can result in more rain (as discussed below), saturating concrete roads and structures, with the saturated water expanding when it freezes again. When saturated wet concrete refreezes during a freeze-thaw event, the freezing water can expand in the material's pores making it more susceptible to spalling, cracking, and the creation of potholes from surface traffic activity. Moreover, elevated transit stations and tracks can have impaired access or operations when thawed snow or rain quickly refreezes on steel stairways, train platforms, and tracks and switches as ice. Freeze-thaw events might also occur more often on the Chicago Transit Authority's elevated facilities, since they would be most affected by more rapid changes in atmospheric temperatures and would not be as buffered by the thermal mass of soils as would those facilities located at grade or underground.

Freeze-thaw cycles can also pose direct public safety risks as well as a higher maintenance burden. The expansive power of water freezing to ice can also affect the integrity of the fasteners connecting building components to a structure's exterior, should precipitation invade a building's structural envelope. Some decorative materials or surface cladding (such as terra cotta, for example) could also crack and fall off buildings as fasteners fail during freeze-thaw events, posing risks to pedestrians and requiring more frequent inspections and repairs by building managers. Winter sidewalks in Chicago already are festooned with signs warning pedestrians of falling ice, and those risks might increase in the future from the rapid thawing of ice on building surfaces or from thawing ice falling from balconies, signs, and other structural projections over sidewalks.

B. Winter Precipitation Trends

The MRCC notes that Chicago historically has received about 37 inches of precipitation per year (as measured at Chicago O'Hare International Airport), but that it varies seasonally, with most precipitation falling in the summer season (33%), followed by spring (27%), fall (25%), and winter (15%). Future projections of seasonal precipitation have a high degree of uncertainty, but "[a] significant number of models project that annual precipitation will increase in the region with seasonal differences expected."[23] Several studies suggest that there are likely to be increases in winter and spring precipitation, but little change in summer and fall precipitation.

The form that such precipitation takes can also have significant impacts on communities. Based on historical records, the MRCC found that precipitation intensity has increased since 1959, meaning that the precipitation is increasingly in the form of heavy storms (see Figure 4).[24] There have been five 24-hour 10-year storms at Chicago O'Hare since the 1980s, for example, and, more ominously, two of those 24-hour 10-year storms have occurred since 2010. Despite a high degree of uncertainty, some studies have projected that the number of days with extreme precipitation (defined as more than 2.5 inches/day) are likely to increase.[25]

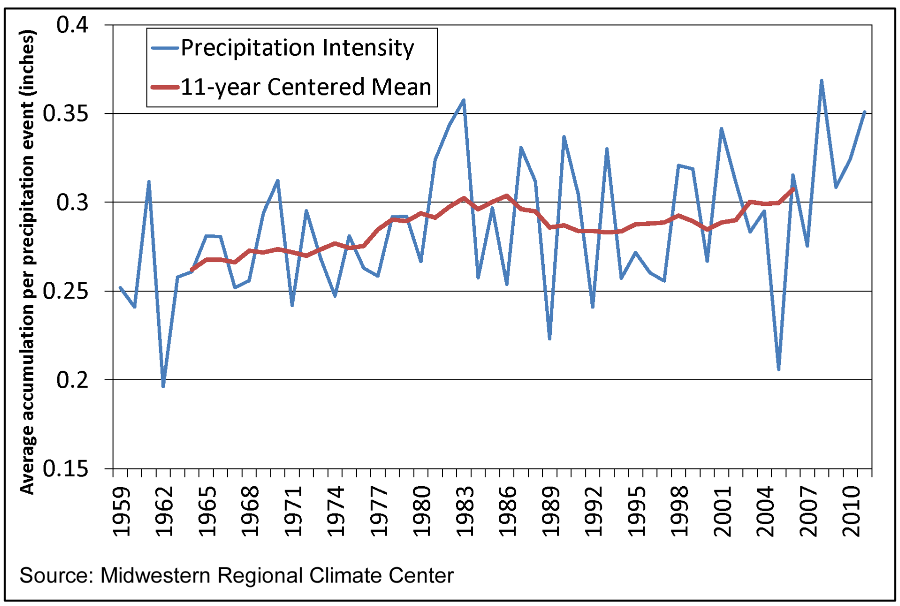

Figure 4. Precipitation intensity, or the average accumulation per event, for Chicago O'Hare. The blue line shows the average precipitation intensity annually and the red line shows the 11-year centered mean.

Increased precipitation is already having significant impacts on Chicago. Basement and street flooding has emerged as a major issue for the City, especially given its old, combined sewer system. Although the Metropolitan Water Reclamation District of Greater Chicago has spent billions in expanding sewer capacity through its Tunnel and Reservoir Project, severe storms still result in large-

[23] CMAP APPENDIX A, *supra* note 16, at 16.
[24] *Id.* at 17-19.
[25] *Id.* at 18.

scale flooding and combined sewer overflow releases to Lake Michigan.[26] The impact is significant enough for Chicago's Division of Water Management to develop and employ sophisticated hydrologic modeling to better predict the basement and surface flooding impacts of storms of various statistical recurrence frequencies (5-year, 10-year, 50-year, etc.) on historically vulnerable neighborhoods.

