Appendix I
Impacts of Climate Change on Drinking Water Supply: Findings from Existing Studies

Paula Conolly and Nikki Thorp – Philadelphia Water Department

Goals of this Report

– Identify vulnerabilities of drinking water supply from climate change
– Determine how to best maintain quality and quantity of drinking water supply
– Identify gaps in existing research, data and information
– Determine how best to mitigate and adapt drinking water infrastructure

Introduction

The following report summarizes existing research on the impacts and vulnerabilities of the Delaware River basin's drinking water supply to climate change. There is a specific focus within the report on the City of Philadelphia's drinking water supply; however, any discussion of Philadelphia's water supply must consider what is happening regionally through the Delaware River basin, since the water supply is influenced by what is happening upstream. This summary report contains recommendations, as provided by researchers and scholars on how to best prepare for, mitigate, and adapt, both the current and future, drinking water supply to projected changes in climate. This report is a follow up to one distributed in April 2009 on which consensus was reached among regional decision makers about the vulnerabilities of drinking water supply system to the impacts of climate change[1].

Preparation of this report required an analysis of existing local, regional, and in some cases national and international studies on vulnerabilities of natural and engineered systems that support the drinking water supply. Studies relevant to the City of Philadelphia's drinking water supply (i.e., surface water in the Delaware River Basin), received special attention. The intention of this research is to: identify vulnerabilities of the drinking water supply, determine effective means of maintaining both the quality and quantity of drinking water needed to support growing populations, identify gaps in the existing body of research in order to identify areas for further research, as well as to develop an understanding of how to mitigate and adapt drinking water infrastructure to changes projected. Conclusions of this report will be used primarily to support efforts by the Philadelphia Water Department and its partners in drafting an adaptation strategy in response to climate change. Yet Philadelphia's source water is shared by numerous other water suppliers in Pennsylvania and New Jersey, so report conclusions are regionally relevant.

Regional Drinking Water Supply

Residents in the Delaware River basin region get their drinking water from both surface and underground sources. Urban areas tend to use nearby rivers for supply, while suburban and rural regions rely more on groundwater from regional wells[2] and aquifers recharged in part by tidal portions of the Delaware River[3]. Approximately 88 percent of water used in this region is from surface water supplies; the remaining 12 percent comes from groundwater sources (based on 1991 and 1993 data)[4]. Surface sources supply 60 percent of the water used for consumption, with

[1] see Appendix 1 attached
[2] The Delaware River Watershed Source Water Protection Plan, p.14
[3] Hull, C. H. J. and James G. Titus, (eds.), p.11
[4] The Delaware River Watershed Source Water Protection Plan, p.14

the remaining 40 percent coming from groundwater stores[5]. Over the past few decades, groundwater has become an increasingly important resource, now supplying about one-third of the water used in the northeast[6]. It is therefore critical that both surface and groundwater supplies are taken into consideration when attempting to protect drinking water supply from climate change.

The Delaware River, its bay, and 216 tributary streams provide a source of drinking water for over 17 million people, or 10 percent of the United States population. Approximately 750,000 people in northeast Philadelphia and lower Bucks County rely on the river for drinking water[7]. In the Delaware River watershed below Trenton, there are eight drinking water treatment plants in Pennsylvania, including Baxter Water Treatment Plant, supplied by the Delaware River. There are three drinking water treatment plants in New Jersey.

Drinking Water Intakes Below Trenton[8]

Facility	**Operator**
Pennsylvania	
Baxter Water Treatment Plant	Philadelphia Water Department
Bristol	Aqua Pennsylvania
Lower Bucks County	Lower Bucks Joint Municipal Authority
Middletown	Bucks County Water and Sewer
Morrisville	Morrisville Borough Authority
Neshaminy	Aqua Pennsylvania
New Hope Waterworks	Bucks County Water and Sewer
Yardley	Pennsylvania American Water
New Jersey	
Burlington	Burlington City
Trenton	Trenton Water Works
Delran	New Jersey American Water Company

The City of Philadelphia’s drinking water supply comes exclusively from surface water sources. There are three treatment plants (two on the Schuylkill River: Queen Lane and Belmont and one on the Delaware River: Baxter) that are owned and operated by the Philadelphia Water Department to serve the entire city population of approximately 1.4 million people with drinking water. Some specific problems associated with the intakes at these treatment plants, as outlined in both the Delaware and Schuylkill River Watershed Source Water Protection plans, include: amount of impervious surface coverage causing runoff pollution, sanitary sewer overflows, discharges from municipal and industrial sources, spills and accidents from transportation and industry, among others[9]. It is out of these concerns that the Philadelphia Water Department established a source water protection program in 1999 dedicated to protecting and improving the water supply[10].

[5] United States Geological Survey. National Water Quality Assessment Program, Delaware River Basin and TDRWSWPP, p.14
[6] Confronting Climate Change in the U.S. Northeast, p.64
[7] The Delaware River Watershed Source Water Protection Plan, p.2
[8] The Delaware River Watershed Source Water Protection Plan, p.36
[9] The Schuylkill River Watershed Source Water Protection Plan, p.2-3
[10] The Schuylkill River Watershed Source Water Protection Plan, p.1

Industrialization and mining in the 19th and 20th centuries heavily polluted the Delaware River. Though water quality has improved, problems with the river as a source for region drinking water remain. Major contributors to these problems include wastewater treatment plant discharges, road salt application, population growth, land cover change, and potential salt line movement[11]. Climate change will exacerbate these problems. Through such effects such as tidal salt line movement or increased contamination the intakes and operation of treatment plants, as well as generated drinking water supply, is threatened. Contamination of the supply for the Baxter Treatment Plant specifically would have negative effects on the water supply to half of the City of Philadelphia[12].

