National Summit on Coping with Climate Change
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Background Paper for
WATER QUALITY SECTOR

"Opportunities to Anticipate and Adapt to the Effects of Climate Change on Water Quality"

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Opportunities to Anticipate and Adapt to the Effects of Climate Change on Water Quality

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Climate change is affecting the global water cycle. As the earth warms, the hydrologic cycle is intensifying, leading to changes in the amount, timing and distribution of precipitation. Also, it is leading to more extremes, such as intense storms and droughts. Combined with the direct effects of temperature on evapotranspiration and sea level rise, the availability and quality of water will be affected.

There has been considerable attention paid in the scientific literature to the implications of climate change for water quantity. But significantly less attention has been paid to the potential impacts on water quality. This has resulted in limited development of information and tools that can be used by water resource managers to understand, anticipate, and adapt to the risks and opportunities presented by a changing climate. In some cases, this lack of "decision support resources" may have serious repercussions since irreversible decisions are being made today (*e.g.,* about investments in expensive and long-lived infrastructure) that are not informed about the effects climate change will have on the effectiveness of the investments and the resulting environmental and human health outcomes.

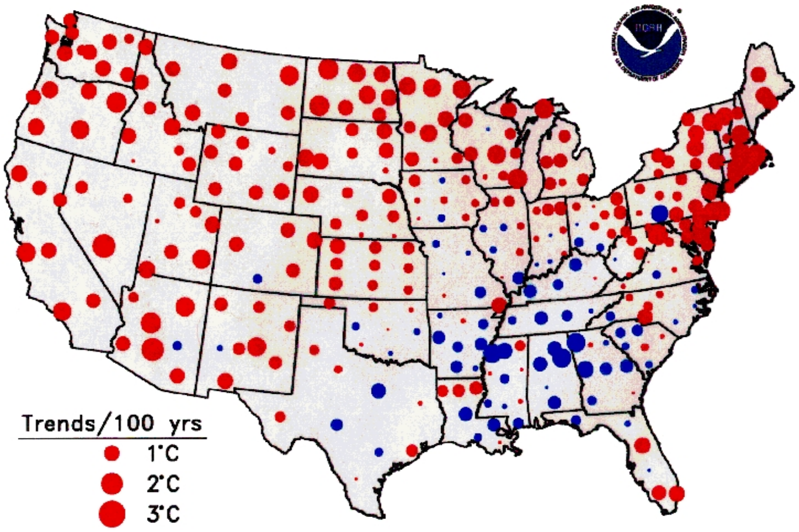
This paper presents an introduction to the potential effects of climate change on water quality, and the opportunities that exist for water resource managers to anticipate and adapt to a changing climate. The mechanisms by which climate change may affect water quality will be discussed. Water impacts will be divided into two broad categories that have distinct characteristics: impacts on infrastructure (*e.g.*, drinking water systems; combined sewer systems) and impacts on aquatic ecosystems (*e.g.*, increased runoff into rivers and streams). The nature of the impacts will be addressed. Finally, it will be demonstrated that sufficient scientific information already exists to develop practical, hands-on tools that enable water resources managers to incorporate climate change into their decision making to protect water quality and aquatic ecosystems.

Factors affecting water quality

Many factors can affect water quality. A wide range of human actions, particularly land-use patterns, can affect the quality of water in a particular location. But climate variability and change can also have a significant impact on water quality through changes in temperatures, rainfall and snowfall, storm intensity and runoff, the amount and timing of snowmelt, changes in the flows of rivers and streams, and the ability of watersheds to assimilate wastes and pollutants.

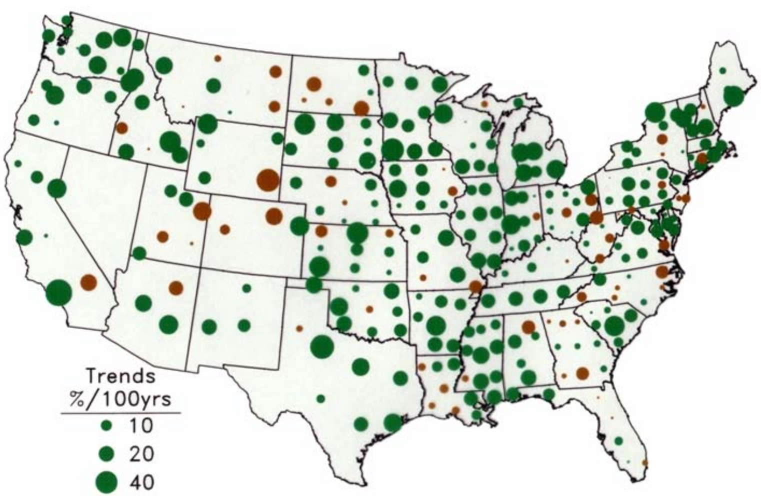
All of the climatic factors that can affect water quality have been changing. In fact, climate change is an ongoing process, and the climate has been changing for millions of years. Some of this change is due to natural causes, and some due to human influence on the earth's climate. But during the past century alone, we have seen temperatures and precipitation increase over many parts of the United States, and the frequency of intense precipitation events rise (Figures 1, 2 and 3).

