Climate Change and Water Resources Management:

A Literature Review for the Ramsey-Washington Metro Watershed District

March 2010

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BARR

4700 West 77th Street
Minneapolis, MN 55435-4803
Phone: (952) 832-2600
Fax: (952) 832-2601

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Executive Summary

At present, there is no single best procedure for considering climate change in the Ramsey-Washington Metro Watershed District's (District's) management goals. Future conditions in the District are uncertain, due not only to the uncertainty of greenhouse gas emissions and climate system responses, but also due to the natural fluctuations that the climate experiences over time. Regardless, it is clear that climate change has the potential to amplify issues already faced by the District. Ultimately, perhaps the most important tools that the District can employ in the face of an uncertain climate future are twofold--monitoring and adaptive management. These will be key to the District's success in understanding and managing its waterbodies in the coming years.

The current body of available climate change information suggests that some of the District's current efforts will become even more important in the context of climate change, especially:

- Monitoring and managing lake water quality
- Monitoring and managing invasive macrophyte species
- Monitoring and, where appropriate, managing sediment release of phosphorus from lake sediments
- Implementing the volume reduction rule (as it is currently defined) in areas of redevelopment
- Implementing low-impact development strategies throughout the District, thereby increasing the watershed's resilience against high runoff events through water retention

In light of the literature review presented in this report, a few additional recommendations are included below.

- Monitor wetland water levels.
- Investigate tools for incorporating projected changes to climate data into the District's hydrologic, hydraulic, and water quality models to better define future conditions in Minnesota.
- When choosing "critical conditions" for lake and watershed models to determine management options in SLMP and TMDL projects, pay attention not only to overall precipitation amounts during *recent* water years, but also patterns of precipitation intensity.

1.0 Introduction

"Although significant uncertainty still remains regarding the exact magnitude of the changes that may occur, it is likely that the Midwest climate over the next century will differ significantly from what we have been accustomed to over the past century. As such, the potential for change should not be taken lightly. In particular, the potential for climate change to interact and strengthen existing stresses within the region must be seriously considered when making policy decisions that will affect the future environment, economy and welfare of the U.S. Midwest." (Webbles and Hayhoe, 2003)

As climate change assertions have become more widely accepted and the evidence of climate change has become more apparent, natural resources managers are asking the questions "How will climate change impact our natural systems on a regional scale?" and "Should we be adapting our approach to resource management?" For this reason, it is important to look to the state of the knowledge of climate science to see how climate change trends may affect the way that the Ramsey Washington Metro Watershed District (District) pursues it goals and tries to realize its vision for the future. The purpose of this report is to present a literature review of recent climate change information and to suggest ways in which the District can best follow and manage the changes that it sees within its water resources in the coming years.

2.0 Recommendations for Considering Climate Change in RWMWD Management Decisions

The District's vision is that "Water resources and related ecosystems are managed to sustain their long-term health and integrity and to enable them to contribute to the well-being of the citizens within the watershed". The District's goals are to promote quality surface water, achieve healthy ecosystems, provide for flood control, sustain quality groundwater, educate and involve citizens and to manage their organization effectively.

At present, there is no single best procedure for considering climate change in these management goals. Future conditions in the District are uncertain, due not only to the uncertainty of greenhouse gas emissions and climate system responses, but also due to the natural fluctuations that the climate experiences over time. Regardless, it is clear that climate change has the potential to amplify issues already faced by the District.

The current body of available climate change information suggests that some of the District's current efforts will become even more important in the context of climate change.

- Monitoring and managing lake water quality
- Monitoring and managing invasive macrophyte species
- Monitoring and, where appropriate, managing sediment release of phosphorus from lake sediments
- Implementing the volume reduction rule (as it is currently defined) in areas of redevelopment.
- Implementing low-impact development strategies throughout the District, thereby increasing the watershed's resilience against high runoff events through water retention

In light of the literature review presented in this report, a few additional recommendations are included below.

2.1 Monitor Wetland Water Levels

The District conducts biological monitoring of its wetlands through the Natural Resources Program. This program will play an important role in observing changes in wetlands in response to climate or other changes in the watershed. Because wetlands are considered especially vulnerable to the threat of climate change, the District should consider monitoring water levels in its wetlands.

Watch for the updates to NOAA's TP40 Precipitation Frequency Data to better define existing precipitation conditions in Minnesota for design purposes.

NOAA's Technical Paper 40 (TP40) is used extensively to define the amounts of precipitation that are expected in areas across the U.S. for different recurrence interval storms. An update to this data is currently underway which will incorporate significantly longer and more detailed precipitation records. New TP40 information for some states is already available online. Minnesota's TP40 update, however, is still in process. The status of TP40 updates across the United States can be found at: http://hdsc.nws.noaa.gov/hdsc/pfds/index.html.

The update will result in changes to the precipitation amounts that are assigned to different storm recurrence intervals for the District's design purposes. For example, the precipitation depth defined for the 100-year, 24 hour storm is 6.0 inches for the Twin Cities Metro Area, according to the 1961 version of TP40. It is expected that the precipitation depth for this storm will be higher with the updated TP40.

It should be noted, however, that some local researchers at the University of Minnesota are concerned that the methods used to create the data in TP40 may underestimate the true potential for heavy precipitation. Recent research by Blumenfeld et al (2004) indicates that the data and methodology used in the 1961 edition of TP40 produced precipitation design values that were valid at the time, but that are probably now too low. In fact, the 1961 TP40 amount for the 100-year, 24 hour storm may underestimate the storm's intensity by as much as 15 to 20% for today's conditions (Richard Skaggs, 2009).

Once the updates to TP40 are published, it will be important to communicate with the state climatology office to discuss whether these new values truly represent appropriate precipitation frequencies for the District's planning purposes. Once new precipitation amounts are defined, the District's hydraulic models should be re-run for flood-prone areas to evaluate whether further management efforts are needed.

Investigate tools for incorporating projected changes to climate data into the District's hydrologic, hydraulic, and water quality models to better define future conditions in Minnesota.

