Recommendations to the City of Chicago For Winter Adaptation Measures and an Indicator Suite For Climate Change Metrics

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INTRODUCTION

The Midwest regional report in the most recent draft National Climate Assessment (S.C. Pryor and D. Scavia. 2013) 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 (with their impacts on natural resources, water resources and crops). 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.

By addressing only these major summer season impacts of climate change, most local adaptation plans ignore the societal and environmental impacts of warmer and possibly shorter winters. This White Paper examines some of the winter adaptation policies that can be considered in developing local Climate Action Plans. In considering winter adaptation measures, we focus especially on the 2008 Chicago Climate Action Plan 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 (R Bierbaum, A Lee and J Smith 2013, pp. 992-993). 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 municipal actions 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 city's Department of 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 (J. Parzen 2008).

In 2011, after the election of a new mayor, Chicago eliminated its DoE in an administrative reorganization, transferring many of DoE's staff to other municipal agencies. A Chief Sustainability Officer position was also created in the Mayor's Office, which assumed management of the Chicago Climate Action Plan and also instituted a new, shorter-range environmental initiative called the 2015 Sustainable Chicago Action Agenda (City of Chicago 2012). 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. The Action Agenda's key climate adaptation actions include (p. 35):

- 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.

As with the Chicago Climate Action Plan, the city's emphasis on climate adaptation within its Sustainable Chicago Action Agenda remains focused largely on mitigating summer impacts (e.g., providing cooling centers and reducing heat island effects). However, the goals and some of the actions are phrased broadly enough to accommodate many winter climate change impacts as well.

This study examines the City's current climate adaptation measures, the projected impacts of winter season climate change, and proposes some new measures and programs that might better address these forecasted impacts. The research was funded by the Great Lakes Integrated Science and Assessment Center at the University of Michigan and Michigan State University. In addition, the City's current monitoring initiative, the Climate Action Plan Dashboard, measures Chicago's progress towards its management objectives by using greenhouse gas emission reductions as the principal performance metric. This metric is consistent with the Climate Action Plan's focus on climate change mitigation, but might be an imperfect measure of adaptation effectiveness as well as too abstract in its consequences to be an effective vehicle for public education and outreach. We therefore propose, in Appendix B, alternative climate change metrics that might be more useful and accessible in educating and engaging the public.

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 Programs' 2009 National Climate Assessment (USGCCRP 2009) 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. The Great Lakes Supplement to NOAA's coastal climate adaptation guidebook (Cruce and Yurkovich 2011) also notes that "[S]ince 1951, there has been an upward trend in [lake-effect] snowfall along the southern and eastern shores of the Great Lakes," and identifies an increased number of nonfatal traffic accidents as one impact of this trend. However, most of these winter impacts have only limited relevancy to Chicago since there are few ski resorts in the metro area, the lakefront is largely armored (reducing its storm and erosion susceptibility), and most of Chicago's major traffic and transit corridors (except for Lake Shore Drive) are located inland, outside of the lake-effect zone.

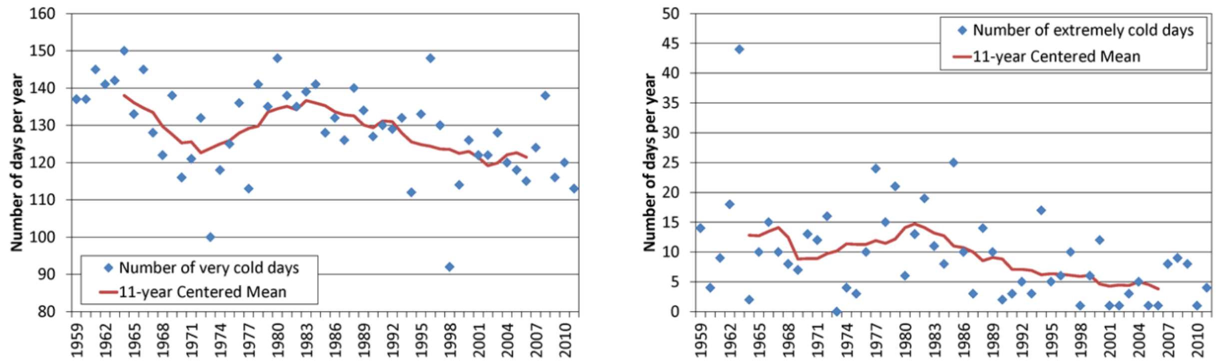
In order to frame the municipal policies and actions that might be developed in the 2008 Chicago Climate Action Plan, a background report for the Plan forecasted climate changes in Chicago (Hayhoe, K. and D. Wubbles. 2008) and examined potential changes and variability in temperatures and precipitation under various emissions scenarios. The background report 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. There will also likely be an increased intensity of heavy precipitation events, leading to a higher frequency of flood 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 Chicago Climate Action Plan's background report makes only a few references to forecasting winter season changes and impacts. These involve both the mortality and morbidity risks of warmer winters (which are difficult to quantify) and the impacts of changes in winter snowfalls, which are likely to decrease slightly under the higher emissions scenario and show little change under the lower emissions scenario (p. xii). More recent research by Kunkel et al. (2013) for the National Oceanic and Atmospheric Administration (NOAA), as part of the U.S. Global Change Research Program, 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. These more recent analyses have also found that the frequency and intensity of extreme precipitation in the region has increased (noting a great deal of uncertainty in the modeling of future precipitation changes), 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.