Figure 1:
Temperature Trends, 1901-1998



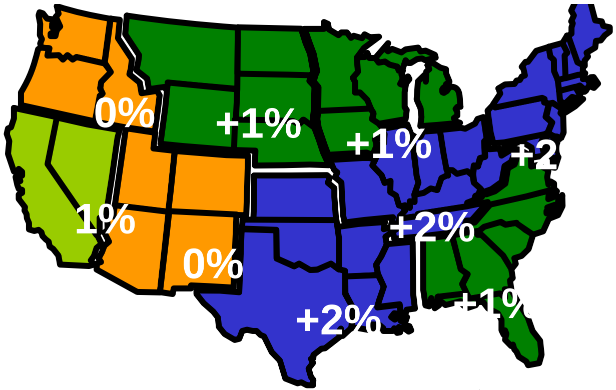
Red circles reflect warming
Blue circles reflect cooling
Source: NCDC/NESDIS/OAA

Figure 2:
Precipitation Trends, 1901-1998



Green circles reflect increases
Brown circles reflect decreases
Source: NCDC/NESDIS/NOAA

Figure 3:
Trends in Proportion of Annual Precipitation of Extreme Intensity (*i.e.*, more than 2" per day): 1910-1995



(Source: Karl and Knight, 1998)

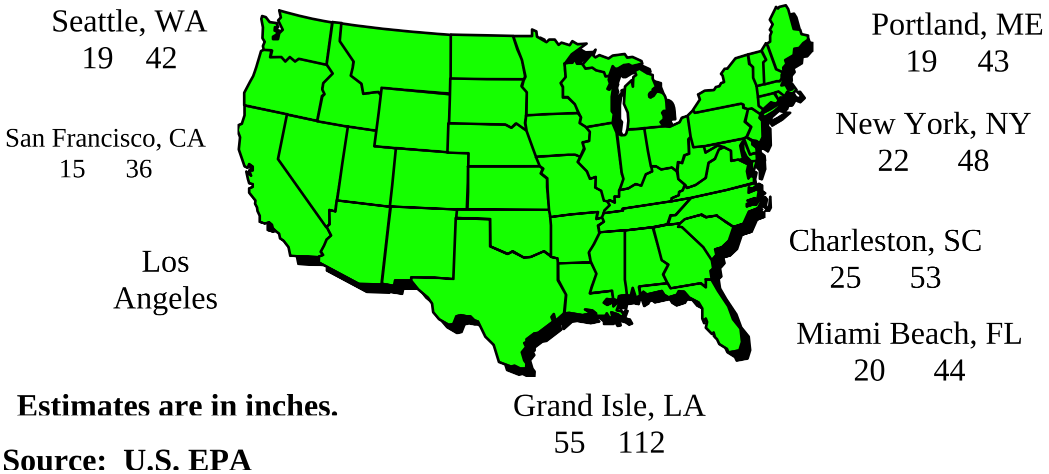
The challenge for anyone interested in understanding the implications of these changes for water quality is that the changes in climate vary by location. There is a regional texture to changes in climate, and therefore to the effects of climate change (Shriner and Street, 1997; Scheraga, 1998). There has been as much as a 3°C increase in average temperatures in some parts of the United States, such as North Dakota and

Oregon. But in other locations, such as Georgia and Mississippi, average temperatures have decreased as much as 3°C. There has been as much as a 20% increase in the mean level of precipitation in some parts of the country, such as the Susquehanna River Basin, the northeast, and New Mexico. But in other locations, such as California and Wyoming, the mean level of precipitation has decreased as much as 20%.

In the same way that there is a regional texture to ongoing climate change, there is a regional texture to the potential impacts of a changing climate. The human and ecological systems that are sensitive to climate change, and the degree to which they are vulnerable, will vary geographically. This variation must be considered as adaptive strategies are developed.

The other important factor affecting water quality is sea level rise. Sea level is projected to rise at an increasing rate along the U.S. coastline due to thermal expansion of the oceans and increased melting of glaciers (Figure 4). Again, there is a regional texture to the increase in sea level relative to the shoreline that will occur in any particular location. The rise in sea level may lead to intrusion of salt water further inland in rivers, deltas, and coastal aquifers, which could affect water quality and freshwater supplies in many coastal areas. Rises in sea level can also lead to more severe storm surges, which pose risks to human health, coastal ecosystems, and infrastructure.

Figure 4:
Regional 50% Probability Estimates
Of Sea Level Rise in 2100 and 2200



Estimates are in inches.

Source: U.S. EPA

Implications of Climate Change and Sea Level Rise to Water Quality

A. Impacts on aquatic ecosystems

Interactions between atmospheric, terrestrial, and aquatic processes in a watershed, as well as the human use of water resources, affect water quality. As the climate changes, temperature, precipitation, and the intensity of precipitation will change, along with flow volumes, rates and timing. Since aquatic ecosystems are highly vulnerable to these changes, climate change will present a significant risk of disruption to many water systems. Possible effects include increased occurrence of floods and droughts, water quality degradation, channel instability and habitat loss, and impacts on aquatic biota. These same systems will be affected by other stressors related to human activities, including (but not limited to) the operation of dams that trap sediment and nutrients, water withdrawals, waste disposal, and agricultural practices.