Currently, there is not a straightforward way to incorporate the potential future effects of climate change into the District's hydrologic, hydraulic, and water quality models. Estimates for future greenhouse gas emissions result in a wide range of future precipitation and temperature conditions for the District. However, District staff should periodically check in with University of Minnesota researchers regarding local (metro-area) predictions for climate change and modeling inputs that could be eventually be used in RWMWD's existing XP-SWMM and P8 models.

Also, District staff could investigate whether the Climate Assessment Tool (CAT) element of the BASINS modeling program would be appropriate for use in RWMWD's existing models. EPA intends to promote the use of the model and provide training to EPA, state and tribal program staff on how to use the model to support assessment of climate-related water resources impacts and program decisions.

Lastly, until there is better guidance from EPA on how to incorporate climate change into the TMDL process, it will be important (at the very least) to choose critical water quality years within recent history (ideally within the past 10 years) when pursuing SLMP and TMDL projects. It will also be important to evaluate both the overall precipitation amount and the various precipitation intensities over recent water years when choosing critical conditions for the purposes of modeling the effects of management scenarios.

It is, however, important to realize that the water quality and hydrologic conditions seen in the District's history may no longer be indicative of those in its future, especially when looking back more than 20 years. As USGS and NOAA scientists asserted in a recent Science article (February 6, 2008): "The idea that natural systems fluctuate within an unchanging envelope of variability, is dead and should no longer serve as a central, default assumption in water resource risk assessment and planning". Until we can better define the future conditions in the District, it will be best to look only to the recent past as a reference for management decisions, keeping in mind the general trends expected for the future.

The bottom line may best be expressed with this excerpt from The European Commission's guidance for river basin management in a changing climate, (Wilby and Miller, 2009):

- *Recognize that climate variability and change are among many factors affecting water bodies so concurrent environmental, meteorological, and biological* ***monitoring*** *are needed to better interpret long-term changes in water quality and ecological status.*

- *Apply an integrated approach to* ***risk assessment*** *of pressures arising from the direct impacts of climate change, as well as from autonomous and/or anticipatory measures taken by others to manage non-climatic pressures, mitigate or adapt to climate change.*

- *Favor* ***options that are resilient*** *to a wide range of possible climate change because there is a limit to the extent to which investment decisions can be led by highly uncertain regional climate projections.*

- *Maximize opportunities for* ***shared delivery*** *of adaptation measures through planning liaison with other groups, stakeholder consultation and regional spatial strategies.*

- *Develop* ***communication strategies*** *to convey the need for action, to improve conditions for sharing experiences at all levels of a business (including external liaison) and showcase integrated adaptation using demonstration field projects and pilot schemes.*

3.0 Literature Review

More than ever, global climate change is in the news. The recent United Nations Climate Change Conference in Copenhagen was charged with politics and massive demonstrations as nations sought a way to reduce greenhouse gas emissions throughout the world. The U.S. Environmental Protection Agency also recently announced two distinct findings that greenhouse gases (GHGs) threaten the public health and welfare of the American people, and that GHG emissions from new motor vehicles and new motor vehicle engines contribute to that threat. Both statements are significant in that they open the door to potential greenhouse gas emission reduction regulations in the future.

A review of current literature on the subject of climate change should include mention of the recent "climategate" headlines. Thousands of hacked emails from the University of East Anglia Climate Research Unit suggest that some data supplied to the Intergovernmental Panel on Climate Change (IPCC) may have excluded data that did not support favored hypotheses. Addressing this scandal on his "WeatherTalk" newsletter on Friday, December 11, 2009, Mark Seeley (University of Minnesota Extension, Department of Soil, Air and Climate) said that the news "exposes poor judgment and behavior on the part of some of the most visible and outspoken climate scientists". However, he also asserts that "'Climategate'… does not negate the hundreds, if not thousands of published studies that document climate change and its significance... In the context of the 'body of evidence' used to conclude that climate change is happening and that the human fingerprint is upon it, 'climategate' does not negate the science that has been done. It is too voluminous, diverse, and significant to ignore."

Mr. Seeley offers the following pieces of evidence to support the climate change hypotheses seen in the news today:

- Nearly all of the world's climate data, gathered and analyzed by many experts (not just those at University of East Anglia) shows significant climate change is going on, especially at mid to high latitude positions on Earth.

- The climate models all mimic the measured climate attributes of the Earth system more accurately if they parameterize the human impacts (land use change and anthropogenic emissions). Driven only by physical and natural parameters which have affected the Earth's climate behavior for over 4 billion years (solar radiation, orbital features, ocean currents, arctic ice, etc), the models do not fit the measurements very well.

- Observations of the physical and biological changes and consequences around us (lakes, terrestrial ecosystems, storm patterns, wildlife behaviors) are consistent with the measured and estimated climate changes that scientists have documented.

Table 1 offers a general, nationwide look at the changes observed in the United States' climate over the last 100 years.

Table 1 **Contemporary changes of the hydrological cycle over the conterminous United States, where ↑ and ↓ indicate increases and decreases, respectively. Source: Groisman et al (2003).**

Changes in the twentiethcentury :		**Additional changes in the past 50 yr:**	
Mean precipitation	↑		
Min temperature	↑	Spring max temperature	↑
Mean streamflow	↑	Spring snow cover in the west	↓
Heavy and very heavy rains in the east	↑	Cloudiness (total, low, Cb)	↑
High streamflow events in the east	↑	Near-surface humidity	↑
Wet conditions in the Mississippi River basin	↑	Evaporation	↑
Dry conditions in the Southwest	↑	Near-surface wind speed	↓

4.0 Observed and Predicted Midwest Temperature and Precipitation Patterns

Although the projections for global temperature changes vary in range and magnitude across different climate models, the assertion of increasing global temperatures has been well documented. However, the impact of increasing global temperatures on precipitation patterns is much more complex and difficult to predict.

According to the U.S. Global Change Research Program (www.globalchange.gov), the observed changes in the Midwest's climate can be summarized as follows.