The MRCC also examined trends in snowfall days and in other winter precipitation variables. An average of 29.4 days per year have more than 0.1 inch of snowfall in Chicago and, because of variability in the climate record, it is difficult to determine what Chicago's winter precipitation trends may be in the future. Historically, 60% of precipitation days in Chicago during the four coldest months (December-March) are days with snowfall, with the rest falling as rain (see Figure 5).[27] Hayhoe et al. projects a decrease in the number of Chicago's snow days by the end of the century, with a 30-50% decrease projected under a low emissions scenario and a 45-60% decrease under a high emissions scenario.[28] Moreover, the Chicago Climate Action Plan's climate change projections found that, as winter temperatures increase, greater amounts of winter precipitation are more likely to be falling as rain rather than snow.[29] There may not be much change in snowfall under a low-emissions scenario, but under a high-emissions scenario, Chicago's average cumulative winter snowfall amount might drop by as much as 10 inches by the end of the century.[30]

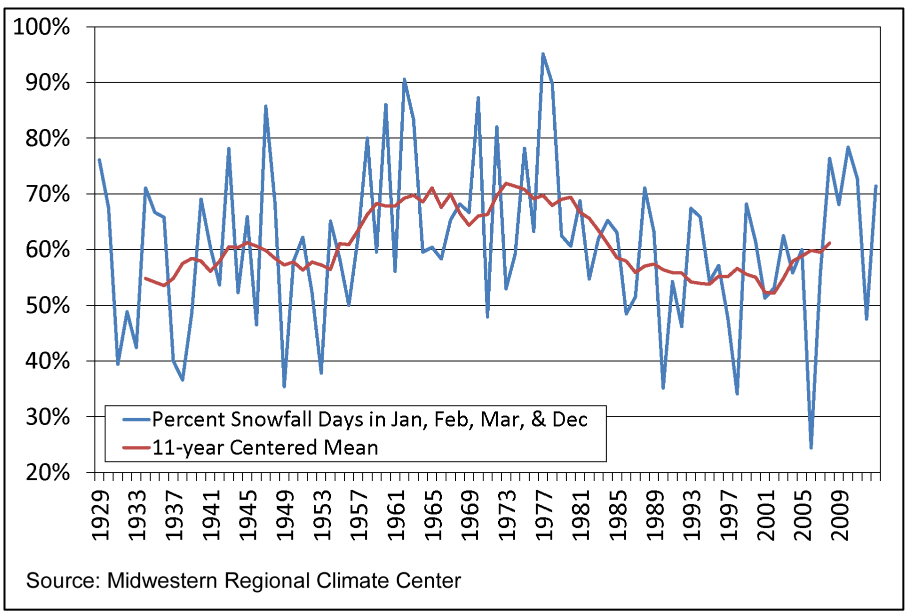

Figure 5. The percent of snowfall days in the snowiest months at Chicago Midway (December-March). The blue line shows the percent annually and the red line shows the 11-year centered mean.

[26] Metropolitan Water Reclamation District of Greater Chicago, Reversals to Lake Michigan (1985-present) in Millions of Gallons (2013), *available at* http://www.mwrd.org/irj/go/km/docs/documents/MWRD/internet/protecting_the_environment/Combined_Sewer_Overflows/pdfs/Reversals.pdf.

[27] CMAP APPENDIX A, *supra* note 16, at 21.

[28] Katharine Hayhoe et al., *Regional Climate Change Projections for Chicago and US Great Lakes*, 36 J. OF GREAT LAKES RESEARCH 7-21 (2010).

[29] HAYHOE & WUEBBLES, *supra* note 11, at xi – xii.

[30] CMAP APPENDIX A, *supra* note 16, at 22.

This shift from declining winter snowfall to increasing winter rainfall can create some significant impacts for the City of Chicago. First the good news – snow entraps pollutants during the winter that are typically released at higher rates to waterways during the spring thaw; with less snow and more rain, this "spring flush" phenomenon may not be as significant (since pollutants would be released at lower rates throughout the winter by snowmelts caused by higher average temperatures and a shorter winter season). So the water quality of waterways in the Chicago region might not be as seasonally variable, possibly because of more consistent rates of snowmelt-related pollutant loading occurring over both the winter and spring. Less snow might also mean less road salting (or possibly lower rates of deicing salt applications), also reducing pollutant loading of chlorides to waterways and landscaped causeways. It would also obviously require less snow plowing.