<u>The effects of changes in temperature</u>. Murdoch *et al.* (2000) produced an extensive review of the impact of climate change on water quality in North America. The results suggested that changes in air temperature can affect water quality (even if precipitation isn't altered) by affecting hydrologic factors and terrestrial factors that control water quality. The key hydrologic factor is increased water temperature.

As air temperature increases, water temperature in rivers, streams, lakes, reservoirs, and ground water are also expected to mirror that rise. Warmer water temperatures reduce dissolved oxygen concentrations, which are a critical aquatic ecosystem requirement. They can also lead to decreased volume of water for dilution of chemical inputs, increased concentration of nutrients and pollutants, and decreased ice cover, ice jam flooding, and depth of lake freezing. Changes in the rate of chemical reactions in the water column, sediment-water interface, and water-atmosphere interface are also expected.

Warming may also result in water temperature thresholds being reached for certain species. Breeding windows may be compressed or shifted. Similarly, other developmental responses that are cued by temperature could be affected. Although metabolism changes and growth rates of species are important possible effects, the more serious biological concern may be invasion by temperature-sensitive exotic species (*e.g.*, increased algal blooms).

Ground water discharge plays an important role in maintaining cooler water temperatures in streams. This cooling effect could be reduced as ground water temperatures are expected to warm with increases in air temperature. Cold-water fish could lose important habitat as temperatures rise above their thermal thresholds. Shading by riparian vegetation could offset this effect (*i.e.*, a possible adaptive response).

The key terrestrial factor is vegetation change, which can lead to species distribution changes, invasion by temperature-sensitive exotic species and pests, and soil change due to increased microbial processing rates in soils.

The combined effects of temperature and precipitation changes. The ultimate effects of any increases in air temperature will depends upon the changes in precipitation that occur. Temperature and precipitation have offsetting effects on water quality in aquatic ecosystems. The combined effects of temperature and precipitation will vary by location. Not surprisingly, when rising temperatures outweigh increased precipitation, the effects on water quality can be the largest.

When water flow changes, the effects of climate change can be complex and uncertain. On the one hand, more rain flow and resulting increases in flows of water in rivers and streams can reduce pollutant concentration. At the same time, it can increase erosion of land surfaces and stream channels, leading to more sediment, and chemical and nutrient loadings. On the other hand, less rainfall and resulting decreases in flows of water in rivers and streams could reduce dissolved oxygen in the water, reduce the dilution of pollutants, reduce erosion, and increase areas in the rivers that are warm.

The ambiguity of the combined effects of temperature and precipitation changes means that site-specific analysis have to be done to determine the impacts of climate change on a particular watershed. Impacts are site specific. This makes the development of decision-support tools for water resource managers challenging. Unless resources are available to develop watershed-specific decision-support tools, developers must devise tools that are flexible enough to account for the unique characteristics of most watersheds and water systems.

The effects of higher intensity precipitation events. Future changes in climate will likely continue to increase the intensity of precipitation events. As precipitation intensity increases, delivery of sediment, sediment-attached pollutants (*e.g.*, phosphorous, ammonium, and pesticides), and soluble pollutants (*e.g.*, nitrates, phosphorous, and pesticides) to water bodies increases. Precipitation intensity has a greater effect on soil erosion than an increase in the frequency of precipitation events. With more intense precipitation events, more pollutants reach watercourses directly and rapidly through surface transport than subsurface (ground water) flow. Soil type, slope, and vegetation cover influence how changes in precipitation intensity and frequency affect soil erosion and runoff. In agricultural areas, the timing of planting, harvesting, tillage practices, and nutrient and pesticide applications interact and lead to different vulnerabilities for soil erosion during the seasons. Spring can be a high runoff and pollutant-loading period because fertilizer and pesticide application combine with little vegetative cover to increase vulnerability. Episodic water quality problems increase in a changing climate.

Implications for water quality goals. Aside from its direct effects on hydrology, climate change may also affect water quality and the cost of environmental protection. In the United States, discharge limits for large point sources of pollution are generally based on the U.S. EPA’s evaluation of water treatment technology – in the parlance of the Clean Water Act, the “best available technology” economically achievable. Hundreds of streams, rivers and lakes do not meet water quality standards even though most large point sources are already complying with these discharge limits. In such cases, more stringent limits – total maximum daily loads (TMDLs) – must be developed for all the pollutant sources within an impaired water body's watershed. For the point sources, increasing their treatment efficiency to meet TMDLs can be an expensive proposition, and climate change may have the effect of increasing the costs of treatment to meet water quality goals.

Flow in the water body is one of the key determinants in setting TMDLs. In the same way that floods (high flow conditions) can be characterized in terms of recurrence interval (*e.g.*, the 100-year flood), so can low flow conditions. Water quality planners use the 10-year recurrence interval low flow (averaged over a seven-day period) as the "design flow," *i.e.*, the basis for determining how much pollutant a water body can receive without exceeding a water quality standard. The lower the flow, the more stringent the TMDL. Some simulations of climate change indicate that precipitation patterns are likely to shift and evapotranspiration increases such that drier periods will become more common. This would lead to a shift in flow patterns; for a given stream, the 10-year recurrence interval low flow would become lower than it is now, and TMDLs would need to be more stringent.