Research by the Great Lakes Integrated Sciences and Assessments Center (GLISA) at the University of Michigan (L. Briley 2013) and the Midwestern Regional Climate Center (MRCC) (M. Woloszyn 2013 and CMAP, Appendix A 2013) supplemented this relatively brief assessment of winter season climate changes affecting the Chicago metro area. 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, is useful to examine both historical trends and winter climate change forecasts with respect to these meteorological factors.

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 as 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, there will be 22 fewer days per year with a minimum temperature below 32°F by mid-century. In addition, climate studies show that there will be a 50% reduction of extremely cold days in Chicago under a low-emissions scenario and a 90% reduction (equivalent to only one day per year) under a high-emission scenario by the end of the 21st Century (CMAP, Appendix A 2013, p. 13).

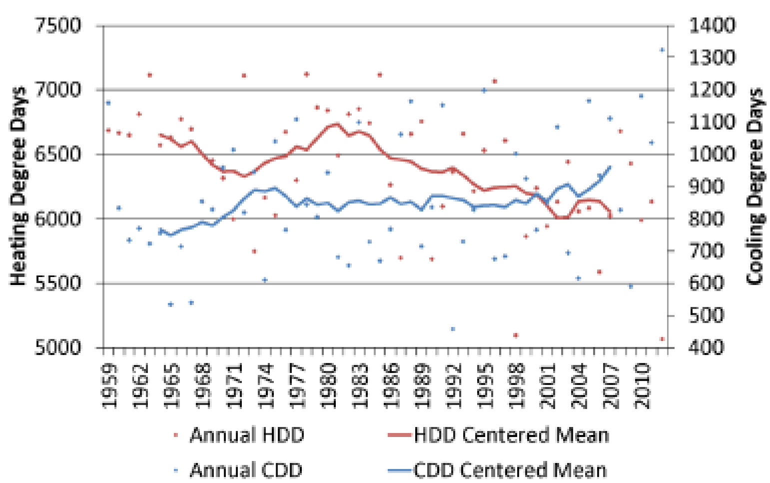


Source: Midwestern Regional Climate Center

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 degree for Chicago (CMAP 2013 Appendix A, pp. 13-14). 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. Warmer summers result in climate models anticipating a 66% increase in cooling degree days averaged across the Midwest by 2041-2070 (CMAP 2013 Appendix A, pp. 14).



Source: Midwestern Regional Climate Center

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 temperature is at least 26°F and the maximum daily temperature at least 43°F when measured above 1-centimeter of bare soil, the MRCC notes that, historically, there are about 7.5 such freeze-thaw cycles per year in Chicago (M. Woloszyn 2013, p. 30).

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) (Woloszyn M. 2013, p. 29). The MRCC, however, concluded that it was not clear how climate warming may affect freeze-thaw cycles, although reduced winter snow cover 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, which also experienced 6-7 annual freeze-thaw cycles (comparable to Chicago) and where modeling suggests that it may experience as many as 11-12 such cycles annually by 2050 (Henry 2008).