Climate Change Impacts Drinking Water Supply

It is necessary to determine both the current and future impacts climate change will have on the drinking water supply to ensure long-term security of the supply[13]. There is however little certainty among the projections and probabilities of the changes that will occur to the natural and built environment, nor consensus around those that will specifically impact drinking water supply. There is credible speculation based on scientific observation about the changes that will occur, however, the rate at which change will take place, and the level and specific location of impact are unknown and difficult to identify. Enhancing predictive capabilities is critical.

Assessing impacts on the region's drinking water supply is difficult largely due to the complexity of the hydrological cycle[14]. A recent report to the Department of Environmental Protection on Pennsylvania's Climate Impact Assessment points out that within the hydrological cycle there are nonlinearities, thresholds and feedbacks within the water system that make it hard to model future conditions[15]. This study among others states that the ability to understand, predict and manage hydrologic systems into the future is dependent on the ability to characterize specific variables critical to the functioning of the hydrologic system, including both how the natural and human systems shape the evolution of hydrologic systems[16].

Various models developed have attempted to predict the impact of climatic changes on regional systems. What has been determined from these models is that under the predicted climate change conditions extreme weather events (floods, droughts, hurricanes) will be more frequent and more intense than have been historically. Models also point out that climate change has the potential of altering estuaries through changes in temperature, winds, streamflow, and sea level, which will affect numerous estuarine characteristics, such as circulation, water quality, and ecology[17].

Using a General Circulation Model the Pennsylvania Climate Impact Assessment report determined that throughout the 21st century in Pennsylvania: precipitation is projected to increase in the winter and stay relatively stable in summer; heavy precipitation events are projected to increase in frequency and intensity; temperature is projected to increase; snow cover, as a result of increased temperatures, will decrease in extent and duration; more precipitation will fall as rain, rather than snow; summer floods and general flow variability are projected to increase,

[11] The Delaware River Watershed Source Water Protection Plan, p.2
[12] The Delaware River Watershed Source Water Protection Plan, p. viii
[13] Shortle, James, et al., p.84
[14] Shortle, James, et al., p.71
[15] Shortle, James, et al., p.71
[16] Dooge, J.C.I. 2008 and Shortle, James, et al., p.84
[17] Shortle, James, et al., p. 79

there will be an increased frequency of short-term droughts, while overall annual runoff will increase slightly[18].

Given these predictions, the most logical approach to prepare for unknown impacts is to assess vulnerabilities of infrastructure, as well as to determine future population projections, in order to quantify and regulate consumption and development patterns that may affect drinking water supply. Infrastructure, both natural and engineered, must be resilient to the projected impacts, as well as emergency preparedness plans put in place that allows individuals, businesses and governments to remain flexible, adaptive, and responsive to the impacts of changing weather events. A number of researchers explain that population growth, urbanization, land use cover changes, and water pollution in the near term will stress the water cycle in ways that exceed the direct impacts of climate change[19]. What is likely is that unsustainable practices, coupled with climate change, will foster situations that are even more disastrous. For instance, peak flooding is likely to increase in urban areas due to the amount of impervious surface coverage, with higher rainfall variability from the onset of climate change, flooding will be more severe[20].

Understanding the potential risks involved will allow effective, efficient strategies and solutions to be developed to secure drinking water systems during changing weather patterns. The impacts of climate change on drinking water supply will be most severe in areas that continue to develop in sprawling patterns, consuming land and natural resources at the same, unsustainable rate, destroying native vegetation and forests, necessary to maintain water quality, to recharge groundwater, and to absorb precipitation thus preventing flooding[21]. The question decision makers are presently confronted with is how best to do this given so many unknowns, as well as to what extent such investment is necessary to ensure a high quality and adequate quantity drinking water supply.

Water Quality and Water Quantity
An assessment of drinking water supply system vulnerabilities is best understood broken down between impacts on quality of the supply and impacts on quantity. Mitigation and adaptation recommendations put forth in an attempt to secure the supply from projected climate change are effectively framed in terms of how they address quality and quantity of the supply.

Inventory of Potential Vulnerabilities of Drinking Water Supply System

Impacts on Water Quality

- erosion of both natural and engineered infrastructure
- salt line movement
- saltwater intrusion in coastal aquifers and freshwater habitats
- freshwater salinization
- degraded water quality (turbidity, dissolved oxygen, dissolved organic carbon, etc.)

Impacts on Water Quantity

- urbanizing, sprawling population increasing demand
- power outages and issues with energy availability
- stressed reservoir capacity
- inoperable, flooded treatment plants and pump stations
- reduced groundwater recharge

[18] Shortle, James, et al., p.71, 78, 84-5
[19] Shortle, James, et al., p.77
[20] Shortle, James, et al., p.77
[21] The Delaware River Watershed Source Water Protection Plan, p. vi

It is however, difficult to completely separate discussions on quality from discussions on quantity of the supply, as they are so obviously related and dependent. Vulnerabilities to the drinking water supply system that begin as issues of quality, such as salt line movement, quickly become an issue of water quantity. This is because a contaminated water supply reduces the amount of the resource available. The reverse is also true. Water quantity concerns, such as decreased supply in water reservoirs, quickly evolve into water quality concerns. For instance, water stored in reservoirs is critical to maintaining appropriate levels of salinity in the supply. However, considering the impacts on quality versus those on quantity is an effective way to break down an understanding of climate changes impacts on the drinking water system, as well as an effective way of developing mitigation and adaption solutions.