A study recently released by the U.S. EPA (2006a) examined the potential impacts of climate change on the costs of implementing water quality-based effluent limits at publicly-owned treatment works (POTWs) in the Great Lakes Region. POTWs discharge billions of gallons of effluent daily to receiving water bodies through the U.S. One of the principal pollutants associated with POTW effluent is organic matter. Naturally occurring microbial populations in receiving waters consume dissolved oxygen (DO) as they decompose organic matter. Low DO is a significant problem for aquatic ecosystems and is a leading cause of impairment for water bodies listed under Section 303(d) of the Clean Water Act.

The design characteristics of POTWs are directly tied to hydroclimatological metrics such as daily precipitation and receiving water low-flow conditions. Generally, these systems are designed to handle storm or flow events of a given intensity, duration, and frequency, and there is an implicit assumption that precipitation and flow are constant over time. Potential changes in climate could reduce low-flow conditions in receiving waters, reducing the dilution of effluent, and increasing the likelihood of DO impairment below POTW discharge locations.

The EPA study characterized the scope and magnitude of climate change impacts on operating costs at POTWs discharging to rivers and streams in the Great Lakes Region. The study focused on 147 POTWs identified as discharging to impaired receiving waters in the region.

The results indicated that climate change would increase the incremental cost of implementing water quality based effluent limits (WQBELs) summed across all 147 POTWs by an additional \$8 million to \$97 million per year over the current cost of implementing WQBELs. This is equivalent to an average annual cost increase of \$54,000 to \$660,000 per facility over the current cost of implementing WQBELs.

These results suggest that climate change could have a significant effect on two of EPA's most important water programs – National Pollutant Discharge Elimination System (NPDES) permitting and POTW financing through the State Revolving Fund. Given the limited scope of this initial EPA analysis (*e.g.*, it looked only at one pollutant, one region, and only included POTWs discharging to impaired streams), it is likely that the cost estimates do not reflect the full scope of climate change impacts on WQBEL implementation.

B. Impacts on infrastructure

Climate change and sea level rise pose risks to infrastructure that is tied to the protection of water quality (*e.g.*, POTWs). In many cases, investments are being made today to redesign and rebuild this infrastructure. Given the long lifetimes of the infrastructure once it is built, resource managers want to ensure that the design of any infrastructure whose performance is sensitive to climate adequately accounts for the future effects of climate change. Otherwise, the future performance of the infrastructure may not be as effective as anticipate at the time it is redesign and rebuilt.

To illustrate this point, two cases studies are presented. The first focuses on the implications of climate change for combined sewer systems; the second focuses on the potential impacts of sea level rise and salt water intrusion on drinking water systems that derive their supplies from surface water.

Combined sewer systems

Aging combined sewer systems (CSS) in the United States are being redesigned to comply with the EPA's Combined Sewer Overflow (CSO) Control Policy (EPA 1994).[1] Billions of dollars will soon be invested in the rebuilding of CSSs in the United States.

There are combined sewer systems in about 770 communities serving approximately 40 million people across the United States (EPA 2006c). Communities in the Great Lakes Region contain 182 CSSs, which are generally found in older cities and towns (Figure 5).[2] CSSs were among the earliest sewers built in the United States and continued to be built until the middle of the twentieth century. These systems collect and co-treat storm water and municipal water, and are designed to overflow directly to surface waters when their design capacity is exceeded. During intense storms, the

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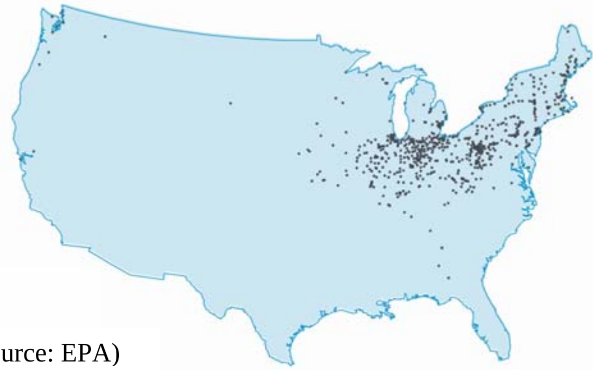
[1] The EPA Control Policy established a consistent national approach for controlling discharges from CSOs to the Nation's waters through the National Pollutant Discharge Elimination System (NPDES) permit program.

[2] The number of CSS communities by State are: Indiana – 24; Illinois – 34; Michigan - 46; Minnesota -3; New York – 23; Ohio – 47; Pennsylvania -3; and Wisconsin – 2.

capacity of combined sewer systems can be exceeded, resulting in the discharge of untreated storm water and waste water into receiving streams.

Figure 5:
Combined Sewer System Communities



(Source: EPA)

Some CSSs overflow infrequently; others, with every precipitation event. But national projections of annual CSO discharges of untreated sewage and storm water are estimated at 1,260 billion gallons per year (EPA 2001).

It will be expensive to redesign the CSSs. It is estimated (EPA 2001) that $44.7 billion (in 1996 dollars) in future investments will be needed to control CSOs. Given the magnitude of this investment, city planners want to ensure that the redesigned systems attain their desired performance levels even as the climate changes. Once the systems are rebuilt, they will have long lifetimes --on the order of 100 years – and will be costly to retrofit.