> *"Average temperatures in the Midwest have risen in recent decades, with the largest increases in winter. The length of the frost-free or growing season has been extended by one week, mainly due to earlier dates for the last spring frost. Heavy downpours are now twice as frequent as they were a century ago. Both summer and winter precipitation has been above average for the last three decades, the wettest period in a century. The Midwest has experienced two record-breaking floods in the past 15 years. There has also been a decrease in lake ice, including on the Great Lakes. Since the 1980s, large heat waves have become more frequent than any time in the last century, other than the Dust Bowl years of the 1930s. The observed patterns of temperature increases and precipitation changes are projected to continue, with larger changes expected under higher emissions scenarios."*

Many researchers have recently focused their efforts on defining climate change in the Midwest, both in terms of existing trends in observed data from the 19th and 20th centuries and in terms of projected changes expected for the 21st century. A summary of some of the most recent research on Midwest climate change is presented in this report. Many, many papers have been published on this subject. The references listed at the end of this memo represent just a small sampling of the body of work that is available. However, the research presented here is generally representative of the findings of other researchers in the field.

4.1 Observed Trends in Temperature

Jim Zandlo, Minnesota State Climatologist, shared the following information in a website entry titled "Observing the Climate" (March 13, 2008). The State Climatology Office manages a great deal of climate data for Minnesota, with some of it dating as far back as 1819. Figure 1 shows the annual average temperatures in northern and southern Minnesota from 1891 to 2007.

As shown in Figure 1, over the period 1891 to the early 1980s, Minnesota's average annual temperature essentially did not change (the change of 1.1 to 1.6 degrees per century is consistent with larger-scale changes depicted by many analysts). However, rates of change dramatically increased during the most recent 20 to 30 years (5.5 degrees per century in the south and 7.2 degrees per century in the north).

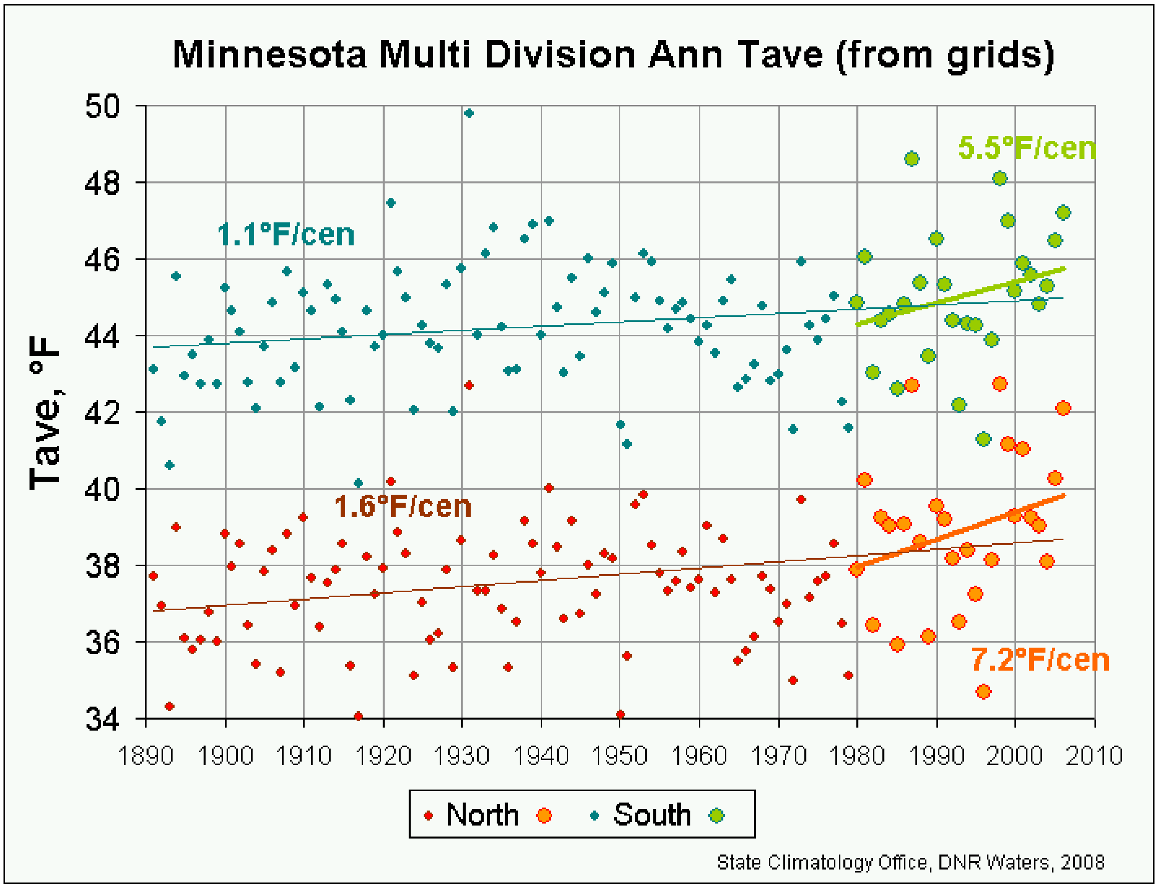


Figure 1 **Annual Average Temperatures in Northern and Southern Minnesota 1891 to 2007. Source: State Climatology Office, DNR Waters, 2008**

Figure 2 shows a different way of looking at this data - comparing the average temperatures seen throughout the state during the last decade to the "normal" temperatures observed throughout the state from 1970 to 2000. This figure indicates that over the last decade, the District has generally been two to three degrees warmer, on average, than it was over the last 30 years.