Drinking Water Supply System Vulnerabilities

As stated previously nearly 17 million people (approximately ten percent of the nation's population) rely on the water from the Delaware River basin for drinking water. Of those about seven million people live in New York City and northern New Jersey[22] and about 750,000 people live in northeast Philadelphia and lower Bucks County[23]. Any reduction to the existing fresh water supply will impact the region's economy, nutritional security, and quality of life.

The Delaware River basin currently experiences the Humid Continental climate pattern. This pattern encompasses relatively normal variations in weather, which are predominantly the result of a series of high and low pressure systems[24]. These patterns may shift depending on the extent to which climate change impacts are realized in this region. Climate change could affect both the source water quality and quantity of the Delaware River through sea level rise and hydrologic changes[25]. Climate change will alter the hydrology of the Delaware River. The increases in evaporation, loss in soil moisture, increased winter precipitation, more severe rainstorms, and season length changes, discussed, are just some of the factors that could alter hydrology[26].

Impacts on Water Quality

There are a number of concerns with the quality of drinking water available for human consumption. Water quality is impacted by issues such as: stormwater runoff especially from extensive impervious surface coverage, increased salinity levels, and other contaminants such as ammonium discharges from wastewater treatment plants. All of these alter sediment characteristics in the water, directly impacting the quality of the supply. These issues require concerted, ongoing study and response to ensure protected quality of the drinking water supply[27].

Runoff and Erosion

Levels of runoff and erosion directly correlate to temperature change. Climate change impact studies generally suggest that there will be a slight increase in runoff across the northeast across all emissions scenarios[28]. As mentioned, future climate projections show wetter winters and

[22] A Multi-Jurisdictional Flood Mitigation Plan, p.19
[23] The Delaware River Watershed Source Water Protection Plan, p.2
[24] The Delaware River Watershed Source Water Protection Plan, p.20
[25] The Delaware River Watershed Source Water Protection Plan, p.97
[26] The Delaware River Watershed Source Water Protection Plan, p.99
[27] Delta Vision Committee Implementation Report, p.7
[28] Milly, et al., 2005.

generally higher temperatures, leading to a 5 percent increase in runoff[29]. A one percent change in precipitation levels will evidently change streamflow volumes by 1.5 to 2.5 percent, depending on storage processes within the watershed[30]. Increased streamflow volumes will lead to greater runoff and erosion in the areas surrounding rivers and streams.

Salinity

There is strong evidence that past climate-induced changes in salinity levels in the Delaware Bay had negative impacts on water supply systems[31]. Waters of the tidal Delaware River at Philadelphia and northward are normally fresh. As previously discussed, several municipalities, including Philadelphia, obtain portions of their public drinking water directly from this part of the river. Increased salinity levels resulting from sea level rise could have a significant impact on drinking water quality in areas that rely on the Delaware River for drinking water supply[32]. Combating the threat from salinity infiltration into the region's drinking water supply will require costly new approaches to water management and conservation. Several studies summarized below examine models that look at the influence of climatic factors on salinity in the Delaware Bay.

Hull and Titus estimated in 1986 that a 0.73 meter rise in sea level coupled with the conditions of the 1960s drought of record would maintain the salt line (250 mg/L isochlor) at a position still below Philadelphia's Torresdale water supply intake at river mile 110. However, a rise in sea level greater than 0.73 meters would likely invade Philadelphia's water supply intake at Torresdale, leaving water too saline for human consumption, agricultural, or industrial uses[33]. In response to increased salinity levels, municipalities would be required to reconfigure treatment processes, regulate quantities consumed to drastically reduce water usage, or find alternative supplies of water, all at a substantial cost[34].

More recent studies have been performed to better understand the threat of salinity infiltration in the Delaware River. In 1997, the U.S. Army Corps of Engineers reported on a project-specific model, CH3D-WES, which was used to assess the impacts of a proposed 5-ft. channel deepening of the Delaware River. CH3D-WES is a 3-dimensional numerical hydrodynamic/salinity model, which has the ability to simulate the effects of physical factors, such as tides, wind, freshwater inflows, and turbulence, on salinity and circulation.[35]. Several scenarios were selected for application in the 3-D model to evaluate the effects of channel deepening on salinity distribution and sub-tidal circulation in the Delaware Estuary[36]. The model output for each scenario provided the maximum intrusion of the 250 mg/L isochlor, or salt front, and the 30-day average chloride concentration at River mile 98, which is approximately 12 miles downstream of Philadelphia's Torresdale intake[37].

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[29] Shortle, James, et al., p.73
[30] Shortle, James, et al., p.73
[31] Shortle, James, et al., p.79
[32] Cooper, et al., p. 13; Hull, C. H. J. and James G. Titus, (eds.), 1986; Major, D.C. and Goldberg, R. 2001
[33] Hull, C. H. J. and James G. Titus, (eds.), p.18 and Cooper, et al., p.13
[34] Hull, C. H. J. and James G. Titus, (eds.), p.18 and Cooper, et al., p.16
[35] Delaware River Main Channel Deepening Project: Supplemental Environmental Impact Statement, p. 5-6
[36] Delaware River Main Channel Deepening Project: Supplemental Environmental Impact Statement p. 5-30
[37] Delaware River Main Channel Deepening Project: Supplemental Environmental Impact Statement, p. 5-24

The simulated scenarios predicted that with a deepened channel and a recurrence of the June-November 1965, the freshwater portion of the estuary would undergo a monthly average chlorinity increase of approximately 15 to 50 ppm (assuming that the current DRBC regulated inflow scheme is kept in place)[38]. At River mile 98, the maximum 30-day average chlorinity would reach about 150 ppm under the same conditions[39]. It should be noted that the DRBC standard for maximum 30-day average chlorinity at River mile 98 is 180 ppm[40]. The 5-foot channel deepening would also result in upstream movement of the 7-day average 250 mg/L salt front. Intrusion of the salt front is predicted to range from 1.4 to 4.0 miles[41]. The study concluded that both the projected changes in Delaware Estuary salinity patterns and salt front location are not significant enough to stress wetland vegetation, freshwater fisheries, and overall estuarine productivity.