The problem is that climate change is already leading to an increase in the proportion of intense rainfall events (Figure 3). This trend is expected to continue as the Earth warms and the hydrologic cycle intensifies, and these intense rainfall events can cause CSSs to overflow. The question facing city planners is whether or not climate change will reduce the likelihood that the redesigned CSSs will satisfy EPA's Control Policies if they are rebuilt without the potential effects of climate change factored into the system designs.

Answering this question is a complex problem because the potential implications of climate change for CSO events in cities across the country are site-specific. Whether or not climate change will lead to an increase in the frequency of CSO events depends upon the particular city and Combined Sewer System under consideration, and the expected climate at that location.

Given the high number of CSSs in the Great Lakes Region, EPA's Global Change Research Program conducted an assessment of the potential impacts of climate change on

CSOs in the Great Lakes Region (EPA 2006b). The assessment framed the problem in the following way: Suppose each community in the Great Lakes Region redesigns their system to achieve an average of four CSO events per year (EPA's so-called "presumption approach" threshold). But also suppose that they base their new system design on *historical* precipitation data, and fail to consider potential changes in future climate. When the climate changes, how might CSO event frequency change, and in how many cases will the four CSO events per year threshold be exceeded? The purpose of this analysis was to inform city planners about the extent to which future climate change should be a concern as they redesign and rebuild their CSSs.

The first step in the analysis was to determine a "benchmark storm event" for each CSS community; that is, the largest storm event that will need to be captured by the redesigned CSS to meet the four-event-per-year average. This was done using historical precipitation data sets developed for the Vegetation-Ecosystem Modeling and Analysis Project (VEMAP). The second step was to project future storm events. In the VEMAP analysis, two GCMs were used to project future conditions: the Hadley Centre Model and the Canadian Climate Centre Model.[3,4]

The historical and projected precipitation data were analyzed using both a 1-day and a 4-day moving average. The moving average approach was used to bracket the effects of short intense storms, as well as longer storms or multiple precipitation events that may occur in sequence.

The historical precipitation data for the 40-year period, 1954-1993, were then compared to the projected precipitation data for the future 40-year period, 2060-2099, for each CSS community.

The assessment provided insights for the Great Lakes Region that were robust across both GCM models. Relative to an assumed four-event-per-year benchmark event, the average annual CSO frequency *across the entire* Great Lakes Region would increase between 13 percent (Canadian model, 1-day averaging period) and 70 percent (Hadley Centre model, 4-day averaging period). In other words, the *average* number of CSO events per year per CSS community would increase to 4.5 (from the 4-events standard) using the lower bound, and 7.1 (from the 4-events standard) using the upper bound. Across all 182 CSS communities and GCMs, this translates to about 237 events per year above the objectives of EPA's Control Policy. *There is, however, variation among CSS communities – further emphasizing the need to do site-specific studies.*[5]

The results of this "scoping" study that used GCM output provide important (and scientifically sound) insights to city planners:

1. Climate change will affect the future performance of many CSSs in communities throughout the Great Lakes Region. City planners need to ascertain the extent to

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[3] VEMAP documentation can be found at http://www.cgd.ucar.edu/vemap/index.html.

[4] Both GCMs provide projections on a grid with intervals of 1 degree latitude and longitude.

[5] The results for variations among CSS communities are presented in EPA 2006b.

which climate change poses a risk that redesigned systems in their own CSS communities will not be effective in meeting the Control Policy's threshold of no more than four CSO events per year.

2. In communities where climate change poses a risk, engineers should not base their calculations of system size (*e.g.*, storage capacity) on *current* hydrology and historic precipitation data.

3. In those communities where climate change may lead to exceedances above the objectives of EPA's Control Policy, city planners must decide whether to make the additional investments necessary to build in an additional margin of safety to ensure the future effectiveness of the new CSSs. This *policy* decision will partly depend upon the risk aversion of city planners; that is, the extent to which they are willing to accept the risk that they'll incur significant costs to retrofit or refurbish the redesigned CSSs in the future.

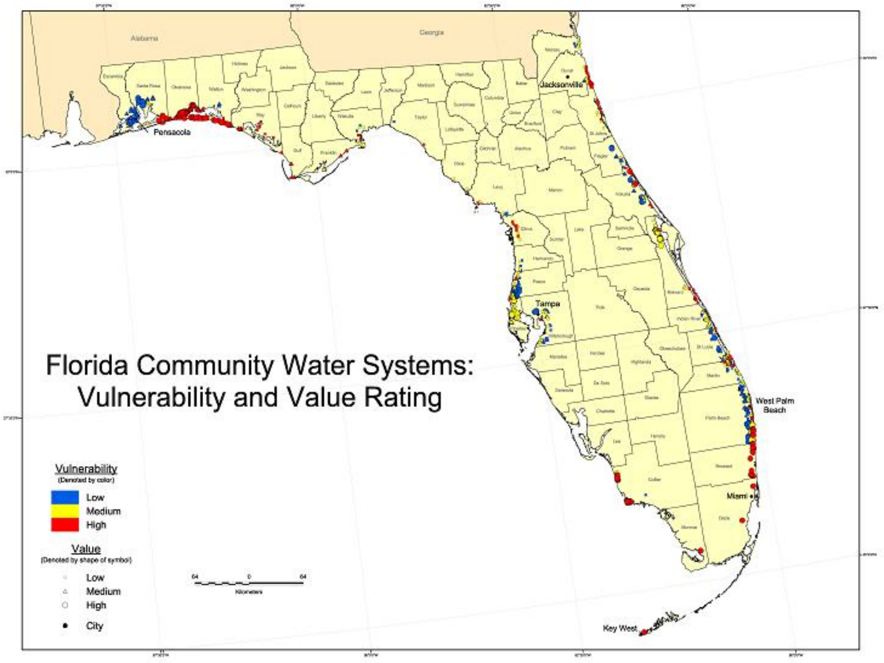
4. The risks posed by climate change to CSSs are manageable. It is possible to anticipate the effects of climate change on CSSs and to adapt their new designs to increase the likelihood that they'll be effective in the future. Once the city planners make a decision about the level of risk they are willing to incur, engineers can adjust the system designs accordingly to account for climate change.