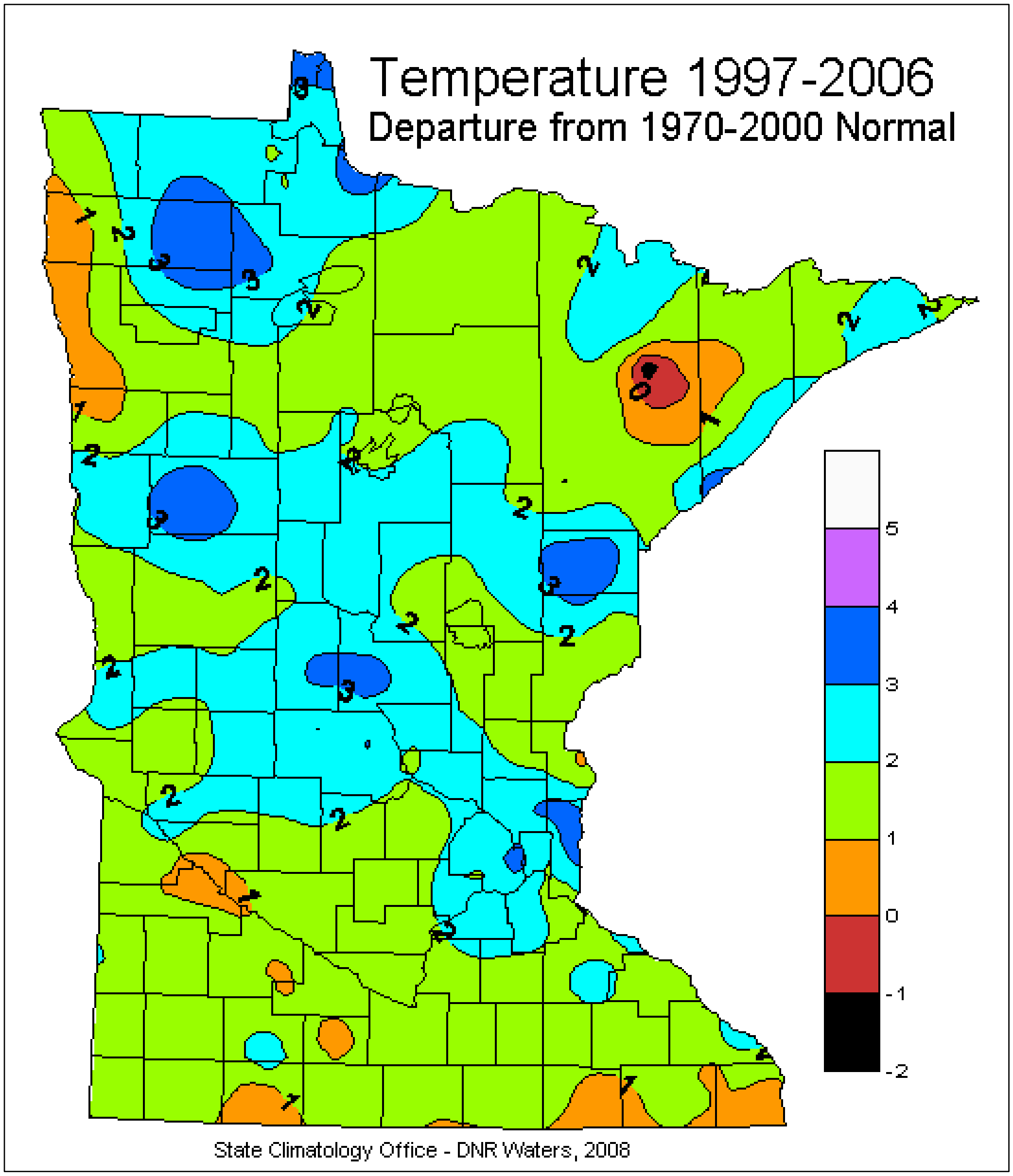


Figure 2 Annual average temperature over the last decade: departure from 1970 to 2000 normal. Source: State Climatology Office, DNR Waters, 2008.

In terms of seasonal fluctuations in temperature, the following trends have been observed:

- Minimum or 'overnight low' temperatures have been rising faster than the maximum temperature. (Zandlo, 2008), (Seeley, 2009), (Grossman et al, 2003)
- Winter temperatures have been rising about twice as fast as annual average temperatures. (Zandlo, 2008), (Grossman et al, 2003), (Johnson, 2009)
- Because the winter and minimum temperature trends are so large, trends in annual temperature will tend to be dominated by trends in winter and minimum temperature (Zandlo, 2008)
- There has been a 16% decrease (over the last 50 years) in March snow cover extent due to increased temperatures (Groisman et al, 2001)
- Minnesota has been experiencing earlier ice-out dates. Already, the ice-out date in the Twin Cities metro area is approximately five days earlier when comparing 1938 to 1972 and 1973 to 2007 periods.

In response to this data, Jim Zandlo says: “The most recent 2 to 3 decades of Minnesota climate have exhibited substantial changes that are consistent with warming and moistening and that are coherent. That said, the current values of many of the indicators have been at similar values in the observational past, namely, about 100 years ago. It seems very plausible that different agents were at play then and now. The current condition is no doubt an amalgamation of more than one influence.”

4.2 Observed Trends in Precipitation

In general, precipitation records throughout the United States are characterized by much more spatial and temporal variability than temperature. Figure 3 shows the linear trends in annual precipitation across the Midwest over the 20th century (Groisman et al, 2001). Annual precipitation in the Twin Cities metro area increased roughly 20 to 30% from 1900 to 1998.

Generally, precipitation in Minnesota has been rising (though not uniformly) since the dust bowl years of the 1930s. Figure 4 shows that the state of Minnesota has received less than the median amount of annual precipitation, as recorded in the full 100+-year record, in only a few years since 1990.

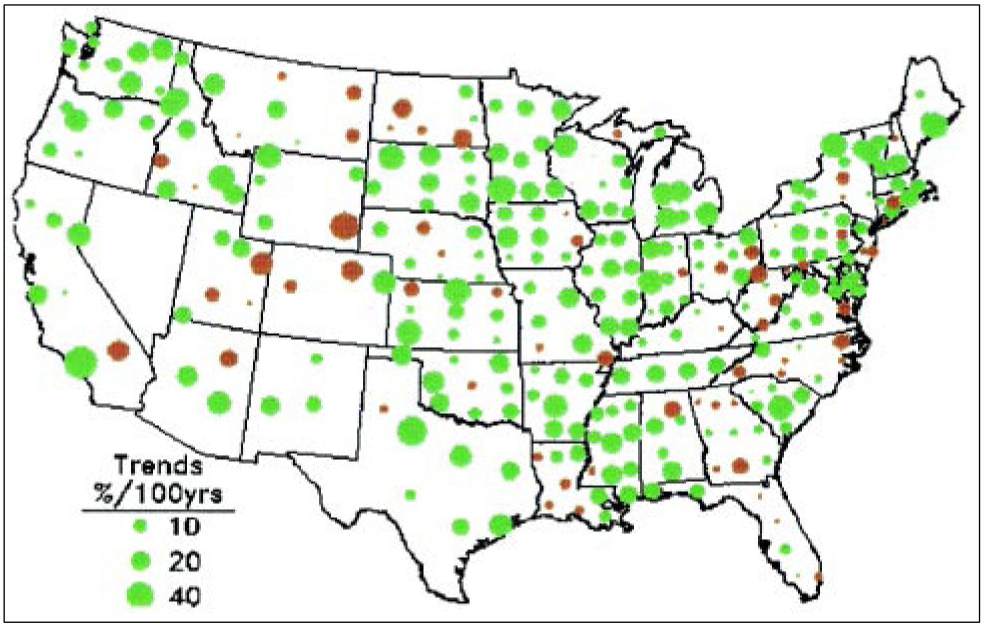


Figure 3 **Linear trends (%/100 yr) of annual precipitation (1900–98) over the contiguous United States (updated from Karl and Knight 1998).**