The CH3D-WES model was also used to simulate salinity changes for the combined system changes of channel deepening and a 1.0 foot rise in sea level. However, results from this analysis proved inconclusive due to a number of model limitations[42].

A 2007 study performed by Drs. Keu W., Kim and Billy H. Johnson, in collaboration with the Philadelphia District of the USACE, assessed the impacts of additional system changes on salinity in the Delaware River. Kim and Johnson reviewed validation of CH3D-Z, a numerical model used in their 1998 Delaware Deepening Study, before applying three discrete and independent system changes. The system changes consisted of a 5-ft. deepening of the Delaware Bay and River navigation channel, a change in anticipated consumptive use of water in the Delaware Basin from 1996 to 2040, and a projected sea level rise from 1996 to 2040[43]. Each change was modeled individually and then all three changes were modeled simultaneously.

Model results indicate that each of the three system changes will result in further intrusion of the salt line in the Delaware Bay and River. Upstream movement of the salt line due to only sea level rise is significantly greater than intrusion resulting from either channel deepening or changes in consumptive use. Salinity increases due to sea level change at Delaware Memorial Bridge, Chester, PA, and Ben Franklin Bridge would be approximately 13.54%, 16.18%, and 10.34%, respectively[44]. If all three system changes occur in combination during 1965 drought conditions, the model projects that salinity will increase in the Delaware river by approximately 20% or more by the year 2040. Combined system changes will also result in a maximum increase of 20 ppm in the running 30-day average chlorinity at River mile 98[45].

The studies described above exame the impact of salinity on Philadelphia's water supply with reference to the location of the 250 mg/L isochlor and the 30-day average chlorinity at River Mile 98. In fact, the Delaware River Basin criteria for Zone 2 where Philadelphia's Baxter intake is located is a maximum 15-day average of 50 mg/L. Research shows that chloride concentrations above 50 mg/L, possible as sea level rises, could cause health problems for water

[38] Delaware River Main Channel Deepening Project: Supplemental Environmental Impact Statement, p. 5-43
[39] Delaware River Main Channel Deepening Project: Supplemental Environmental Impact Statement, p. 5-61
[40] Delaware River Main Channel Deepening Project: Supplemental Environmental Impact Statement, p. 5-4
[41] Delaware River Main Channel Deepening Project: Supplemental Environmental Impact Statement, p. 5-39
[42] Delaware River Main Channel Deepening Project: Supplemental Environmental Impact Statement, p. 5-62
[43] Kim, K.W. and B.H. Johnson, p. 4
[44] Kim, K.W. and B.H. Johnson, p. 12
[45] Kim, K.W. and B.H. Johnson, p. 13

users with high blood pressure, those on dialysis, and those on restricted-sodium diets[46]. Future studies by the water department will investigate the ability of current flow policies in the Delaware to keep chlorides below 50 mg/L under current and future conditions.

As the Kim and Johnson study indicates, understanding the potential for significant sea level rise is necessary in order to gauge the overall effects of climate change on salinity. Extrapolating the trend of rising sea level that has occurred from 1961 to 2003 predicts a 5.5 inch (0.14 meter) average increase in relative global sea level above 2005 levels by 2100. However, climate change scenarios warn that historic data are no longer reliable to predict what will occur in the future. That being said many believe that an understanding of trends in historical data is likely to remain important[47]. Researchers Shuang-YeWu, Najjar, and Siewert used the output of five global climate models run under two greenhouse gas scenarios in combination with tide gauge observations to project sea-level increases ranging from 7.9 to 35.4 inches (0.2 to 0.9 meters) by 2100[48]. The Intergovernmental Panel on Climate Change (IPCC) estimates two scenarios for sea level rise by 2100: a lower emissions scenario with 7.09 inches (.18 meters) rise and a higher emissions scenario projecting 23.23 inches (.59 meters) rise over the next century. These figures do not include the addition of melting polar ice sheets. German oceanographer and climatologist Stefan Rahmstorf predicts a 55.12 inch (1.4 meters) rise of relative global sea levels by 2100. Rahmstorf's figures include the melting of the ice sheets in Greenland and Antarctica[49].

In fall 2008 a University of Pennsylvania City Planning Studio used these estimations to predict the relative global sea level rise likely to be experienced throughout the Delaware River region, determining that by 2050 parts of the basin will experience up to an 18.9 inch (.48 meter) rise and a 41.73 inch (1.06 meter) rise by 2100. The rate of relative sea level rise in the Delaware River basin region is higher than the global average. This is primarily a result of local subsidence driven by post-glacial rebound[50], as well as due to extensive groundwater withdrawal[51]. The east coast of the United States is slowly sinking[52]. Thus it is estimated that relative sea level rise in the Delaware estuary will be 10 to 12 inches (.25 to .30 meters) per century greater than relative global sea level rise[53].

Other Contaminants

Water quality concerns, other than salinity, have to do with other contaminants in the water. These contaminants typically come from four sources: natural (most significant is salt water, already discussed), point (introduction of both industrial and municipal waste to water ways), non-point (stormwater runoff from urban and suburban areas), and accidental (spills or leaks from cars, trains, ships, pipelines)[54].