Drinking water systems in coastal areas

Drinking water systems will, to varying degrees, be put at risk by sea level rise. These include systems that derive their supplies from surface water, and systems that derive their supplies from groundwater (Figure 6).

Furlow *et al.* (2002) conducted the first formal assessment of the sensitivity of drinking water systems that derive their water from surface water in coastal areas to sea level rise. The study focused on communities served by coastal *surface water* systems along the Gulf and Atlantic Coasts in the US, where most of the country's low-lying areas vulnerable to sea level rise are found.

Figure 6:
Groundwater Supplies in Florida Vulnerable to Sea Level Rise



(Source: U.S. EPA)

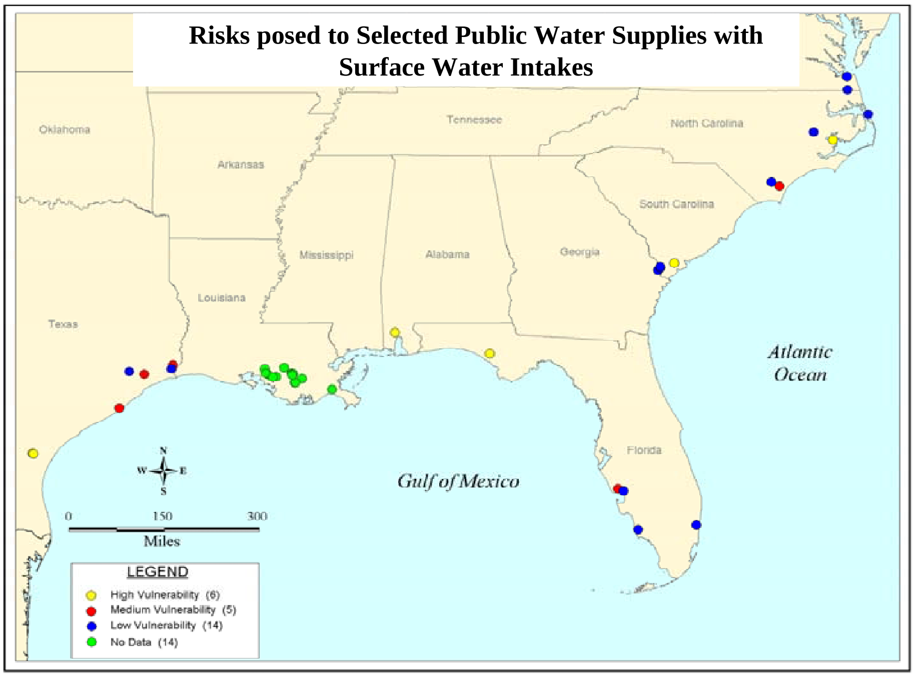
Data and resource limitations dictated that the study be limited to a scoping exercise that would evaluate the potential magnitude of the problem. The decision to initially focus on surface water systems was made because they typically serve larger populations than ground water systems (and thus have higher resource value).

Systems whose intakes are vulnerable to sea level rise were identified. A multi-stage screening process was developed and applied to a sample of about 500 systems. The screening analysis was designed to identify public water systems (PWSs) withdrawing water from tidal, freshwater reaches of rivers. Though these situations are not common, they represent systems vulnerable to sea level rise (as well as more frequent droughts, another possible effect of climate change) due to the potential for the intake water to become brackish.

Once the relevant PWSs were identified, the screening process followed several steps to determine which of the systems are truly at risk as sea level rises. First, all systems above the “fall line” were eliminated. The fall line is an imaginary line that forms a boundary where upland rivers drop to the coastal plain, forming waterfalls and related navigational barriers. It was assumed that a waterfall would pose a physical barrier to protect upstream intakes. Second, the remaining surface water intakes in low-lying areas were screened for those protected by a dam. Third, systems with intakes on the Mississippi River and its tributaries were eliminated, based on the assumption that the flow of the Mississippi is such that salt is not likely to intrude upstream, leaving systems along the river at low risk. Fourth, an indicator of risk due to sea level rise was found. It was decided that sites closest to brackish water would be the first to be affected by a migrating salt front, and an indicator of the proximity of brackish water to the remaining intakes was needed. Proximity to an estuarine wetland was used as a risk indicator for a public water system intake, since it was determined that intakes in an estuarine area might face salinity problems now, and ones in close proximity to an estuary might be at risk as sea level rises.