On the other hand, increased winter precipitation in the form of rain could greatly increase flood risks, especially during an increasing number of freeze-thaw and winter storm events. Rain, especially in the form of heavy rainstorms, falling on snow or on frozen ground would have a higher runoff coefficient than would rain that could infiltrate into soils. This would likely increase the amount of stormwater being discharged to municipal sewers and associated waterways and increasing basement, street, and overland flooding risks to Chicago residents. So winter stormwater release rates and volumes might increase substantially over current conditions for a given storm, even when the pollutant load of the stormwater might be less on a per gallon basis. Moreover, emerging stormwater management practices employing green infrastructure tend to be less effective during the winter, when evapotranspiration rates decline from dormant plants, permeable soils may be blocked if covered by snow, or permeable soils may become saturated and then freeze, impairing infiltration. This would particularly be the case if rain gardens and vegetated swales are used for snow storage during the winter for any snow that may be plowed or removed from pavement, a common seasonal snow management guideline. The stored snow can also displace and reduce the volume of stormwater that could be stored on-site in the rain garden or stormwater management facility, as well as impair its operation.[31]

If rain becomes more common in the winter, what form will this rain take? Because of the possible trend of increased rainstorms during the colder winter season, GLISA was asked to examine whether there will likely be more ice-storms and freezing rain events in Chicago.[32] GLISA defines "freezing rain" as rain that falls on sub-freezing surfaces and forms an icy layer. Crop and fruit damage is a well-known consequence of freezing rain in rural areas, but freezing rain can also pose significant public safety risks and have large societal consequences in urban areas, since it often damages trees and other landscaping, causes power blackouts from downed power lines, and poses higher safety risks from pedestrian slips and falls and more likely automobile accidents. GLISA's analysis of global climate models and the research literature suggests some good news – their study found a decrease in freezing rain events across the Midwest from 1948-2000, and the western portion of the Midwest (which includes Chicago) has fewer freezing rain events than the eastern portion of the region. Moreover,

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[31] *See generally* DEB CARACO & RICHARD CLAYTOR, CENTER FOR WATERSHED PROTECTION, STORMWATER BMP DESIGN SUPPLEMENT FOR COLD CLIMATES (1997).

[32] *See* GREAT LAKES INTEGRATED SCIENCES & ASSESSMENT, *supra* note 15.

Chicago's urban heat island effects (which exacerbate heat waves and air pollution events during the summer season) may also further reduce the frequency of freezing rain events during the winter season, since the number of freezing rain events within the City of Chicago is less than the frequency of such events occurring outside the city. The GLISA study concludes that "[t]here is agreement amongst all pieces of evidence (observations, climate models, and theory) to suggest that Chicago, IL will experience less freezing rain events in the future."[33] This finding suggests that as Chicago's climate continues to change, freezing rain and ice storms may not pose as many potential risks to municipal services and facilities as in the past.

GLISA's report on freezing rain in Chicago also notes that "[S]nowfall has decreased in Chicago but the number of storms passing over the Great Lakes has also decreased. At the same time total precipitation in Illinois has not changed significantly, so we expect more winter precipitation to be falling as rain and in potential heavier storm events."[34]

The MRCC also found that there has been a slight increasing trend in snowfall intensity (calculated by dividing the total annual snowfall by the number of days with measurable snowfall) in Chicago since the 1930s, with more snowfall associated with each event (see Figure 6). Since the 1930s, snowfalls averaged about 1 to 1.25 inches in Chicago, but have increased recently to the 1.25 to 1.5 inch range.[35] Future projections suggest that more precipitation in winter and higher temperatures could result in a higher probability of both heavy snowfall and rainfall events, consistent with the increased moisture-holding capacity of the atmosphere from warmer temperatures.

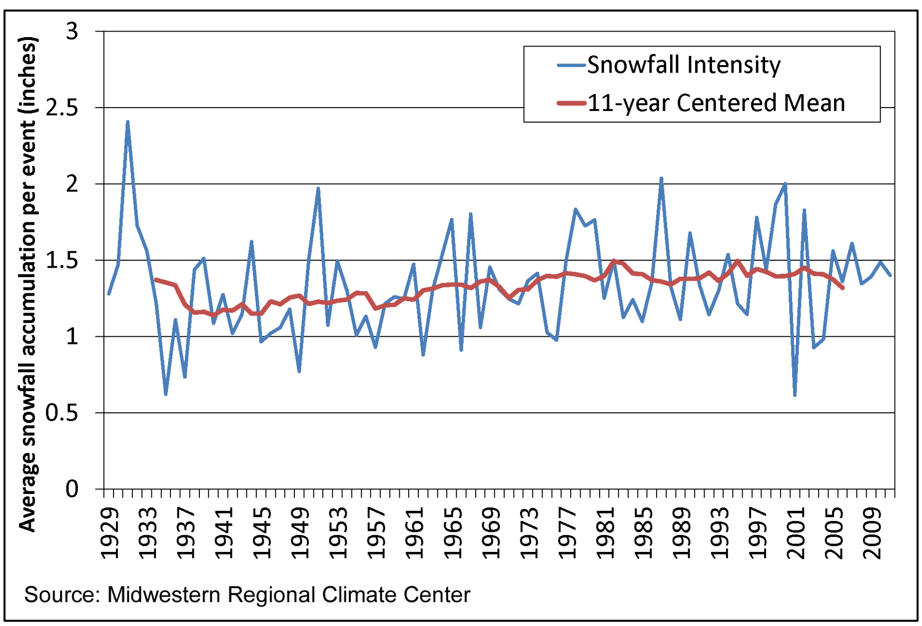

Figure 6. The blue line shows the average snowfall accumulation per event in the winter, while the red line shows the 11-year moving average for Chicago Midway.