Turbidity and other suspended contaminants in the river tend to increase as a function of precipitation, runoff and river flow[55]. These are projected to increase even under the most

[46] The Role of Coastal Zone Management Programs in Adaptation to Climate Change: Final Report of the CSO Climate Change Work Group
[47] Shortle, James, et al., p.83
[48] Shuang-YeWu, et al., p.1
[49] Climate Change and the Oceans. <http://www.pik-potsdam.de/~stefan/>
[50] Shuang-YeWu, et al., p.2 and Davis, J. L. and Mitrovica J. X. 1996.
[51] Shuang-YeWu, et al., p.2 and Davis, G. H. 1987.
[52] Hull, C. H. J. and James G. Titus, (eds.), p.6 and Hoffman, J. S., D. Keyes, and J. G. Titus, 1983.
[53] Hull, C. H. J. and James G. Titus, (eds.), p.8
[54] The Delaware River Watershed Source Water Protection Plan, p.iv
[55] The Delaware River Watershed Source Water Protection Plan, p.37

conservative of climate change projections. Nutrients contaminants, such as nitrate and nitrite, are also a concern because they cannot be removed during the water treatment process and can cause health related concerns in small children and babies[56]. Additionally, the Philadelphia Water Department has expressed specific concerns with changes in the concentrations of disinfection byproduct precursors such as bromide, TOC, DOC, and UV254, found in the water supply[57]. The effects of industries putting chemicals and foreign materials in the water has negative impacts on aquatic food webs, causes algal blooms, and encourages non-native species necessary for maintaining quality of the water supply. Low flows and higher water temperatures are likely to decrease habitat suitability for aquatic biota since it will lead to a decrease in dissolved oxygen content[58].

Impacts on Water Quantity

There are a number of concerns with maintaining quantity of water supply available over the next century to support population projections. Water quantity is impacted by: consumption patterns, variability of stream flow, energy usage and availability, storage, as well as by performance of treatment facilities.

Numerous upstream consumptive uses of water throughout the Delaware basin reduce the essential quantity of fresh water flow into the estuary needed to push the salt line downstream increasing the threat of salinity in freshwater. In 2008, basin-wide withdrawal of fresh water was estimated at 351 cubic meters per second (8 billion gallons per day), of which 90% is diverted from surface water flows [59]. An average of 10% of water withdrawn for public water distribution systems throughout the basin is used consumptively (i.e. evaporated or otherwise removed from the basin instead of draining back into the estuary) [60]. The Upper Estuary has the highest absolute consumptive use, as many power generating and industrial facilities are located along the Delaware River in this subbasin. The average daily per capita water use in the basin is 133 gallons per capita per day (gpcd) and ranges from 90 to 190 gpcd, with the Schuylkill Valley subbasin showing the highest per capita use with a value close to 200 gpcd[61].

In addition, diversion of Delaware River water to New York and northeastern New Jersey is authorized. Approximately 736 million gallons of water are exported for populations in NYC and northeastern NJ, which accounts for about 8% of total water withdrawals in the basin[62].

Population size and people's water use is likely to impact water demand, an important stress on current and future freshwater resources[63]. Increased water use may not only occur as a result of increasing populations, but as a direct response to certain climatic changes. The 2008 Pennsylvania Climate Change Report from the Union of Concerned Scientists states that "over the next several decades (2010-2039), annual average temperatures across Pennsylvania are projected to increase by 2.5ºF." Summer months in particular may experience temperature increases as high as 11ºF by late this century (2070-2099) if greenhouse gas emissions are not

[56] The Delaware River Watershed Source Water Protection Plan, p.iii
[57] The Delaware River Watershed Source Water Protection Plan, p.xi
[58] Shortle, James, et al., p.79
[59] Delaware River State of the Basin Report 2008, p.17
[60] Delaware River State of the Basin Report 2008., p. 15
[61] Delaware River State of the Basin Report 2008, p. 15
[62] Delaware River State of the Basin Report 2008, p.16
[63] Shortle, James, et al., p. 82

actively reduced[64]). These predictions lead to questions concerning the impact of climate variability on water consumption levels. There are several challenges to estimating water demand, including such factors as the inherent non-linearity of water demand functions, the complexity of pricing structures, and the uncertainty related to understanding the direct effects of climatic conditions on consumption patterns[65]. Despite these challenges, several studies have attempted to establish a relationship between climate change and water demand. One such study based in Albuquerque, New Mexico found that summertime residential demand is the most sensitive component of total water demand to climate variability, specifically in regards to changes in temperature, humidity, and precipitation[66]. In Albuquerque, residential water demand follows the seasonal cycle of maximum temperature, peaking during the summer months. A regression model using both temperature and precipitation changes to estimate per capita water demand revealed that as temperature increases, demand increases, and as precipitation increases, demand decreases; an outcome that is concurrent with results from previous studies performed in the southwestern US[67].

The Philadelphia region should also begin to consider the impacts of climate change on consumptive use as one of several factors that may increase the demand placed on limited freshwater supplies. An increase in demand will most likely necessitate a decrease in non-essential water usage, presenting the opportunity for region-wide intervention and conservation efforts.

Gaps in Existing Research, Information and Data

Gaps Identified in Research, Information and Data

– Drinking water supply systems should be analyzed distinct from overall water supply
– Other disciplines should be engaged and contribute to discussion, research and solutions
– Climate change projections and probabilities should be available at a local level
– Mitigation and adaption techniques should be applicable and available to households

Climate change research must consider specific vulnerabilities and impacts on the drinking water supply separate from considerations of those on the water supply in general; if for no other reasons than the fact that drinking water supply requires much more stringent water quality criteria than other water uses. As has been stated previously, quality is susceptible to changes in temperature and weather patterns[68]. Managing drinking water quality standards is an ongoing, ever increasing challenge given the impacts climate change is likely to bring, such as turbidity, dissolved oxygen, dissolved organic carbon, dbp formation, and increased salinity levels.