Six intakes appeared to be within an estuary. Nine intakes seemed to be within one kilometer of an estuary. Of these, five were on fresh water creeks or rivers that are separated from the estuary by land, and were designated as being at medium risk. Four more were in low-lying lakes or ponds, and were classified as having low risk to contamination from sea level rise. The remaining 10 intakes were classified as having low risk because they are more than one kilometer from the nearest estuarine wetland (Figure 7).

Figure 7



<u>Insights for policymakers</u>. Several million people are served by coastal surface water systems that are unprotected (by a dam or other structure) from sea-level rise. But the results of the screening analysis suggest that only five surface water systems serving over 100,000 people are at high risk of salt water intrusion.

The Furlow *et al.* (2002) assessment was important because it helped dispel the misconception that there is a widespread risk posed by sea level rise to drinking water systems that rely on surface water in coastal areas. Although work still needs to be done to examine possible ways that the communities at risk can adapt, the study suggests that it would be preferable to focus most further analyses (and scarce research dollars) on the implications of sea level rise for drinking water systems that rely on groundwater. Also, the results may help decision makers prioritize adaptation projects to ensure that the scarce resources available for adaptation are directed towards those investments that will have the highest payoff.

C. Implications for human health

Certain health outcomes are known to be associated with weather and/or climate, including: illnesses and deaths associated with temperature; extreme precipitation events; air pollution; water contamination; and diseases carried by mosquitoes, ticks, and rodents. Because human health is intricately bound to weather and the many complex natural systems it affects, it is possible that projected climate change will have measurable impacts, both beneficial and adverse, on human health. Projections of the extent and direction of potential impacts of climate variability and change on health are extremely difficult to make because of the many confounding and poorly understood factors associated with potential health outcomes, population vulnerability, and adaptation.

The effects that climate change has on water quality have potentially important implications for the spread of water-borne diseases, some food-borne diseases, and marine and coastal issues, including harmful algal blooms and ecological disruption. Changes in precipitation, temperature, humidity, salinity, and wind have a measurable effect on the quality of water used for drinking. Also, heavy rainfall has been associated with water-borne disease outbreaks throughout the United States. For example, changes in precipitation and runoff, combined with land use practices, have been known to affect the transport of the water-borne disease *Cryptosporidium*. The distribution of *Vibrio cholerae* is also known to be affected by El Nino frequency and intensity, temperature, and ocean salinity.

Although environmental regulations protect much of the U.S. population, current deficiencies in watershed protection and storm drainage systems can increase the risk of contamination events if rainfall increases with climate change. We’ve already seen, for example, how during periods of heavy rainfall, combined sewer systems can discharge excess wastewater directly into surface water bodies that may be used to provide public drinking water.

Adaptive strategies that could reduce the risks of water-borne diseases include:

- Improved surveillance for infectious diseases.
- Enhanced water systems and improved water systems engineering.
- Watershed protection policies.

- Enforceability of drinking water regulations.
- Water quality management approaches that foster continuous improvement and protection.

What can be done to protect water quality as the climate changes?

As illustrated in the combined sewer system study, many of the risks posed by climate change to water quality are manageable. But new tools need to be developed to help water resource managers, land-use planners, and other decision makers understand the implications of climate change for water quality. These tools must enable the users to assess the effects of climate change in the context of the other factors that affect water quality, including land use practices, agricultural practices, regulatory policies, and water uses that affect water withdrawals. And they must provide water resource managers with the ability to incorporate climate change into their decision making.

With tools like this in hand, water managers could begin to systematically reexamine engineering designs, operating rules, and water allocation policies under a wider range of climate conditions and extremes than has been used traditionally. And they could facilitate improved management of watersheds and the multiple stressors on water quality, including climate change.

Sufficient scientific information already exists to develop practical, hands-on tools that enable water resources managers to incorporate climate change into their decision making to protect water quality and aquatic ecosystems. To illustrate this point, I present EPA's newly-released BASINS Climate Assessment Tool for water resource managers.

EPA's BASINS Climate Assessment Tool

EPA's Global Change Research Program recognized the need to provide water resource managers with a better understanding of climate change impacts to improve their ability to meet future supply needs, comply with water quality regulations, and protect aquatic ecosystems. The Program developed a Climate Assessment Tool (CAT) that enables water resource managers and other stakeholders to incorporate considerations of climate change – along with the myriad other stressors with which they are concerned – into their decision-making processes. The CAT is embedded in EPA's BASINS modeling system. BASINS is a well-documented, widely distributed tool for decision support in watershed management. As such, it offered a unique platform upon which to develop a Climate Assessment Tool that would be useful to stakeholders concerned with climate change.

With the development of the CAT, resource managers now have a practical, hands-on tool to help them take the necessary steps to protect watersheds from the effects of climate variability and change. The tool can be applied to specific watersheds, because the BASINS system has the flexibility to account for the unique characteristics of most watersheds and water systems. And it can account for stressors such as land-use/land-cover change and point source loading together with climate.