[33] *Id.*
[34] *Id.*
[35] Woloszyn, *supra* note 16, at 20-21.

Snow density is also a complicating factor. Based on its water content ratio, the MRCC classified snow as heavy (from 1:1 to 9:1), average (9:1 to 15:1), and light (over 15:1) and found that, historically, "average" snow events have been increasing while both light and heavy snowfalls have been declining (see Figure 7).[36] However, since very few climatic studies have examined future snow density trends, the MRCC hypothesizes, based on theory, that Chicago's snowfalls may become denser because of warmer winter temperatures.[37] If precipitation does in fact increase over the winter season, with the intensity of snowstorms increasing while the frequency declines, then a higher percentage of the blizzards and large snowstorms that would occur may consist of those with heavier and wetter snow.

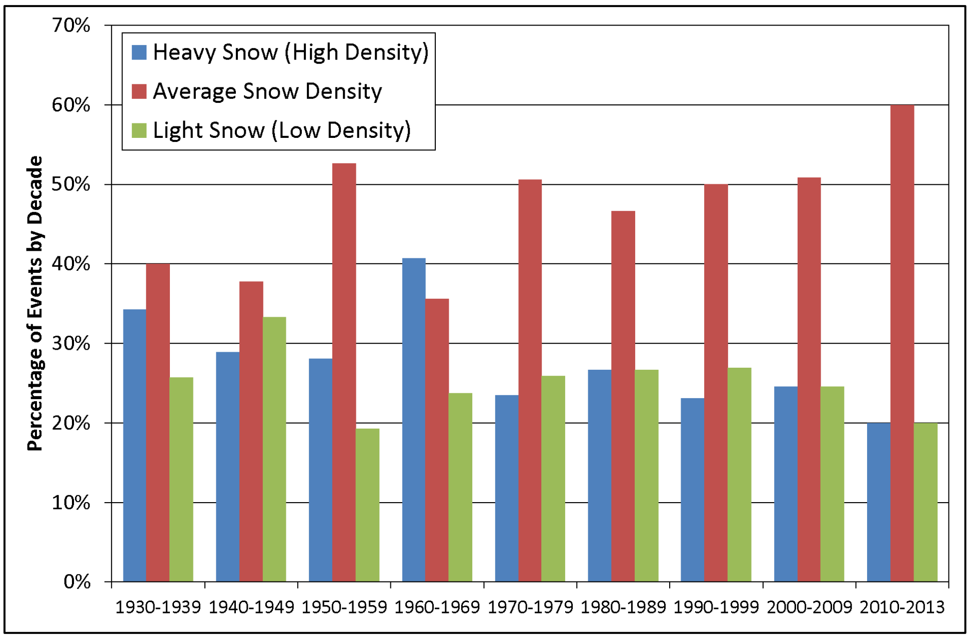

Figure 7. The percentage of high density (blue), average snow density (red), and low density (green) snow events by decade at Chicago Midway.

The impacts of such heavy, wet snowfalls have not yet been discussed with Chicago's Department of Streets and Sanitation staff, but a few scenarios can be developed. Heavy, wet snow does not drift as much as light snow so highways and roads might be less impaired by blizzards. Wet snow might also require lower deicing salt application rates, reducing chloride levels and pollutant loading in the snowmelt runoff and in road spray from vehicles. Any reduction in deicing salt application rates might stress parkway landscaping and street trees less, reducing Chicago's tree maintenance and replacement needs.

On the other hand, many of the impacts of heavy, wet snow would mirror those of heavy ice deposited by ice-storms and freezing rain, with the heavy weight of the snow damaging trees and,

[36] *Id.* at 25-27.
[37] *Id.* at 28.

possibly, automobiles and structures from falling trees and branches.[38] The City of Chicago's urban tree planting lists are currently being re-evaluated in terms of climate change-induced shifts in planting zones, but many of the street trees on Chicago's current planting list do not show up on the list of ice storm-resistant species and therefore may be vulnerable to damage from heavy snow density blizzards. Moreover, structural loading of roofs and buildings is likely to increase from large snowfalls of heavy, wet snow. This may particularly pose problems where green roofs have been installed or retrofitted – structural modifications that already increase the static loading of roof trusses and membranes – which might also increase the risks of large, heavy snowfalls promoting roof and building failure.