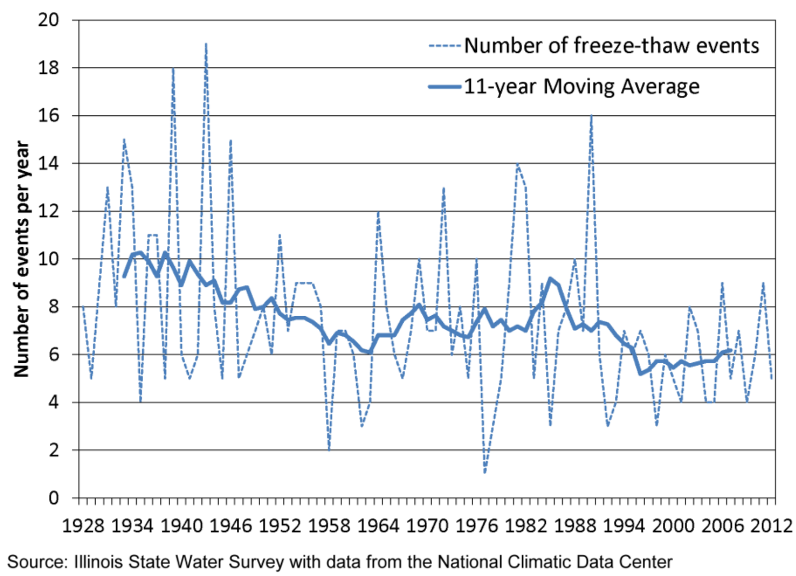


Figure 3: The number of freeze-thaw events at Chicago Midway per year (dotted blue line). The solid blue line shows the 11-year moving average.

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 (CMAP 2013 Appendix A, p. 16)." Several studies suggest that there are likely to be increases in winter and spring precipitation, but little change in summer and fall precipitation.

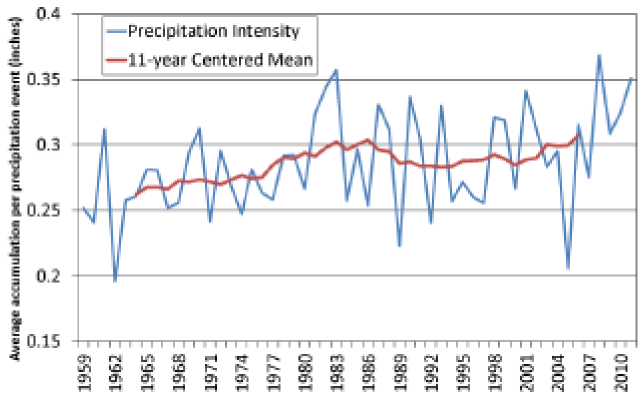


Figure 4: Precipitation intensity, or the average accumulation per event, for Chicago O'Hare. The blue line shows the average precipitation intensity annually and the red line shows the 11-year centered mean.

The amount of precipitation during single events can have significant impacts on communities. Based on historical records, the MRCC found that precipitation intensity has increased since 1959, meaning that the average accumulation of precipitation per event is increasing (see Figure 4) (CMAP, Appendix A 2013 pp. 17-19). For example, there have been five 24-hour 10-year storms at Chicago O'Hare since the 1980s, 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 (CMAP, Appendix A 2013 p. 18).

The MRCC also examined trends in snowfall days and in other winter precipitation variables. An average of 29.4 days per year have produced more than 0.1 inches of snowfall in Chicago. The variability of snowfall in the historical climate record makes it 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) (CMAP Appendix A, pp. 21). Hayhoe et al. (2010) 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% under a high emissions scenario. 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 (CMAP Appendix A, pp. 22).

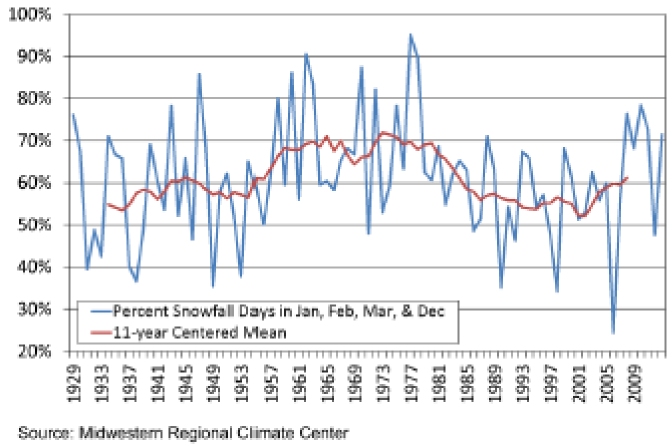


Figure 5: The percent of snowfall days in the snowiest months at Chicago Midway (December-March). The blue line shows the percent annually and the red line shows the 11-year centered mean.