Individual trends from 1221 Historical Climatology Network stations (Easterling et al. 1996) have been area averaged inside the U.S. climatic divisions (Guttman and Quayle 1996). Green dots indicate increasing and brown dots decreasing trends. Source: Groisman et al, 2001.

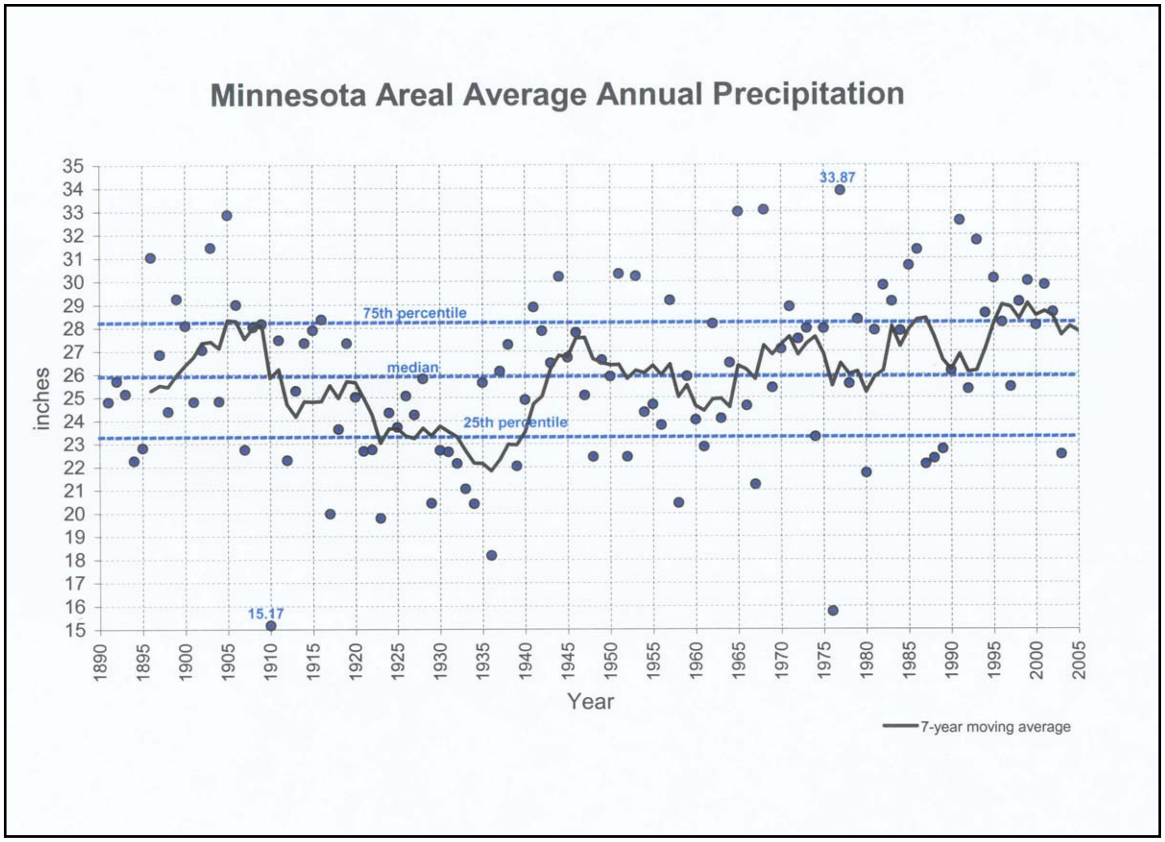


Figure 4 Minnesota-wide average annual precipitation from 1890 to 2004. Source: State Climatology Office, DNR Waters, 2008.

Research shows that the observed increase in annual precipitation in North America during the 20th century is due to an increased frequency of heavy to extreme precipitation events (Karl and Knight 1998). Groisman et al (2001) reported a 50% increase during the 20th century in the frequency of days with precipitation exceeding 101.6 mm (4 inches) in the upper Midwest.

In response to the question "Are larger precipitation events as portions of the total precipitation in a year changing?", the State Climatologist says: "Yes, the amount of precipitation occurring as large events has been increasing for decades but about 100 years ago that fraction was similar to or even higher than what it is today."

Kunkel (2002) also observed this, showing that the frequencies of extreme events were about as high around the turn of the 20th century as they were at the end of the 20th century. This early episode of high frequencies occurred at a time when anthropogenic forcing of the climate system was relatively small. This suggests that natural variability in the frequency of precipitation extremes is quite large on decadal time scales and cannot be discounted as the cause or one of the causes of the recent increases. However, with regard to the future, there are sound physical reasons to expect increases in extreme precipitation if and when significant warming occurs (Kunkel, 2003).

4.2 Projected Trends in Temperature

High variability in temperature makes it hard to predict long term temperature trends, and the assumption of greenhouse gas emission levels greatly affects temperature predictions in global climate models (GCMs). Annual air temperatures are projected to increase by an average of 2.9 to 4.7 degrees C by the late 21st century under three different models of greenhouse gas emissions in the Great Lakes region (Cherkauer and Sinha, in review). According to Dr. Lucinda Johnson of the Natural Resources Research Institute at the University of Minnesota-Duluth, a two to three degree increase in average daily temperature is now inevitable (due to the residence time of CO_2 in the atmosphere), even if greenhouse gas emissions are greatly reduced in the near future. Temperature increases will likely vary by season. Wuebbles and Hayhoe (2004) found that by the end of the century, regional temperatures may increase by one to seven degrees C in the winter and three to 11 degrees C in the summer.