Falling tree limbs from heavy snow blizzards might also possibly increase the risks of power blackouts as well as expand the risks of property and automobile damage. This is particularly the case in older cities that still rely on above-ground utility lines. Historical trends are not able to be discerned in power blackouts in the Chicago region that could be correlated with changing trends in winter precipitation and storm events. Although electrical utilities in Illinois are required to file annual reliability reports with the Illinois Commerce Commission (ICC) indicating the extent of energy disruptions and blackouts each year, the data shows no clear trends. Moreover, such analyses would be greatly confounded by a lack of available information concerning the extent of tree trimming undertaken by private landowners, municipalities, and utilities. In other words, a blizzard with heavy, wet snow might cause a tree branch to fall, knocking down a power line and creating a blackout, but if tree branches were trimmed near those power lines the exact same storm might not have the same impact. Since weather reports of severe snowstorms rarely, if ever, report the snow density of the blizzards and ICC records do not indicate the spatial extent of tree trimming activities, it is difficult to determine the cause of the power blackouts or their relationships to either storm events or snowstorm density. But, in theory, heavier and larger snowfalls ought to pose larger risks to trees and, by association, to above-ground utility lines, even though no data is publicly available to show such a correlation.

The societal impacts of an increase in heavy, wet snow from warmer winters have not yet been fully explored in the climate adaptation literature. Shoveling heavy "heart attack" snow certainly poses direct health risks to the person doing the shoveling, especially if there is a family history of premature heart disease.[39] There can also be secondary public health risks posed by the associated winter power blackouts as well. The health impacts of summer power blackouts have been well studied,[40] but little attention has been directed towards winter blackouts. For example, central space heating usually goes out during a blackout, making buildings uninhabitable as interior temperatures drop should a power blackout continue for a long time. This may lead to attempts by residents to heat their buildings and apartments with stoves and ovens and use candles for illumination, with both responses possibly posing increased fire risks and increased risks of carbon monoxide poisoning. If building interiors remain warm,

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[38] RICHARD J. HAUER, MARY C. HRUSKA & JEFFREY O. DAWSON, DEP'T OF FORESTRY, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN, SPECIAL PUBLICATION 94-1,TREES AND ICE STORMS: THE DEVELOPMENT OF ICE STORM-RESISTANT URBAN TREE POPULATIONS (1994), *available at* http://web.aces.uiuc.edu/vista/pdf_pubs/icestorm.pdf.

[39] *See* Robert B. Nichols et al., *Snow Shoveling and the Risk of Acute Coronary Syndromes*, 101 CLINICAL RESEARCH IN CARDIOLOGY 11 (2012).

[40] *See, e.g.*, Shao Lin S et al., *Health Impact in New York City during the Northeastern Blackout of 2003*, 126 PUB. HEALTH REPORTS 384 (2011).

food poisoning risks might also increase as stored or frozen food spoils as temperatures rise in non-functioning refrigerators and freezers, similar to the food safety issues that arise with summer season power blackouts.

III. Winter Climate Adaptation Measures for Chicago

A literature review of winter climate adaptation measures and policies within local climate adaptation plans turned up only a scant few examples that could possibly be adapted to Chicago's Climate Action Plan and the climate change goals of the Sustainable Chicago Action Agenda. For example, the City of Keene, New Hampshire has examined winter impacts to the local economy (especially winter recreation), plant species' growth cycles, and roof sturdiness under snow loading, adopting policies to encourage more pitched roofs, crowning highways with a tighter design radius to remove water better, examining the use of road materials more tolerant of freeze-thaw cycles, and retraining people who might lose their jobs (snow plowing, maple sugaring) because of climate changes.[41] NOAA's Great Lakes Environmental Research Laboratory in Ann Arbor, Michigan, undertook a needs assessment of climate changes in the Great Lakes, identifying a need to consider how projected climate change impacts will affect various economic sectors[42] – for instance, whether communities would need to change their current snowplowing operations in order to respond to the regional trend of heavier but fewer snowstorms.

The City of Toronto, Canada, has also examined winter climate change adaptation issues. Using climate modeling, the city forecasted its winter climate impacts, focusing on managing stormwater flows and basement flooding risks. Its policies also promote the installation of back-up power generation capability at wastewater and water treatment plants that might be impacted by winter power blackouts. Other winter adaptation measures include improved monitoring for snow and freezing rain conditions, the installation of more resilient traffic signal controllers, and improved design standards for infrastructure that might be damaged by winter storms.[43] In examining potential climate change adaptation measures that could be considered by the City of Chicago, it would be useful to organize the strategies in terms of those specific winter climate changes that are likely to have the largest impacts on city facilities and operations. These would include historical and projected changes in average winter temperatures, winter precipitation, and in the frequency of freeze-thaw events.