If rain becomes more common in the winter, what form will this rain take? Because of this possible trend of increased rainstorms during the colder winter season, we asked GLISA to examine whether there will likely be more ice-storms and freezing rain events in Chicago (Briley 2013). 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, 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. Because of this finding, freezing rain and ice storms may not pose as many potential risks to municipal services and facilities as in the past, as Chicago's climate continues to change.

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." 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 1.25-1.5 inch range (Woloszyn M. 2013, p. 20-21). 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.

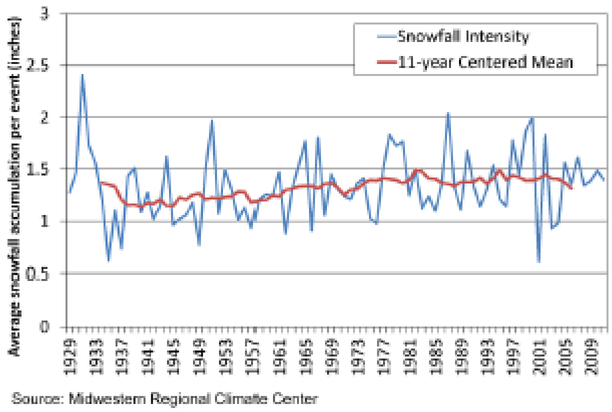


Figure 6: The blue line shows the average snowfall accumulation per event in the winter, while the red line shows the 11-year moving average for Chicago Midway.

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) (Woloszyn M. 2013, p, 25-27). 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 (Woloszyn M. 2013, p. 28).

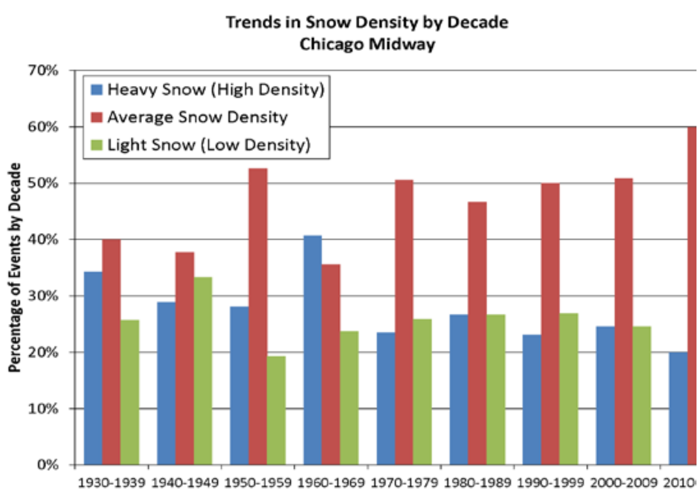


Figure 7: The percentage of high density (blue), average snow density (red), and low density (green) snow events by decade at Chicago Midway.

Winter Climate Impacts and 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 (City of Keene 2007) 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. 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 winter impacts will affect various economic sectors – for instance, how a community could reassess its snowplowing operations to respond to the regional trend of heavier but fewer snowstorms (Nelson, Elmer and Robinson 2013).

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 (City of Toronto 2011). 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.

Warmer Winters

Despite the substantial seasonal changes in both heating and cooling degree days from a warming climate, we estimate that these trends will result in only a minimal economic impact for the average Chicago household, which will end up paying only about $48 less per year on its energy costs, largely because of the much greater energy efficiency of air conditioning units when compared to heating technologies (see Appendix A). It's 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 costs may not necessarily correspond to future trends in carbon and other greenhouse gas emissions from power-plants and other sources, whose public health and functional impacts are likely to be exacerbated by summer air pollution, heat wave and urban heat island conditions**. 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.**

