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Climate Change Adaptation in the Water Supply Sector

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Executive Summary

Climate change has been affecting New Jersey in recent decades, such as through rising sea level and an increased intensity of precipitation events. Throughout this century it is projected to further modify our weather patterns, hydrology, ecosystems, and water supply resources and utility systems. This white paper provides an overview of anticipated climate change implications for water supply, and provides a wide variety of possible management responses to address these concerns. The responses range from planning to physical mitigation projects, with responsibilities residing with our state government to the local government and utility levels.

The focus of this white paper is on adaptation. While mitigation of climate change itself is ongoing at many levels, the NJ Climate Adaptation Alliance (NJCAA, http://njadapt.rutgers.edu/) specifically focuses its efforts on climate change preparedness and impact mitigation. This paper does include a very general overview of the climate change impacts that may be most important for water supply sources and utilities, but does not attempt a more detailed analysis. Important impacts include a variety of hydrologic changes that in turn will modify water availability and quality, temperature change effects on water quality and landscapes, sea level rise, coastal storm intensity, and aquatic ecosystem changes. Readers interested in a national overview of projected climate change impacts may wish to read the Third National Climate Assessment (Melillo et al., 2014).

The fundamental science of climate change is well accepted within that portion of the scientific community that has direct competence in the issue. It is acknowledged, however, that ongoing scientific investigation is constantly expanding our knowledge regarding the detailed mechanisms of climate change, including positive and negative feedback systems. No one model is generally accepted as fully addressing all climate change impacts. Therefore, this white paper recommends the selection of multiple scenarios that cover a range of the most plausible scenarios. Planning and management efforts would be used to address as many of the scenarios as possible. Where all scenarios can be addressed successfully, we can have a higher confidence in our adaptability for whatever comes. Where one or more scenarios cannot be addressed, we will know where more work is needed to understand how success might be possible in the future.

The first step in climate change adaptation is understanding what is at risk, why the risk will change, and whether that risk constitutes a priority concern. Hazard mitigation planning at the state and county level can incorporate this information and develop responses. Water supply utilities also have a direct responsibility to plan for these risks. In both cases, the climate change scenarios can be used to modify or create various models related to water availability (both ground and surface water), water quality in source waters for public water supplies, and landscape changes (i.e., ecosystem shifts). While regional and statewide models will have inherent uncertainties, they will provide at least a qualitative sense of future conditions, and may provide good quantitative estimates as long as uncertainties are included.

Asset risk assessment and management is, or at least should be, a fundamental responsibility of every water supply utility and water resource management entity. Using the results of climate change impact modeling, utilities and regulators should be able to incorporate the risk assessment into their ongoing,

broader asset management programs. Asset risk assessment and management requires knowledge of the complete utility system, the integrity of all significant components, the identification of critical assets (i.e., where failure causes disproportionate harm to services), the assessment of risks to those critical assets, and a planned program of system improvements to reduce system risks.

Water supply adaptation extends beyond asset risk assessment and management, however. Utilities, regulators and others share a responsibility to manage water resources in a way that reduces vulnerability to climate change. For instance, if water resources are currently used to their absolute maximum, there is no capacity buffer to ensure supply should New Jersey suffer a more severe drought than our historic 1960s drought. Water conservation, water use efficiency, beneficial reuse of wastewater and stormwater, and new approaches to energy provision for water supply utilities all increase the resilience of the water supply sector.

Source water protection is also important, both under current and climate change conditions. Source water protection requires an even larger collaboration than water supply management, as it incorporates a wide variety of pollutant sources, stormwater sources, and land use impacts. Climate change will likely exacerbate the challenges of source water protection.

The last section of the white paper provides a quick overview of the larger funding sources available for climate change adaptation in the water supply sector. However, it should be recognized that most of the funding for these purposes will come from a combination of utility customer charges and general government revenue. Achieving successful adaptation will require a recognition of the risks, agreement on the most useful adaptation approaches, and a willingness to fund implementation. There must be a recognition that we will pay for climate change adaptation sooner or later. The question is whether we act while we still have the widest range of adaptation alternatives and the longest implementation timeframe, or when our alternatives are constrained and the impacts are already damaging our water supplies. It could be argued that we are already within the latter period, but not to the point where we have no more time to act.