Reports issued to date on how drinking water systems are projected to be impacted by climate change are primarily written from the perspective of scientists and engineers, government and quasi-governmental agencies, water departments, and natural resource protection agencies. Critical perspectives in this discussion are not yet contributing. For instance, protection of the

[64] Climate Change in Pennsylvania, p. 9
[65] Technical Briefing Paper (8): Water Demand Impacts and Utility Responses., p. 1
[66] Interannual Variability of Water Demand and Summer Climate in Albuquerque, New Mexico, p. 1781
[67] Interannual Variability of Water Demand and Summer Climate in Albuquerque, New Mexico, p. 1779
[68] 2008 Delaware River and Bay Integrated List Water Quality Assessment, p.1

drinking water supply is often framed as a public health concern; the medical community is rarely at the table when studies, plans, and reports are being developed. There is very little information about how the medical community is involved in this critical public health issue. It would also be insightful to gather information and perspective from professionals in the fields of education, agricultural, community development, as well as to hear from home- and business owners with regard to threats posed by diminished or degraded drinking water supply.

Most the projections on the impacts of climate change have been produced on a national or regional geographic scale, rather than at a local level where specific roadways and development can be determined as being at a certain level of risk. There is a real need for climate change projections and probabilities to be available at a local level. This would enable local decision makers and property owners to take the necessary mitigation and adaptation options in preparation for projected impacts of climate change.

Although research on mitigation and adaptation is growing there continues to be a dearth of information on what individuals, households and business owners can do to assist in the mitigation of this impending problem. A number of municipalities across the country are attempting to integrate and advocate for green infrastructure solutions. Property owners and citizens must be educated and incentivized to participate in these practices.

Recommended Mitigation and Adaptation of Drinking Water Infrastructure and Supply
Suggestions for mitigation and adaption of the drinking water supply have been put forth in a number of the reports and studies reviewed. The following is a sample of those most relevant to the Philadelphia drinking water supply.

	Action	Partners
Conservation	Provide financial incentives to promote use of alternative water supply for non-potable use: reused water, recycled water, stormwater, and desalinated water for watering lawns, washing cars, etc.	
	Incentivize local and regional efforts that make use of alternative sources of water such as brackish water and desalinized water[69].	
	Provide incentives for water reuse in both urban and agricultural sectors[70].	
Partnership	Ensure coordination between local, state, and federal agencies focuses on protecting drinking water supply within various climate change scenarios.	
	Expand outreach efforts on source water protection and consumption.	
	Build a successful coalition of state, federal, and local interests, inextricably intertwined, as critical to the success of improvements in water supply reliability, ecosystem health and protection.	
	Legally acknowledge co-equal goals of restoring river ecosystems and creating a more reliable drinking water supply[71].	
	Support requirements on wastewater treatment plant dischargers to perform year round disinfection, and to include forest and canopy protection into existing non-point source pollution regulations[72].	

[69] Delta Vision Committee Implementation Report, p.1
[70] Delta Vision Committee Implementation Report, p.1
[71] Delta Vision Committee Implementation Report, p.16
[72] The Delaware River Watershed Source Water Protection Plan, p.ix

	Examined resolutions governing reservoir releases and minimum flows under climate change conditions[73].	
	Raise the profile of the Delaware and Schuylkill rivers as a drinking water supply that needs to be maintained and protected in the eyes of the public, government, and regulatory communities[74].	
Planning	Conduct a vulnerability assessment of drinking water system infrastructure to identify areas most vulnerable to climate change, and devise appropriate adaptation options for specific locations.	
	Improve monitoring of sodium sources such as road salt, wastewater treatment plants, sodium hypochlorite disinfection, and water softening chemicals and other drinking water contaminants in the water[75].	
	Complete a region-wide emergency response plan outlining requirements for emergency preparation such as stockpiling clean drinking water[76].	
	Expand Delaware Valley Early Warning System to protect water supply[77].	
Modeling	Model the behavior of the salt line under climate change and higher sea level conditions.	
	Determine minimum flow requirements needed to adjust to changing hydrologic conditions[78].	
	Devise methods of monitoring variables of the hydrological cycle, such as ground water dynamics, along with observations of changes to land cover and population size[79].	
	Identify any climate change and land cover change impacts on water contamination such as on bromide, DOC, TOC, and UV254[80].	
	Improve water management strategies including consideration of demands under climate change, given population and economic change scenarios[81].	
Development	Acquire easements or fee title to lands needed to form a flood bypass in areas along the Delaware River that are most vulnerable to flooding and sea level rise.	
	Ensure discharge and brine from desalinization plants do not go back into the water supply[82].	
	Ensure flood insurance rates reflect changing risk due to sea level rise for property owners, in preparation for sea level rise.	
	Ensure state policies restrict development along the shore to mitigate hazards or protect water quality preserve open space also help coastal ecosystems adapt to rising sea level.	
	Take stock of existing drinking water supply infrastructure and facilities that are vulnerable to inundation from sea level rise and flooding, elevate equipment where necessary and possible to avoid substantial damage.	
	Ensure the Baxter Water Treatment Plant is adequately protected under	

[73] The Delaware River Watershed Source Water Protection Plan, p.xi
[74] The Delaware River Watershed Source Water Protection Plan, p.xii
[75] Climate Change in Pennsylvania, p.19
[76] Delta Vision Committee Implementation Report, p.1
[77] The Delaware River Watershed Source Water Protection Plan, p.xi
[78] The Delaware River Watershed Source Water Protection Plan, p.iv
[79] Shortle, James, et al., p.82
[80] The Delaware River Watershed Source Water Protection Plan, p.xi
[81] Shortle, James, et al., p.83
[82] San Francisco Bay Plan, p.69

	regional water policy from climate change effects on the salt line movement and streamflow volumes[83].	
	Increase collector-system, storage, or treatment-system capacity as weather patterns change[84].	