We believe that significant municipal impacts are likely with more winter snow events taking the form of heavier snowstorms comprised of denser snow. High density, wet snow does not drift as much as light snow so highways and roads might be less impaired by blizzards. The higher winter temperatures causing denser snow will also likely require lower deicing salt application rates, reducing chloride levels and pollutant loading in the snowmelt runoff and in road spray from vehicles (Salt Institute 2013). 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 dense, wet snow would mirror those of heavy ice deposited by ice storms and freezing rain, with the weight of the snow damaging trees and, possibly, automobiles and structures from falling trees and branches. Lists assessing the susceptibility of various street tree species to ice storm damage have been compiled by researchers at the University of Illinois at Urbana-Champaign, for instance. (Hauer, Hruska and Dawson 1994).   The City of Chicago's urban tree planting lists are currently being re-evaluated by the Morton Arboretum 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 UIUC's lists of ice storm-resistant species, so may remain 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, and 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. We have tried to discern historical trends in power blackouts in the Chicago region that could be correlated with changing trends in winter precipitation and storm events.   Electrical utilities in Illinois are required to file annual reliability reports with the Illinois Commerce Commission, indicating the extent of energy disruptions and blackouts each year. But the data shows no clear trends, since it is confounded by the degree of tree trimming undertaken by 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 the exact same storm might not have the same impact were the tree branches trimmed better around the same power lines. Moreover, 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 utility tree trimming activities, we were unable to determine the cause of the power blackouts or their relationships to either storm event 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, but no data is publicly available to show such a correlation.

The trend towards fewer but larger winter precipitation events over a shorter winter season 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? 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, the same issues as with freeze-thaw cycles. We did not have an opportunity to interview Street and Sanitation Department staff responsible for snow plowing operations for the City of Chicago, but believe that the City's snow plowing operations and response planning may also need to change as a result of a shorter winter season with less aggregate snowfall, but with more of the snowfall occurring in the form of more intense snowstorm events.

Designing and scaling municipal snow removal programs to deal with the most severe snowstorm events will likely not be cost-effective from an operational perspective as the snow season continues to contracts as a result of climate change (though it might still be deemed desirable from a political perspective). **Instead of increasing the number of plows and crews to address the risks of larger blizzards, a more efficient approach may be delaying the plowing of neighborhood streets after a major snowstorm and focusing snow clearance efforts on priority routes**. The possible higher frequency of warmer ambient temperatures from climate change-induced weather variability might also mitigate some of the adverse impacts of delaying the plowing and deicing on local streets until after the major thoroughfares are cleared.

Winter Precipitation

As winter temperatures increase, more of the winter precipitation is more likely to be falling as rain rather than snow (Hayhoe and Wubbles 2007). This precipitation shift from declining winter snowfall to increasing winter rainfall can create some subtle environmental impacts for the City of Chicago. For example, **ambient water quality might not be as seasonally variable because the "spring flush" phenomenon (where pollutants entrapped in snow are released at higher rates to waterways during the spring thaw) may not be as significant since pollutants would be periodically released in snowmelt at lower rates throughout the winter as a result of higher average temperatures, more freeze-thaw cycles and a shorter winter season**. Less snow also means less road salting, lower rates of deicing salt applications and the reduced loading of chlorides to waterways and landscaped causeways from urban runoff and snowmelt (Salt Institute 2013).

Increased winter precipitation in the form of rain could also 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 (D. Caraco and R. Claytor 1997). 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 (D. Caraco and R. Claytor 1997).

Although the slower rate of snowmelt discharge 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 may greatly increase overland flooding risks, especially if snow storage 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 should be modified to accommodate these additional winter stormwater loads to Chicago's currently undersized combined sewer systems. The extent of future basement flooding during warmer winters, for example, may be larger than that anticipated from modeling average annual precipitation patterns because of the winter drainage impairments caused by snow and the synergistic effects of combined snowmelt and stormwater discharges.   Increased precipitation intensity is already having significant impacts on Chicago. For example, basement and street flooding have already emerged as a major issue for the City, especially given its old, combined sewer system. Although the Metropolitan Water Reclamation District of Great Chicago has spent billions in expanding sewer capacity through its Tunnel and Reservoir Project, severe storms still result in large-scale flooding and combined sewer overflow releases to Lake Michigan (MWRDGC 2013).