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Major Recommendations

This white paper includes many thoughts regarding the implications of climate change for water supply. The most critical observations and recommendations are as follows:

1. **Governance**: Water supply is the responsibility of a very large number of agencies and entities from the state to the local level, including many non-governmental players, and includes functions of protecting, securing, storing, treating and delivering water for consumers. Water supply management systems must necessarily include consideration of everything from the natural source (watershed or aquifer) to the infrastructure that makes cities and suburbs possible. Our governance systems for water supply are overly reliant on the concept that the future will be similar to the past. Climate change demands projection of possible conditions, adaptive management, and acceptance of shifting risks.

2. **Hydrologic Changes**: Climate change implications for water resources are complex. Higher temperatures will increase evaporation (from surfaces) and transpiration (from plants), as will a longer growing system. Stream flows rely heavily on flows from ground water, which in turn rely on recharge rates that could change either for the better (in response to more precipitation and longer frost-free periods) or for the worse (in response to competition from vegetation during a longer growing season, and more precipitation going to runoff due to more intense storms). While more precipitation is possible, more frequent short droughts are as well. Increased temperatures also change water chemistry and quality, as will more severe storms, complicating the protection of water supplies. The net effect is likely to be a greater variability in water availability. Improved management approaches will be needed to ensure sufficient supply of sufficient quality. As a result, two recommendations should be addressed. First, water supply management should be based on projected scenarios, not a repeat of past conditions. Second, additional research on the implications of hydrologic changes will be needed, with the results linked back into the scenario development process.

3. **Vulnerability**: To the extent that storms intensify, riverine and coastal flooding and storm surges will place water infrastructure at risk. The risks are to water supply infrastructure specifically, but damage of wastewater infrastructure can release pollutants that harm water supply quality as well. Sea level rise will increase stress on coastal aquifer quality in areas with possible saltwater intrusion, and will pose a threat to coastal development and the related water supply infrastructure. All of these issues increase vulnerability, which will require incorporation of climate change risk into hazard mitigation plans and also will demand additional capital expenditures and improved systems to manage and mitigate risk.

4. **Avoid Doing Harm**: By acting as if the future will be like the past, we actually are increasing the potential or certainty of increased hazards and harms. It is feasible to assess potential risks for climate change and act accordingly, but doing so all too often will run afoul of entrenched public attitudes and desires. In the water supply field, it is feasible to modify our understanding of future aquifer and reservoir yields, gradually incorporating them into regulatory and management decisions. Distribution systems can be gradually upgraded to mitigate risks. However, we need to avoid actions that inevitably increase risks, such as relying on outdated

flood risk mapping or choosing to ignore authoritative evaluations regarding whether an action will improve or degrade hazard mitigation capabilities.

5. **Water Conservation and Efficiency**: A sound response to uncertainties and concerns regarding water availability is to engage in a sound, ongoing program of reducing water demands through improved conservation practices (e.g., leak reduction, non-wasteful behaviors) and water use efficiency (e.g., better water use fixtures and appliances). Despite improvements over time, much more can and should be done. In the process, savings should be allocated to risk mitigation, not just to support of new demands.

6. **Source Water Protection**: New Jersey's development and agricultural land uses place a significant stress on natural water supplies, and climate change is likely to exacerbate these stresses. Where source water quality declines, additional costs are incurred to treat the water for public protection. Source water protection requires a very difficult level of collaboration among water supply utilities, government land use regulation, pollution controls, and private land use decisions. Improved stormwater management, development and redevelopment controls, water allocation criteria, and retrofitting of existing land uses will be critical to protecting our water supplies.

7. **Available Funding**: Some federal and state funds are available to address some of the issues posed in this white paper, especially for capital projects by water supply utilities. Water utilities clearly will play the dominant role regarding capital and operating costs to address issues directly related to their infrastructure. Very limited funding is available for other purposes, such as source water protection activities that cannot be addressed through regulatory programs. If we hope to address the implications of climate change for water supply, much less for the many other issues involved, we must be more willing to modify spending patterns so that funds are directed to the most cost-effective activities that incorporate climate change rather than ignoring it.

Introduction

Climate change is in the news every week and often every day, with new research findings on causes and implications, political debates, policy alternatives and technical methods for mitigation and adaptation all are fodder for the news. Much of the focus has been on mitigating the severity of climate change itself, such as through the recent Paris COP21 agreement (UNFCC, 2015). However, there is increasing acknowledgement that we are already seeing impacts of climate change on our water resources and other natural and human systems. The climate change scientific community recognizes that climate change impacts are inevitable at this point, even if future greenhouse emissions are controlled. Therefore, society will need to respond to these impacts through adaptation.

The NJ Climate Adaptation Alliance requested this white paper to explore a wide range of adaptation options for the protection and management of water supply resources and utilities. The white paper is linked to a Basis and Background paper (Millsaps, 2016) that has more detailed information on specific methods and issues discussed here.