If the projections are correct, Minnesota winters may be significantly different in the future. Wuebbles and Hayhoe (2003) also state that by 2090, the region may see 20 to 50 more days where the temperature exceeds 32 degrees C than found under current conditions and 40 to 75 less days where temperature falls below freezing. By the end of the 21st century, these changes could result in a shortening of the frost season in the Midwest by moving the date of autumn frost 35 days later and the date of last spring frost 15 to 35 days earlier.

4.3 Projected Trends in Precipitation

Groisman et al (2003) notes that not all precipitation trends that have been quantified for the past 50 or 100 years will continue. Furthermore, the global near-surface air temperature increase that has occurred in the past century is approaching levels not observed during the past several hundred years (Houghton et al. 2001), and that the effect of this increase on precipitation is difficult to predict in the extremely complex, non-linear climatic system of the earth.

Increases in the intensity and/or frequency of extreme flood-producing precipitation events is a plausible, though not certain, outcome of global warming. Indeed, the most recent assessment of the Intergovernmental Panel on Climate Change (IPCC) asserts that increases in North American extreme precipitation events are highly likely in the future as a result of climate forcing by increasing greenhouse gas concentrations (Kunkel, 2003).

For example, in a recent model of the Chicago area, rainfall events above 2.5 inches were projected to occur twice as often by the end of this century under a low emissions scenario and three times as often under a high emissions scenario. Similar increases are expected across the Midwest (USGCRP, 2009).

Increased frequency of intense precipitation events could lead to higher runoff and increased risk of flooding. Figure 5 shows model-predicted changes in annual runoff across the U.S. for the period 2041 to 2060 (relative to a 1900 to 1970 baseline). Minnesota's runoff would increase by 2 to 5 %, according to this model's prediction.

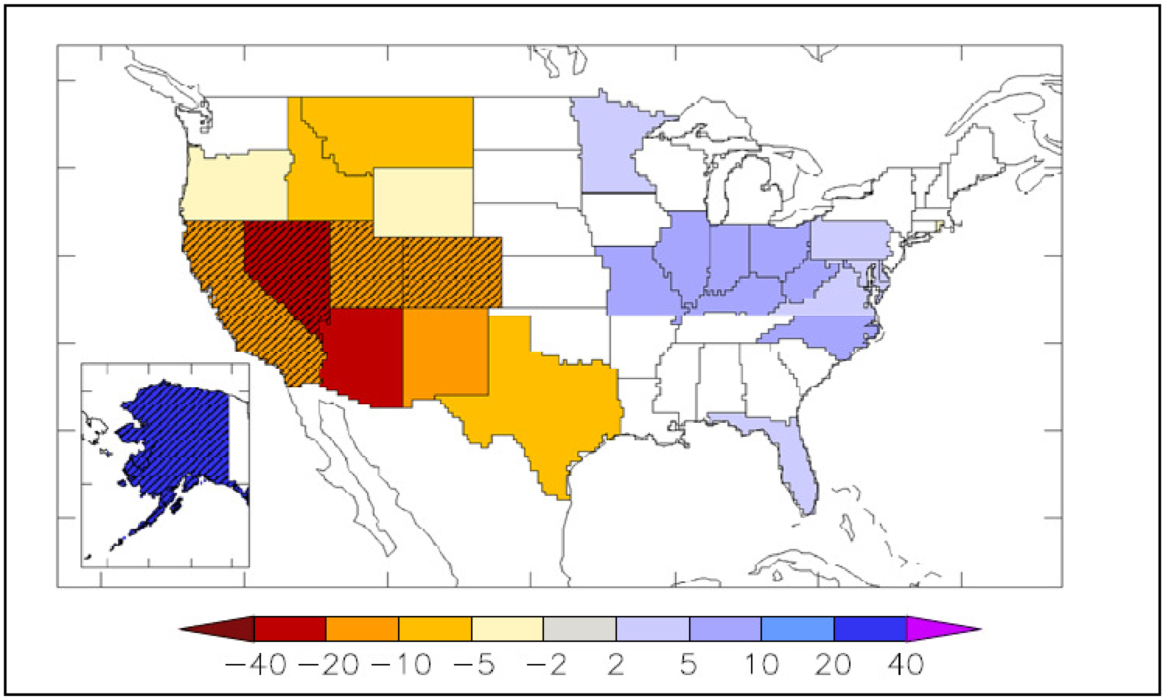


Figure 5 **Model-Projected Changes in Annual Runoff for U.S., 2041-2060.**
Percentage change relative to 1900-1970 baseline. Any color indicates that >66% of models agree on sign of change; diagonal hatching indicates >90% agreement. Source: Milly et al., 2005.