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 can possibly the increase maintenance burden on some green infrastructure practices as plant materials become stressed and need to be replaced.   This maintenance burden might be mitigated, however, if warmer winters and heavy, wet snowfalls require lower rates and quantities of deicing salt applications to ensure adequate traffic safety during the winter. Deicing salt applications might need to be increased during wet snowfalls, simply because of the dilution effect s of denser snow (Wisconsin Transportation Information Center 2005). However, the contraction of the main snowfall season to only the mid-winter months and the smaller number of snowstorms per season with warmer winters may still result in substantially less aggregate deicing salt use over the entire snow season.

More monitoring of on-site green infrastructure performance during the winter months makes sense, and, until 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 stormwater practices and facilities (perhaps oversizing green infrastructure by 20-25% to account for its likely future impaired efficiency during the winter) might be a good precaution**. This might be a reasonable adaptation measure for stormwater best management practices, 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, CTA 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.

The societal impacts of an increase in denser, wetter snowstorm events 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 (Nichols et al. 2012). 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 (Lin et al. 2011; Marx et al 2006; IWGCCH 2009), 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 also increased risks of carbon monoxide poisoning.

Food poisoning risks might also increase during power blackouts as stored or frozen food spoils as temperatures rise in non-functioning refrigerators and freezers, similar to the food safety issues that often arise with summer season power blackouts. **Public service announcements issued by the Chicago Department of Public Health as to which frozen or refrigerated foods are still safe for consumption after blackouts would go far in reducing such risks (USDA 2006).** Unlike the food poisoning hazards typically encountered during summer season power blackouts, the colder outdoor temperatures found in the Great Lakes region during the winter season might mitigate some of these health risks. For example, outdoor temperature-related guidelines could be developed for interim food storage outdoors or in the non-heated areas of residential buildings (such as in porches, garages, etc.). In such cases, however, care must be taken to also develop public health guidelines to ensure secure outdoor storage in order to guard against any vector-borne disease risks arising from the partial consumption of the stored food by stray pets and feral urban wildlife (such as birds, squirrels, insects, raccoons and rats). 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.

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, municipal franchise arrangement 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.

Freeze-Thaw Events

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 water expanding when it refreezes. When saturated or wet concrete refreezes during a freeze-thaw event, the ice expands within the material's pores making it more susceptible to spalling, cracking and 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 and icing hazards 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 located at grade or underground.

With an increase in freeze-thaw cycles, municipal road and transit maintenance budgets may need to increase, as well as the frequencies of roadway inspections and resurfacing projects. Alternatively, different types of road construction (or reconstruction) can be used to improve drainage of precipitation and reduce the saturation of the paving materials by freezing water -- permeable concrete, for example, tends to perform well during freeze-thaw cycles since water tends not to be retained in the material's voids, unless the permeable paving is clogged or its underlying soils freeze, impairing drainage and allowing the permeable paving material to remain saturated (NRMCA 2004). Deicing of elevated train stations and switching gear might also need to occur more often as the number of freeze-thaw events increase with climate change, with concurrent increases in equipment corrosion and maintenance.

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 downtown Chicago already are festooned with signs warning pedestrians of falling ice, and those risks might also increase more 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 sidewalk

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, 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.

One policy to address these risks is for the City of Chicago to **continue to promote the improved 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 the 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 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 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). 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.

Structural vulnerability from 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**. Measures to address these risks can include mandatory insurance requirements for buildings with projections over public ways, more frequent inspections of structural and glazing integrity, and possibly even the encouragement of building design features to reduce pedestrian exposure (such an incentives for building setbacks that increase with building height or pedestrian arcades**, both of which will "shelter" pedestrians from falling debris). The City's current 5-year inspection schedule under its façade inspection program may also need to be shortened should freeze-thaw cycle frequency begin to increase from climate change.

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.

The impacts of these changes are likely to be minor at first, possibly accelerating as the rate of climate change increases with ambient greenhouse gas concentrations in the atmosphere. The Chicago Transit Authority is the only agency that specifically addresses winter season operational impacts in its emergency operations plan and in its Federal Transit Administration pilot project grant focused on climate change adaptation.   Other City agencies should also begin focusing more attention on adapting to some of the impacts from warmer winters and changes in winter temperatures and precipitation. Some of these impacts and adaptive strategies are summarized below, in Table 1.