Water Supply Governance

New Jersey has a highly diverse and fragmented water supply governance structure. Three state agencies are responsible for different planning and regulatory decisions regarding utility infrastructure. The NJ Department of Environmental Protection (NJDEP) is responsible for drinking water quality standards, water allocations to those capable of withdrawing more than 100,000 gallons per day from surface waters and aquifers (50,000 in the Highlands Preservation Area), infrastructure construction standards, well construction requirements, and loan programs for water supply infrastructure. NJDEP is also responsible for the Statewide Water Supply Plan (last adopted in 1996) and regional water supply studies, all of which should directly address climate change implications. The NJ Department of Community Affairs (NJDCA) is responsible for the Residential Site Improvement Standards (which cross-reference NJDEP requirements for water supply facilities), the Uniform Construction Code, and budget oversight regarding municipal water utility departments and municipal utility authorities. The Board of Public Utilities is responsible for approving the rates of all investor-owned water supply utilities and a few government-owned systems that provide services outside their jurisdiction.

Provision of raw water supplies and operation of public community and public non-community water supply systems can be by municipal government directly, municipal utility authorities (including what are called county utility authorities), legislatively-created regional agencies, private companies (i.e., with no publicly-traded shares), investor-owned companies, and one state agency, the NJ Water Supply Authority.

Protection of water supply resources (also known as source waters) is a major responsibility of the NJDEP, but also includes roles for municipal governments through land use regulations and stormwater system management. Municipal, regional and county health agencies also play a role regarding ensuring the testing of certain wells, septic systems construction and other issues.

The result is that every major aspect of climate change adaptation for water supplies will require collaboration of multiple entities.

Background: Implications of Climate Change for Water Supply

This section summarizes climate change impacts that may increase the vulnerability of our water supply sources and utilities to disruption or degradation. This white paper is not intended as an intensive review of the climate change literature, but rather focuses on potential water supply impacts and potential adaptation options for reducing vulnerability, which are addressed in later sections.

Hydrologic Changes

The hydrologic system drives our entire water supply approach, and so climate change impacts to the hydrologic system would alter the very basis for our ability to deliver sufficient supplies to users, from both a quality and quantity perspective. A very good introduction to the nature and assessment of New Jersey watersheds is available from USGS (Watt, 2000).

Watershed Function

Watersheds are geographic areas where surface waters flow downhill to a single point of exit. Ground water within the watershed will often follow a similar flow pattern, but in some cases will cross watershed boundaries and exit into another watershed. Some ground water moves quickly (days) to surface water (e.g., streams, rivers, lakes, ponds, saline waters) while other ground water may move deeper and remain within the ground for centuries or more, as in the confined aquifers of South Jersey.

Of total precipitation in New Jersey, a general rule of thumb for natural watersheds is that roughly 50 percent or more moves back to the atmosphere through evaporation from the ground surface and transpiration through plants, generally grouped in the term evapotranspiration (see Sloto and Buxton, 2005). Roughly 10 to 20 percent may move quickly to streams as runoff. The remainder infiltrates the ground surface and becomes ground water, where all the voids in the geologic formation are filled with water. Some ground water is of sufficient volume and quality to be capable of meeting significant human uses; these are aquifers.

Ground water near the land surface generally flows to streams, supplying the vast majority of annual average stream flow in watersheds with limited development and water withdrawals. That flow is much steadier than the typical pulse flows from rainfall events, which will cause a quick rise and relatively fast decline in stream flow as the precipitation event ends. Stream structure and ecosystems evolve in accord with that pattern of steady flows from ground water and peak flows from storms. Only in more developed watersheds will runoff provide major portions of total flow, causing shifts in stream structure and aquatic ecosystems.

Ground and surface waters are closely related in New Jersey watersheds. In watersheds where a great deal of ground water is withdrawn from the shallow aquifers and transferred out of the watershed, the flow of ground water to the streams will drop. Increasing ground water withdrawals may reach a point where runoff becomes, by default, a larger percentage of total flow, even in an area with little development. Again, stream structure and ecosystems will alter in response.

With this very general understanding of watershed function, we can explore how climate change may alter watersheds in ways that affect water supply availability and infrastructure.