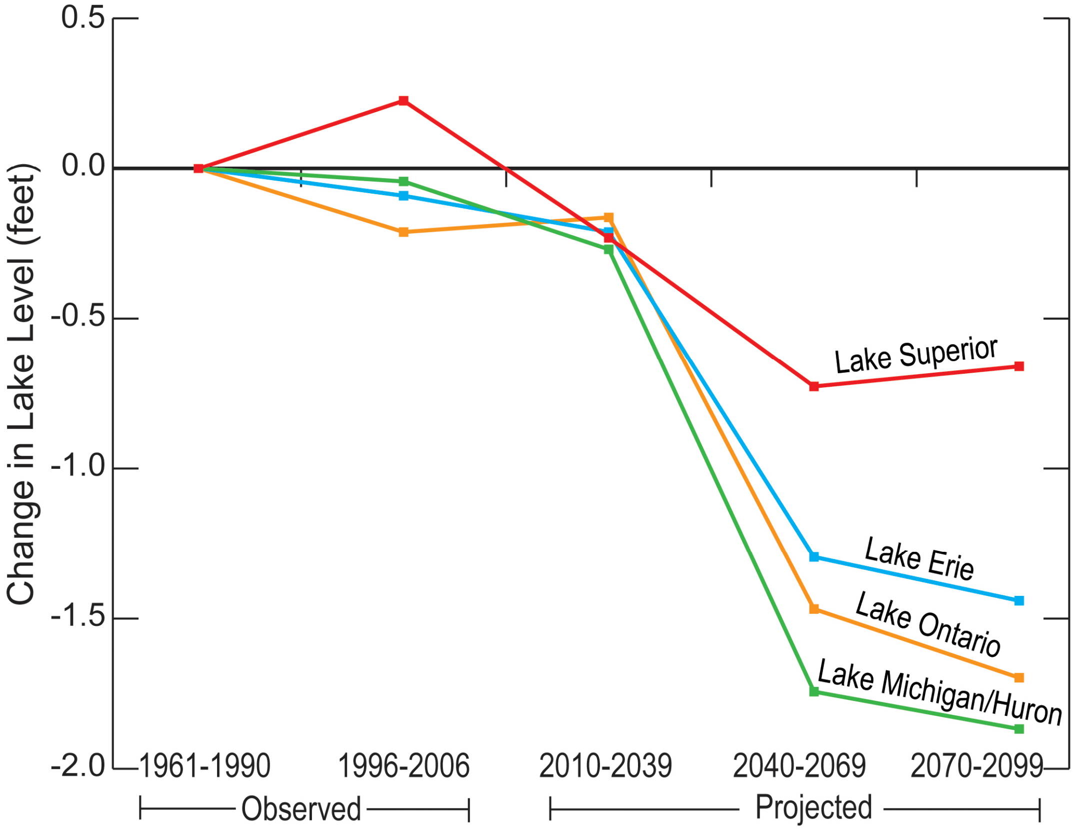
Changes to annual average precipitation in the Midwest could be as minor as 0 to 10% (Christiansen et al 2007) but many model projections indicate that there will be a shift in the seasonal distribution of the precipitation. Average winter precipitation across the region is likely to increase (up by 30% at the end of the century), while summer precipitation will likely remain the same or increase (Wuebbles and Hayhoe, 2004). Coupled with model projections of little net change in annual average precipitation but increased occurrence of precipitation intensity, this indicates that although rain may fall in more intense events, it may also fall less frequently, leaving drier periods between events and possibly increasing the risk of drought as well (Wuebbles and Hayhoe, 2003).

5.0 Projected Trends for Water Resources

Changes in the Midwest's temperature and precipitation could affect our water resources in many ways. In the winter, higher temperatures may result in shorter periods of ice cover and higher rates of evaporation, lowering water levels in lakes and wetlands. In the summer, with increasing evaporation rates and longer periods between rainfalls, the likelihood of drought may increase and water levels in rivers, streams, and wetlands are likely to decline. Lower summer water levels are also likely to reduce the recharge of groundwater, cause small streams to dry up (reducing native fish populations), and reduce the area of wetlands in the Midwest (USGCRP, 2009). An example of lowered lake levels (in the Great Lakes) as a result of climate change is shown in Figure 6.

If air temperatures increase, so will water temperatures. In some lakes, this may lead to an earlier and longer period in summer during which mixing of the relatively warm surface lake water with the colder water below is reduced. In such cases, this stratification can cut off oxygen from bottom layers, increasing the risk of oxygen-poor or oxygen-free "dead zones" that kill fish and other living things. In lakes with contaminated sediment, warmer water and low-oxygen conditions can more readily mobilize mercury and other persistent pollutants such as phosphorus (USGCRP, 2009 and IPCC, 2008). Because warmer waters support more production of algae, many lakes may become more eutrophic due to increased temperature alone, even if nutrient supply from the watershed remains unchanged (USGCRP, 2009).

Due in part to their limited capacity for adaptation, wetlands are considered among the most vulnerable ecosystems to climate change (IPCC 2008). According to the IPCC (2008), in North America's Prairie Pothole region, models have projected an increase in drought with a three degree C (5.4 degree F) regional temperature increase and varying changes in precipitation, leading to large losses of wetlands and to declines in the populations of waterfowl breeding there.



Hayhoe *et al.*[283]

Average Great Lakes levels depend on the balance between precipitation (and corresponding runoff) in the Great Lakes Basin on one hand and evaporation and outflow on the other. As a result, lower emissions scenarios[91] with less warming show less reduction in lake levels than higher emissions scenarios.[91] Projected changes in lake levels are based on simulations by the NOAA Great Lakes model for projected climate changes under a higher emissions scenario.[91]

Figure 6 Observed and Projected Changes in Great Lakes' lake levels. Source: USGCRP, 2009

The relationship between temperature, precipitation and streamflow is difficult to predict and varies widely from region to region. However, some recent regional models give some clues as to what can be expected. In a recent paper by Cherkauer and Sinha (in review), projected climate data, taken from the IPCC AR4, were downscaled and bias-corrected and applied to a hydrology model of the four states surrounding Lake Michigan. Winter and spring flows increased significantly by the late 21st century, but summer flows became more variable with a decrease in low-flows and an increase in peak flows. The number of days with flows above the annual mean flow decreased in summer, but flashiness increased. These results suggest that the diversity and density of stream biota in Midwestern stream habitats may be at risk (Konrad and Booth, 2005). Also, increased occurrence of low flows would lead to decreased contaminant dilution capacity, and thus higher pollutant concentrations, including pathogens (IPCC 2008).

Increased rainfall amounts and intensities would put a strain on stormwater management in several ways:

- Increases in heavy precipitation, coupled with expanding impervious surfaces, could increase urban flood risks and create additional design challenges and costs for stormwater management (EPA, 2008)
- Increased rainfall intensities indicate a potential need to redefine precipitation amounts for design recurrence intervals that would change stormwater infrastructure design.
- Increased rainfall amounts and intensities will lead to greater rates of erosion unless protection measures are taken (Kundzewicz et at 2007).
- Increased erosion and lake level fluctuation would create challenges for shoreline management.

Plants and animals living in our water resources will likely face increasing challenges:

- Native plant and animal species are very likely to face increasing threats from rapidly changing climate conditions, pests, diseases, and invasive species moving in from warmer regions (USGCRP, 2009).
- Higher lake and stream temperatures would likely affect fish and amphibian success, survival and spawning (Field et al, 2007) due to lowered water and oxygen levels.
- Potential reproductive failures in amphibians and fish and differential responses among species could alter aquatic community composition and nutrient flows (IPCC, 2008).