Appendices to this report also list some useful indicators for climate change, in order to improve public outreach on this issue.   The City of Chicago currently uses averted greenhouse gas emissions as a performance metric in its Climate Action Plan dashboard, but we believe these measures may be too abstract for most residents.   Instead, a variety of meteorological metrics can be considered to help build public understanding and support for climate-focused changes in municipal programs and services, but these may need to be made more accessible by a employing a running ten year average in order to discern longer-term climate trends affecting the metro region. Basing policy and plans on responses to extreme events may not be an optimal strategy, especially since weather variability is likely to increase as the climate continues to change in the northern Great Lakes region.   Moreover, forecasting both weather and climate trends involve longer-range probabilistic estimates with relatively high margins of error, so a more cautious and incremental policy response may be warranted.

<table>
<tr><th>Projected Climate Changes</th><th>Potential Impacts</th><th>Policy Recommendations</th></tr>
<tr><td colspan="3">Temperature-related variables</td></tr>
<tr><td>Overall increase in average temperature</td><td>Fewer extremely cold days during the winter, which could reduce harm to vulnerable populations in winter.</td><td rowspan="2">A more efficient approach to plowing in the future may be to delay plowing of neighborhood streets after a major snowstorm and focusing snow clearance efforts on priority routes.</td></tr>
<tr><td>Decrease in heating degree days and increase in cooling degree days</td><td>Minimal economic impact for the average Chicago household, largely because of the much greater energy efficiency of air conditioning units when compared to heating units.</td></tr>
<tr><td rowspan="2">Increase in freeze-thaw cycles</td><td>Concrete roads and structures more susceptible to spalling, cracking, and potholes.</td><td>Inter-departmental coordination with respect to infrastructure repair and replacement, as well as roadway resurfacing projects and maintenance budgets may need to increase. Alternative paving materials like permeable surfaces may be beneficial to reduce the saturation of paving materials by freezing water, which contributes to cracking.</td></tr>
<tr><td>Increased risk to pedestrians as freeze-thaw cycles can compromise the integrity of building fasteners, causing them to loosen and fall.</td><td>Increase in structural inspection of vulnerable buildings and those with projections over sidewalks. Mandatory insurance requirements for buildings with projections over public ways. Encourage building design features to reduce pedestrian exposure to falling façade.</td></tr>
<tr><td colspan="3"></td></tr>
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Table 1. Climate Changes, Impacts and Adaptation Measures

Projected Climate Changes	Potential Impacts	Policy Recommendations
Precipitation-related variables		
Overall increase in average winter and spring precipitation	Increased risk for surface and basement flooding throughout the year.	Chicago's flood risk model should be modified to accommodate the additional winter stormwater loads to Chicago's currently undersized combined sewer systems.
Extreme precipitation likely to increase		
Precipitation shift from declining winter snowfall to increasing winter rainfall	Less road salting over the entire snow season (reducing pollutant loading of chlorides)	Green infrastructure (GI) tends to be less effective in the winter. Therefore, more on-site monitoring of GI performance during winter months may be needed until stormwater modeling can better account for changing winter precipitation patterns. Increased margin of safety in the design of GI may be a good precaution (e.g. oversizing GI by 20-25%)
	Ambient water quality might not be as seasonally variable (reduce the "spring flush" phenomenon.	
	Increased flood risk as the runoff coefficient is higher when rain falls on snow or frozen ground.	
	Increase combined sewer overflow issues.	
Higher frequency of heavier and more dense snowfall events	Increased risk for winter power blackouts.	Public health risks may require establishing emergency heating centers (same locations used as cooling centers in summer and possibly CTA buses for centers affected by blackout).
		Issue public service announcements as to which foods are safe for consumption after blackouts to reduce food safety risks.
		Increased schedule of tree trimming around above-ground power lines.
		Building codes and development regulations governing new development should specify or encourage underground installation of utilities.
	Increased risk for falling trees and branches, causing damage to automobiles, structures, and possibly causing blackouts.	Reconsider the urban tree planting list to include tree species that are less vulnerable to damage from blizzards and snowstorms with higher snow density.
	Highways and roads could be more impaired by blizzards since denser snow does not blow as much.	Deicing salt applications may need to increase during wet snows.

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