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[41] *See* CITY OF KEENE, NEW HAMPSHIRE. ADAPTING TO CLIMATE CHANGE: PLANNING A CLIMATE RESILIENT COMMUNITY (2007), *available at* http://www.ci.keene.nh.us/sites/default/files/Keene%20Report_ICLEI_FINAL_v2_0.pdf.

[42] DAWN NELSON, HEATHER ELMER & PATRICK ROBINSON, NOAA TECHNICAL MEMORANDUM GLERL-158, PLANNING FOR CLIMATE CHANGE IN THE LAURENTIAN GREAT LAKES BASIN: A NOAA NEEDS ASSESSMENT: FINAL REPORT 13 (2013), *available at* http://www.glerl.noaa.gov/ftp/publications/tech_reports/glerl-158/tm-158.pdf.

[43] CITY OF TORONTO (ONTARIO), TORONTO'S ADAPTATION ACTIONS (2011), *available at* http://www1.toronto.ca/staticfiles/City%20Of%20Toronto/Environment%20and%20Energy/Our%20Goals/Files/pdf/toronto_cc_adapt_actions.pdf.

A. Warmer Winter Temperatures

Based on the projected seasonal changes in both heating and cooling degree days from a warming climate, these trends will likely result in only negligible economic impacts to the average Chicago household, which will end up paying only about $48 less (in 2013 USD) per year on its energy costs by mid-century. This low economic impact is due to the greater energy efficiency of air conditioning units when compared to space heating technologies, though these household expenditures can increase greatly if energy costs substantially more in the future. It is also important to distinguish these changes in seasonal energy costs from their seasonal energy impacts. Since peak energy use is in summer, these projected changes in annual household energy expenditures may not necessarily correspond to future trends in carbon and other greenhouse gas emissions from power plants and other sources. Moreover, the public health and functional impacts of such energy use are likely to become even more exacerbated by the projected increased frequency of summer air pollution, heat waves, and urban heat island effects. This suggests that Chicago's current policies to reduce air pollution from fleet vehicles and power plants in its Sustainable Action Agenda still makes a lot of sense from a summer season climate change perspective.

The extent and seasonal patterns of water pollution may change considerably with warmer winters and should be accommodated in Chicago's urban stormwater management programs. Even if not released at ambient levels that can pose direct air pollution health risks during the winter, the particulates and other pollutants still settle out of the air and can still impair the region's aquatic ecosystems either directly, through atmospheric deposition to Lake Michigan, or indirectly, by being deposited on the ground and carried by stormwater and snowmelt to a waterway via Chicago's combined sewer system. Moreover, modeling such pollution paths is likely to be complicated by more frequent winter season snowmelt events as temperatures continue to rise during the winter season. More frequent winter thaws might also likely change the region's traditional seasonal fluctuations in water pollution loads by periodically releasing smaller quantities of pollutants entrapped by the snow more often during winter thaws, instead of retaining pollutants for a longer period of time over the winter and then releasing them to waterways at higher concentrations during the spring thaw.

B. Winter Precipitation

A higher frequency of snowmelt during the winter from warmer average temperatures, coupled with increased frequencies and intensities of winter precipitation (especially more winter precipitation in the form of rain) will likely further increase surface and basement flood risks within the City of Chicago. Some of these risks are already being assessed by the city's Department of Water Management, which has developed its own hydrologic simulation model using sewer capacity, precipitation, and topographic data in order to identify specific areas of the city that are likely to experience significant street and basement flooding during heavy rain. These areas are often targeted for municipal urban stormwater management practices. The city's Green Neighborhoods initiative, for example, is converting vacant lots into rain gardens in older South-side neighborhoods with a history of flooding problems.

It is hard to assess many of the tradeoffs of reducing winter flood risks, since most precipitation forecasts in down-scaled global climate models have relatively large margins of error. For instance, in the case of blizzards, the lower discharge rate of snowmelt runoff during thaws might reduce some of the peakiness of stormwater contributions to waterways, reducing peak stream levels and their associated flood risks. The higher frequency of winter rainstorms, however, may greatly increase overland flooding risks, especially if the snow stored on parkways and curbs from street plowing blocks street grates, and the stored snow also reduces the storage capacity and operational efficiency of on-site stormwater management facilities. Chicago's flood risk models may need to be modified to accommodate these additional winter stormwater loads to Chicago's currently undersized combined sewer system. The extent of future basement flooding during warmer winters experiencing a greater share of the city's annual precipitation, for example, may be greater than that anticipated from modeling historical average annual precipitation patterns because of the winter drainage impairments caused by snow, the synergistic effects of combined snowmelt and stormwater discharges from more winter thaws, and an increased frequency of heavier winter rain events.