6.0 Modeling Climate Change on a Local Scale

Due to their immense computational burden, global climate models cannot supply information at the scales typically required for regional management decisions. Regional downscaling of global climate models involves the development of climate information for a point or small area (like the District) from global climate models. Until relatively recently, downscaling was mainly performed within research institutions. However, in recent years, there has been an increasing availability of user-friendly downscaling resources made available in certain parts of the world (Wilby and Miller, 2009).

Although this is an appealing prospect in terms of modeling the hydrologic and hydraulic changes that regional water resources could experience in the future, there have been relatively few examples of such activities. One reason for this is that using down-scaled climate model data does not eliminate the uncertainty in future regional climate projections. In fact, down-scaling adds new layers of uncertainty to model projections. Large uncertainties stemming from the choice of "host" climate model (for example, the degree to which the model can adequately simulate the behavior of the earth's climatic system and its response to forcing), difficulty in predicting future human behavior and its effect on anthropogenic emissions, choice of downscaling technique, downscaling predictor variables, and uncertainties in the regional impacts model all affect model outcomes (Wilby and Miller, 2009).

For these reasons, care must be taken to ensure that downscaled scenarios are applied appropriately. Specifically, regional downscaling is most justified when:

- There is strong consensus amongst different models about the rate and direction of the region's climate change
- A range of projected changes are modeled as a sensitivity study to test the robustness of management options

(Source: Wilby and Miller, 2009)

6.1 The Effect of Climate Change on Managing Impaired Waters through the EPA's TMDL Program

In March, 2008, the United States Environmental Protection Agency (EPA) National Water Program released a document entitled: *National Water Program Strategy: Response to Climate Change*. This document provides an overview of the likely effects of climate change on water resources and the nation's clean water and safe drinking water programs. The Response to Climate Change Document describes over 40 specific actions the National Water Program intends to take to adapt program implementation in light of climate change. A subset of the climate change impacts on water management programs cited in this document are as follows:

- Increased pollutant concentrations and lower dissolved oxygen levels may result in additional waterbodies not meeting water quality standards and, therefore, being listed as impaired waters requiring a total maximum daily load (TMDL)
- Discharge permits and nonpoint pollution control programs may need to be adjusted to reflect changing conditions
- States and EPA may need to consider the effects of changing air and water temperatures on water quality
- Increased water use would put stress on water infrastructure and demands on the clean water and drinking water State Revolving Funds
- Drinking water and wetlands managers may need to account for water losses due to increased evapotranspiration rates resulting from temperatures increases.
- Need to recognize the possibility of increased risk of high flow and velocity events due to intense storms as well as potential low flow periods
- Damage from intense storms may increase the demand for public infrastructure funding.
- In urban areas, stormwater collection and management systems may need to be redesigned to increase capacity.
- Greater use of biological monitoring and assessment techniques would help water resource managers assess system impacts of higher velocities from more intense storms and other climate change impacts.
- The demand for watershed management techniques that mitigate the impacts of intense storms and build resilience into water management through increased water retention (e.g. low impact development techniques) is likely to increase.

- The management of wetlands for stormwater control purposes and to buffer the impacts of intense storms will likely be increasingly important.

EPA expects that the number of waterbodies recognized as impaired is likely to increase, even if pollution levels remain stable (EPA, 2008). This is because warmer air temperatures result in warmer water, which holds less dissolved oxygen, making instances of low oxygen levels and hypoxia more likely to foster harmful algal blooms and change the toxicity of some pollutants. In addition, projected increases in more extreme water events and intense rainfall would result in more nutrients, pathogens, and toxins being washed into waterbodies (Zhang, 2009). EPA's National Water Program is planning to consider the long-range implications for waterbody impairment associated with climate change and to make needed revisions to TMDL guidance (Key Action #25 in the Response to Climate Change document).

Specifically, climate change affects the TMDL process in three important ways:

- Selection of critical condition in modeling for the TMDL report:

  The process of properly defining a waterway's critical conditions is one of the key challenges in developing a TMDL, particularly as such efforts increasingly attempt to account for planning condition under climate change context (Zhang, 2009).

- Margin of Safety :

  It is expected that climate change may add significant uncertainties to certain aspects of TMDL estimation, thus making rigorous uncertainty analysis even more valuable for the Margin of Safety (MOS) determination required by TMDL (Zhang, 2009).

- Selection of water quality standards by the MPCA

EPA recognizes that there are three principal responses to climate change with respect to defining water quality standards, as stated in the Response to Climate Change document (EPA, 2008):

Expanded efforts to meet current standards

"*Dischargers and watershed activities may need to change to reflect the increased degree of difficulty in meeting current standards, where those standards remain the appropriate targets and where they remain attainable. In these cases, program efforts will concentrate on ways to better implement actions to meet standards in an altered or changing climate*"

Modifying criteria to protect uses

"Some standards (i.e., pollutant-specific goals) may need to change to reflect more sensitive environmental conditions. In these cases, program efforts will concentrate on providing better recommendations that reflect necessary levels of protection in an altered or changing climate. For example, expected increases in sediment loads could be addressed with development of sediment criteria. Program efforts will also focus on ways to implement and meet these new recommendations."

Modifying designated uses

"Some designated uses and associated criteria may need to be removed and replaced with alternative uses and criteria where conditions have changed, or are anticipated to change, to the point that the current water quality standards are not appropriate or are not attainable. In these cases, program efforts will concentrate on providing the means to discern these situations and providing options and approaches for developing revised standards in an altered or changing climate."

7.0 Conclusion

At present, there is no single best procedure for considering climate change in the District's management goals. Future conditions in the District are uncertain, due not only to the uncertainty of greenhouse gas emissions and climate system responses, but also due to the natural fluctuations that the climate experiences over time. Regardless, it is clear that climate change has the potential to amplify issues already faced by the District. Ultimately, perhaps the most important tools that the District can employ in the face of an uncertain climate future are twofold--monitoring and adaptive management. These will be key to the District's success in understanding and managing its waterbodies in the coming years.

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