Adaptive capacity describes the ability of the built, natural, and human systems to accommodate changes with minimum disruption or minimum additional costs[85]. As a rule, systems that have high adaptive capacity are better able to deal with climate change impacts. It is therefore important, given uncertainties associated with climate change, that there be an attempt, through the development of any new or rehabilitation of existing infrastructure, to develop in a manner that is adaptive to impacts of changing climates.

The degree of adaptation incorporated into drinking water system infrastructure should vary depending on the type of emergency most likely to be experienced in a given place. Emergencies vary by length of time and by severity of disruption – some systems will be able to get back to normal operations in a reasonable amount of time, others may not. For instance, sea level rise projected to impact parts of the Delaware River basin region is more of a permanent inundation from which infrastructure will have to be removed. Vulnerability assessments of infrastructure must therefore be conducted to identify areas most vulnerable to detrimental effects of climate change. This will allow appropriate adaptation options to be devised for specific locations.

Developed adaptation plans should make careful consideration, on a case by case basis about whether or not, and if so how, particular sections of infrastructure, critical to the supply of drinking water, will be protected with structures (barriers), elevated above the expected water lines, relocated landward, or left alone and potentially given up permanent inundation. For each adaptation measure considered, policy makers and resource managers must carefully assess the potential barriers, costs, and unintended social and environmental consequences ensuring that benefits of the investment are worthwhile, and outweigh the costs.

Common Points Shared Among Reports and Studies

Shared Approaches and Solutions

– The time to act is now
– Continually revise research, data, information and understanding
– Advocate living in concert with and utilizing natural system solutions
– Work across sectors, involve regional partners, to leverage resources

Most reports and studies point to a sense of urgency when discussing impacts and vulnerabilities of the drinking water supply system. Authors tend to acknowledge a need for better understanding of the vulnerabilities of the supply; however, they are quick to point out that such investigation should not excuse inaction. The report on Assessing Pennsylvania’s Climate Impacts states that strategies generated and solutions put in place should meet a “no regret” criteria[86]. That is, if the best option devised to mitigate a concern will lead to societal benefits,

[83] The Delaware River Watershed Source Water Protection Plan, p.xii
[84] Climate Change in Pennsylvania, p.17
[85] Preparing for Climate Change, p.78
[86] Shortle, James, et al., p. 81

regardless of the actual degree of climate change, than it is worthwhile[87]. Most studies point to a need for increased planning and preparation in order to adequately preserve and protect drinking water supply, but are timid about making specific recommendations with regard to how to best adapt infrastructure to deal with the projected impacts. The "no regret" criteria is a viable measure of determining appropriate mitigation and adaptation strategies.

Given the fact that the predictions of what will happen under climate change scenarios are mere probabilities much of the literature agrees that continual revision of research, data, and information will be necessary to continually perfect an understanding of the threat, as well as evolve our approach to mitigation and adaption. Although data and information collected each year may not be a reliable indicator of future behavior, understanding the trends in the data is likely to remain important[88].

Authors tend argue that adapting to climate change is really about reframing the way people live and function to be more respectful and sensitive to the natural systems on which sustain and protect quality of life. Learning to mitigate and adapt to changes brought on by climate change is not just a self correction that needs to take place over the next few years, rather authors suggest it is about discovering new ways to approach the engineering of systems in ways that respect and work with natural ecosystems, co-beneficially. Authors of the report on Pennsylvania's Climate Impact Assessment suggest that monitoring hydrologic variables has to go hand-in-hand with observations of changes to land cover and population size[89].

Many reports propose large-scale habitat restoration as an effective method of improving the quality of drinking water supply. Habitats suggested for restoration include forests, tidal marshes, floodplains, open water, adjacent grasslands, seasonal wetlands, and migratory corridors (both in-stream and riparian). Specific recommendations on how to use natural systems to protect drinking water supply include suggesting that habitats should be connected, in ecologically beneficial ways, to engineered infrastructure. Lands adjacent to tidal marshes should be conserved as agricultural or open space uses to buffer impacts of sea level rise[90]. Additional points for consideration include the fact that forests and wetlands provide a natural buffer between human activities and water supplies, filtering out pathogens such as *Giardia* or *E. coli*, nutrients such as nitrogen and phosphorous, metals and sediments. This natural process provides cleaner drinking water and by reducing harmful algae blooms, increasing dissolved oxygen and reducing excessive sediment in water[91].

Most reports and studies conclude that the most effective approach to these issues is one that is multi-pronged, working across sectors toward mutually agreed upon goals. Municipalities across the nation are attempting to determine the most logical approach to protect drinking water supply systems, concluding that it is through leveraging a variety of tools in land use, transportation, zoning, property rights, environmental protection, insurance, policy, and education that a truly comprehensive, effective, efficient mitigation and adaptation strategy can be devised. A regional approach will help secure the drinking water supply far into the future.