Rain falling on snow or on frozen ground will also have a higher runoff coefficient than rain falling on bare ground in warmer seasons, further complicating the assessment of winter flood risks. For example, there is less evapotranspiration when plants in rain gardens or vegetated swales are dormant during the winter, impairing the operational efficiency of some green infrastructure practices. Moreover, deicing salts carried by snowmelt or winter stormwater runoff could possibly increase the maintenance burden on some green infrastructure practices as plant materials become stressed and need to be replaced.

Some of this maintenance burden might be offset, however, if warmer winters and more winter rainstorms require lower rates and quantities of deicing salt applications to ensure adequate traffic safety during the winter. More monitoring of on-site green infrastructure performance during the winter months makes sense, and, until the city's stormwater modeling can better account for the projected shifts in winter precipitation patterns induced by climate change, an increased margin of safety in the design of such facilities (perhaps oversizing green infrastructure by 20-25% to account for its likely future impaired efficiency during the winter) might be a good precaution, especially since the useful lives of such installations in new development will likely extend into the mid-century, when climate change and its associated impacts become more apparent.

An increase in snowstorm intensity, coupled with a greater frequency of heavy, wet snowfalls, will also likely lead to more frequent power blackouts and more extensive tree damage during the winter season. Some of the impacts of power blackouts during the winter season were discussed above, but Chicago's responses to the public health risks posed by these events may be different if they occur during the colder winter season rather than during the warmer summer months. For example, reducing some of these public health risks may require establishing emergency heating centers, the same way that the city responds to heat stroke risks to vulnerable populations during heat waves by operating emergency summer cooling centers. Either the same facilities used for emergency cooling during heat waves could be used for emergency heating during winter power blackouts, or alternate strategies could be considered by Chicago's emergency response operations, especially if the cooling/heating centers also become nonfunctional because they are located within an area subject to the power blackout. In such cases, Chicago Transit Authority buses may possibly be used for emergency heating until power can be restored to residences, assuming the same larger snowstorm events that took out the power do not also prevent emergency access to vulnerable households to allow such emergency heating services to be provided.

Food might also spoil in refrigerators during winter blackouts, posing food poisoning risks to households similar to those encountered with power blackouts during the summer season.[44] Unlike some of the summer season health risks, though, some food items vulnerable to spoilage could be moved from the refrigerator and stored temporarily out of doors, especially if cold or below-freezing outdoor temperatures were to continue until power is restored. Chicago's Department of Public Health does not currently have any guidelines concerning food safety or emergency space heating during power blackouts, and a public outreach and education initiative on these issues could help minimize these risks.

This trend towards fewer but larger winter precipitation events poses some interesting challenges to municipal services, especially regarding tradeoffs in municipal road salting and snow plowing operations. Should fewer plows and salting vehicles be purchased, but staffed and operated for longer periods of overtime during each less frequent blizzard? Or, should more plows and salt trucks be used during the rarer large snowstorms, with the higher acquisition costs offset by longer equipment service lives and lower overtime charges for the larger snowplow staff? The answers to such questions will depend on the sizes and allocations of future municipal budgets and on cost-effectiveness analyses that can better monetize and compare the different operational tradeoffs. An increased frequency of heavy winter rainstorms also poses equally significant challenges to municipal operations, especially with respect to combined sewer overflow and urban flooding issues.

Other adaptation measures that could be considered to address the impacts of an increased frequency of larger, heavier, and wetter snowfalls is the reconsideration of Chicago's tree planting lists. Such lists are already being reevaluated to address shifts in growing seasons caused by a changing climate, but the selection of tree species that are less vulnerable to damage from blizzards and snowstorms with heavier snow density also makes sense should the frequency of such events increase in the future. Similarly, franchise arrangements with utility providers should specify an increased schedule of tree trimming around above-ground power lines, to account for the higher blackout risks from heavier snowfalls. Building codes and development regulations governing new development should also specify or encourage the underground installation of all utilities to further reduce these power blackout risks.

C. Freeze-Thaw Events

An increase in the frequency of winter freeze-thaw events is likely to impose greater stress on the built environment, especially if entrapped water freezes and expands within a saturated medium (such as concrete) or within the intersection of two different media (such as concrete and asphalt). This condition will likely result in a higher probability of roadway pothole formation, the spalling of concrete,

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[44] *Keeping Food Safe during an Emergency*, FOOD SAFETY AND INSPECTION SERVICE, U.S. DEP'T OF AGRIC., http://www.fsis.usda.gov/wps/portal/fsis/topics/food-safety-education/get-answers/food-safety-fact-sheets/emergency-preparedness/keeping-food-safe-during-an-emergency/CT_Index (last visited Dec. 16, 2013).

masonry or other similar structural surfaces, and the increased loading (by ice expansion) of structural fasteners on building exteriors or on projections over sidewalks and other public ways. These freeze-thaw events can result in increased road repairs and structural inspection and maintenance costs.