The CAT facilitates the evaluation of potential adaptation strategies to increase the resilience of water systems to change. A key advantage of this tool is the capability it provides for the user to define a wide range of hydrologic and water quality endpoints (*e.g.*, 100-year flood events; annual nutrient load to a river), and to systematically assess the sensitivity of the user-defined endpoints to potential changes in climate.[6]

Users can evaluate how water resources could be affected by a range of potential changes in climate. For example, the tool can be used to determine the change in annual rainfall or timing of runoff that would need to occur for a reservoir operation plan to be revised. Also, the tool helps managers evaluate the effectiveness of different management practices for increasing the resilience of water resources to climate change. For example, it can be used to explore the future effectiveness of a state's proposed Total Maximum Daily Load (TMDL) implementation plan under different climate change scenarios. Combined with the other features of BASINS, the Climate Assessment Tool can also be used to explore the importance of climate-related impacts relative to the impacts of other stressors such as land cover change and pollutant discharges.

BASINS/CAT can be used to conduct *standard assessments* ("What would be the effect of climate change on X?") and *sensitivity analyses* ("What would we have to believe is true for X to happen?"). Sample applications of BASINS/CAT to conduct standard assessments include:

(1) an assessment of how increases in precipitation of 10%, 20%, 30%, etc. over historical conditions will influence non-point pollution loading to a stream;
(2) an assessment of the flooding that would be caused by an historical extreme weather event given recent increases in urban development within the watershed; and
(3) an assessment of the future effectiveness of a proposed TMDL implementation plan under a projected climate change scenario.

Sample applications of BASINS/CAT to conduct sensitivity assessments (which reverse the question to assess what type of change would need to occur for a valued system endpoint to be affected) include:

(1) determination of the change in annual precipitation or timing of runoff that would need to occur to require revision of a reservoir operation plan;
(2) determination of the change in precipitation event intensity that would need to occur to require revision of a TMDL implementation plan; and
(3) determination of the change in mean annual air temperature that would increase stream temperatures to the point where trout cannot survive and reproduce.

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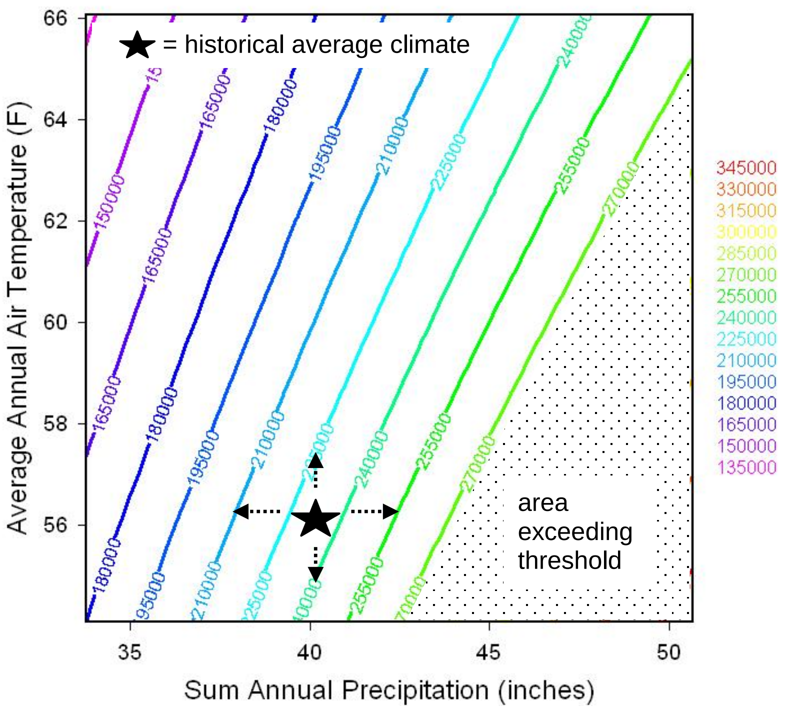
[6] BASINS/CAT has been officially released and is available on the internet with BASINS version 4 at http://www.epa.gov/waterscience/BASINS/

Figure 7:
BASINS/CAT Sensitivity Analysis of Annual Nitrogen Loading
to Changes in Temperature and Precipitation



The array of capabilities in the CAT helps water resource managers address the high sensitivity of water resources and aquatic ecosystems to changes in climate (*e.g.*, increased risk of floods and droughts, disruptions to the stability of river channels, water quality degradation, and loss of wildlife habitat). The CAT provides them with a capability to consider these risks as they strive to meet future demands for water, comply with water quality regulations, and protect aquatic ecosystems.

Conclusions

Climate change and sea level rise will have important implications for water quality. Aquatic ecosystems will be affected, along with the ecosystem services they provide. Infrastructure that is designed and built to protect water quality will also be affected, leading to changes in the water resources they are intended to protect.

Water resources managers must consider climate change in the context of all the other stressors (such as land use change) on water quality. Climate change may or may not be the most important stress on the water resources within the manager’s purview, but it must be considered in the manager’s decision making processes.

The challenges posed by climate change to water quality are often manageable problems. There are many opportunities to reduce the risks of climate variability and change for U.S. water resources. And tools can now be developed to support this effort. Tools like EPA's BASINS/CAT can enable water resource managers to better understand the potential impacts of climate change, and to incorporate considerations of climate change into their decision making processes.

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