[87] Shortle, James, et al., p.81
[88] Shortle, James, et al., p.83
[89] Shortle, James, et al., p.82
[90] Delta Vision Committee Implementation Report, p.7
[91] Costanza, et al., p.5

Different Points Among Reports and Studies

Different Approaches and Solutions

– Methods of determining and ranking system and supply vulnerabilities
– Global versus local approach to mitigation and adaptation
– Partners, stakeholders, organizations consulted and involved
– Scale and balance of natural versus engineered infrastructure

There are differences in how the existing studies and reports approach the issue of drinking water system vulnerabilities, as well as difference in how these documents outline approaches to protection. For instance, the Valuing New Jersey's Natural Capital report points out that the most important determinant of an adequate drinking water supply is the amount of precipitation a region receives[92]. This suggests that in fact most mitigation and adaptation measures should address an increasing or decreasing rate of precipitation. Other reports tout increased salinity and salt line movement as the most critical issue facing drinking water supply. These discrepancies, which stem from the particular water supply source that a particular report is concerned with, are part of a dynamic conversation that must continue to evolve in order to effectively prioritize the best solutions to secure the drinking water supply.

There are differences in the level at which reports recommend approaching the issues of climate change. Some seem to advocate it as a global concern that must be acted on both nationally and regionally, similar to the approach put together by the EPA Climate Ready Estuaries Program; however, others argue that climate change is a local issue; best dealt with through local resource management and home/business owner mitigation and adaptation efforts. There is little doubt that a multitude of approaches will be necessary to get the most effective understanding of the issues faced in each region and locality.

There is a lack of consistency among what level of government discussions and plans are produced in regions across the county. There are differences in the partners and stakeholders convened in the production of studies and reports on the subject. It is debatable whether there is a need for consistency among approaches, but an understanding that consistency is beneficial when sharing best practices or coordinating efforts across states or regions is undeniably helpful. Inconsistency about who is responsible and how efforts should be coordinated leads to inefficiency, whereas shared resources and practices can greatly improve the approach.

There is debate among authors whether to use natural systems to protect the drinking water supply, such as through wetland restoration and development setbacks along waterways, or structurally engineer solutions, such as building dikes and levees to protect the drinking water supply infrastructure. In many studies and reports both options are highlighted, but specific recommendations as to how to integrate these approaches throughout one system is lacking.

Summary and Next Steps

This report, having reviewed studies and reports that discuss the impacts of climate change on drinking water supply, gives regional decision makers relevant information to enable the

[92] Valuing New Jersey's Natural Capital, Part III, p. 20

formulation of informed opinions about how to best approach an adaption strategy for the region's drinking water supply system. This report highlights gaps in the existing research, data and information, information that may be necessary prior to making critical decisions about the protection and adaption of infrastructure that ensures adequate supply of high quality drinking water to the region.

The next step in this process, developing an adaption plan for the drinking water supply, as part of the Climate Ready Estuaries Program, will be to rank vulnerabilities of the drinking water supply. Vulnerabilities identified both in this report as well as in the *Inventory and Assessment Report of Potential Vulnerabilities of Philadelphia's Drinking Water Supply* produced in April 2009 should be considered[93]. This ranking will include a summary of the considerations used in setting priorities. In addition to ranking vulnerabilities, regional decision makers must identify and rank additional research, data, and information needs. This information is critical to ensure appropriate decisions are made about the investment of limited resources. Ranking vulnerabilities and research needs will allow the development of an adaptation plan that ranks adaptation needs, stressing the protection of critical infrastructure, as well as the ensured safety and reliability of the region's drinking water supply.

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[93] See Appendix 1 attached

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Appendix 1: *Inventory and Assessment Report of Potential Vulnerabilities of Philadelphia's Drinking Water Supply*

Climate Change Will Bring:	Effects as a Result of these Changes:	These Effects will Impact Water Systems Through:	
Warmer Temperatures and Drastic Weather Fluctuations	increased precipitation *(rainfall expected to increase mainly in the Northern and Eastern parts of the country)*	increased river discharge and stream flow	1, 2, 6
		increased runoff	1, 2, 6
		increased groundwater levels	1, 2, 6
		extreme flooding	1, 2, 4, 6, 10
		changes in watershed vegetation and forest cover	1, 6
	decreased precipitation *(rainfall expected to decrease mainly in the Southwest, but could be short-term periods in the East)*	decreased river discharge and stream flow	3, 6, 7, 9
		decreased groundwater levels	3, 6, 7, 9
		increased frequency of short-term drought	3, 6, 8, 9
		increased number and intensity of wild fires	1, 6, 9, 10
		changes in watershed vegetation and forest cover	1, 6
	increased frequency and magnitude of storms	lightening and electrical disturbances	5, 10
		storm surge	1, 2, 4, 5, 6, 8, 9, 10
	warmer water temperatures	disruptions to aquatic ecosystems (including wetlands)	6, 7, 8
		sea level rise	1, 4, 5, 6, 7, 8
	thawing permafrost, reduced ice cover and snow pack, and reduction in freezing season	flooding	1, 2, 4, 6, 10
		sea level rise	1, 4, 5, 6, 7, 8
		decreased river discharge and stream flow (spring and summer)	3, 6, 7, 9
		changes in watershed vegetation and forest cover	1, 6

Leading to Issues with the Drinking Water Supply	
1	erosion of infrastructure
2	overflowing reservoir capacity
3	decreased supply in reservoirs
4	flooding of treatment plants and pump stations
5	inoperable treatment plants
6	degraded water quality of source water and finished water (turbidity, dissolved oxygen, dissolved organic carbon, taste and odor compounds, dbp formation etc.)
7	upward salt line movement
8	saltwater intrusion in coastal aquifers and freshwater habitats
9	increased demand for supply
10	power outages and issues with customer supply