With an increase in freeze-thaw cycles, municipal road maintenance budgets may need to increase, as well as the frequencies of roadway inspections and resurfacing projects. One policy to address these risks is for the City of Chicago to promote and improve inter-departmental coordination with respect to infrastructure repair and replacement and roadway resurfacing projects. Infrastructure repair and replacement often requires the digging up of paved streets and the use of asphalt patching after subsurface maintenance. Since asphalt and concrete have different coefficients of expansion during seasonal temperature changes, there are opportunities for water to breach the point of connection between the two materials, creating structural failure as the water freezes and thaws. Better scheduling of subsurface infrastructure repair that is coordinated with street resurfacing projects can minimize patching of utility trenches and ensure the roadway's surface integrity against freeze-thaw stresses for a longer duration. The use of innovative paving materials, such as permeable paving, to help control stormwater runoff by encouraging its percolation into subsurface storage vaults or into permeable soils may also reduce freeze-thaw stress by removing the water from the paving material's pores before it can freeze and expand (provided these materials do not become saturated).[45] But this paving strategy may also require increased maintenance (such as periodic street sweeping or vacuuming to prevent clogging from fine sediments), which must be offset against the savings from avoided pothole repairs.

Pedestrian safety issues arising from structural vulnerability caused by freeze-thaw cycles can be addressed by an increase in the structural inspection frequency of vulnerable buildings (e.g., those with terra cotta cladding) and with those buildings that have obstructions over sidewalks and public ways. These may pose the greatest risks to pedestrians should water breach the exterior cladding or structural fasteners and then expand when frozen. The City's façade inspection ordinance currently requires inspections every five years, but an accelerated inspection schedule may be needed as freeze-thaw cycles increase in frequency. Other measures to address these risks can include increased mandatory insurance requirements for buildings with projections over public ways and possibly even the greater encouragement of design features in new buildings to reduce pedestrian exposure (such as increasing the zoning bonuses for building setbacks that increase with building height or for pedestrian arcades, both of which can "shelter" pedestrians from falling debris).

Deicing of elevated train station platforms, stairways, and switching gear might also need to occur more often as the number of freeze-thaw events increase with climate change. Elevated facilities might be at greater exposure to the icing hazards of thawed and refrozen snowmelt or frozen winter rain than transit facilities located at grade or underground simply because they are decoupled from the thermal mass of soils. Protecting transit users from icing hazards, however, may involve some operational tradeoffs, since a greater frequency of deicing salt applications may result in increased equipment corrosion, requiring higher maintenance and replacement expenditures. When these secondary impacts of salt use are considered, the installation and greater use of infrared heating lamps on elevated transit stairs and platforms might be a more cost-effective strategy to reduce passenger icing

[45] NATIONAL READY MIXED CONCRETE ASSOCIATION, FREEZE-THAW RESISTANCE OF PERVIOUS CONCRETE (2004).

hazards than the increased use of deicing salts. These decisions will require careful economic analyses to better assess the tradeoffs, especially if future energy costs increase.

IV. Conclusions

We probably know a bit more about winter climate adaptation issues now than in the past, but local adaptation plans still emphasize summer climate change impacts over winter ones. There is a need within the Great Lakes region to consider both summer and winter climate changes in assessing municipal vulnerability to climate change. Many of the climate changes projected for the Chicago metropolitan region are also relevant to other areas of the Great Lakes basin, and many of the possible winter climate change adaptation measures are also likely to be transferable to other, smaller communities within the region. These changes include warmer winters, more winter rainfall, more frequent blizzards, and larger snowstorms (often with a higher snow density), and local policies and practices should recognize these changes and their impacts.

Given the breadth of municipal enabling legislation and home rule authority, there should be few legal constraints involved with a city modifying its operations and responses to winter conditions to address emerging climate change trends and impacts. Making operational changes proposed within a municipal climate adaptation or sustainability plan often imposes unwanted costs on residents and taxpayers, but, over the longer term, failing to change municipal practices and requirements to address emerging winter climate trends may end up imposing even greater costs on both individuals and society.

Most of our recommendations concerning the Chicago Climate Action Plan and Sustainability Action Agenda represent relatively minor and incremental changes to existing programs. Moreover, we believe that most adaptations to climate change must be incremental, since, in the case of adopting climate adaptation measures, increased short-term weather variability (several 100-year storms in a single year, for example) will often hide the longer-term climatic trends and processes that will have the largest aggregate impacts on city operations and staffing. Despite its current popularity, an adaptive management framework may not be a preferred approach where such trends can only be discerned by analyzing a century or more of meteorological records. The climate-change "signal" that would be used to trigger municipal action under an adaptive management framework is likely to be hidden in the "noise" of a decade's worth of data averaging, especially if weather variability is also increasing as a result of a changing climate. Careful long-term trend analyses and periodic (perhaps every decade) reviews of and adjustments to municipal programs and operations in light of the perceived or forecasted trends may be a more useful and cost-effective approach than one that uses an extreme weather event (e.g., a drought, heat wave, or blizzard) as a justification to radically transform public policy.