Total Precipitation

Year to year precipitation varies widely, including several moderate to severe drought events, especially the drought of record (maximum historical drought) of the mid-1960s, and other major droughts such as in 1981-82 and 2001-2002, and many major precipitation events, including but not limited to tropical storms (or their remnants) and nor-easters. The Office of the NJ State Climatologist has documented a clear increase in annual average rainfall over time. “Since 1895, annual precipitation has increased at a rate of 4.1 inches (or about 9%) per century” (RCI, 2013), though with high variability within that period. This increase is in line with averages for the Northeast United States, where “precipitation increased by approximately five inches, or more than 10% (0.4 inches per decade)” (Horton, et al., 2014).

Increasing rainfall provides opportunities for greater water supply, especially if the rainfall occurs during periods where ground water infiltration and aquifer recharge can occur, supporting both long-term stream flow that enhances surface water availability and direct withdrawals from the aquifers for human use.

Therefore, to the extent that increased rainfall results in greater water availability, climate change would be seen as a positive for this particular consideration. However, average annual rainfall is not the only issue with precipitation. One guarantee that we have from meteorology is that actual rainfall will not occur in storms that are average. Precipitation events vary tremendously in duration, intensity and total precipitation – it is unlikely that any one storm will be “average.” Therefore, attention must be given to how climate change affects storm characteristics such as frequency and intensity.

Precipitation Intensity and Flood Potential

The U.S. National Climate Assessment notes that the Northeast United States has already seen “a greater increase in extreme precipitation than any other region” with a roughly 70 percent increase in intense storms between 1958 and 2010, defined as the heaviest 1 percent of precipitation events (Horton et al., 2014). Global Circulation Models (GCMs) are used to assess the potential for climate change globally and in major regions of the world. On average, GCMs indicate that our region of the nation may experience a further increase in the intensity of storms.

The increase in heavy rain events is broadly consistent with climate model simulations, which show a greater fraction of precipitation falling in heavy rain events. Such models also project an increase in the frequency of dry spells.

If annual average rainfall were to follow historic patterns, the result of increased storm intensity would be fewer total major rainfall events, with longer periods between significant rainfall. Having more intense storms also translates into potentially greater flood events. Should increasing storm intensities be combined with increased annual average precipitation, we could expect an increase in significant major storm events in our region. However, the recent record is not long enough and the modeling results are not large enough to be certain that such effects will occur.

Storm events and flooding can affect water supplies in many ways:

- Direct damage to water supply infrastructure that is flooded or exposed to stream erosion, such as treatment facilities, non-submersible pumps, pipelines that border or cross rivers, etc.
- Water quality degradation due to additional stormwater runoff, stream erosion, flooding of wastewater treatment facilities that then discharge inadequately treated effluent, mobilization of hazardous substances, etc.
- Increased treatment costs due to water quality degradation caused by storm events or later eutrophication in reservoirs that receive high nutrient loads from the storms.

- Lost revenues due to flooding of customer buildings, resulting in less water demand for the period of restoration.
- Operational difficulties due to impassible roads, bridges, water movement into operational areas, employees that need to address flooding effects on their families, etc.

Water supply systems will need to address all of these potential impacts in their planning, asset management and resilience processes, as discussed in "Options for Climate Change Adaptation."

Evapotranspiration Rates

All else remaining unchanged, we can expect that a warmer climate will also lead to an increase in potential evaporation and transpiration (i.e., the rate that would occur in the presence of sufficient moisture). Several scenarios are possible. If rainfall is more frequent, that also means more periods where moisture is available at the surface to evaporate. If rainfall is more intense and less frequent, then evaporation rates could be a lower percentage of total precipitation, and runoff would likely increase relative to evaporation. Higher temperatures facilitate greater evaporation from land and water surfaces (including reservoirs), which will reduce runoff, recharge and water storage.

Transpiration might increase because higher temperatures increase plant stress and therefore increase their need to move water through the plant tissues, but also may reduce if water stress from very high temperatures slows plant growth. One significant ecological expectation is that increased heat stress and insect pest migration will cause some plants that are not as heat tolerant or are prone to pest infestations (such as hemlocks in both cases) to not thrive or even survive in New Jersey, while other, more southern, species will expand their presence; shifts of this nature are already observed in various parts of the Northeast (Horton et al., 2014).

Evapotranspiration (ET) is important because it is such a large portion of the total hydrologic equation in New Jersey. As one example, assuming no change in precipitation or runoff patterns, a relatively small increase in ET, say from 45 to 50 percent (an increase of 11 percent), mathematically results in a major decrease in ground water infiltration, say from 25 to 20 percent (a decrease of 20 percent). That change in infiltration into the ground will affect the yield of aquifers and the flow of streams on which our surface waters rely.

Infiltration and Recharge Rates

Short-term changes in infiltration are difficult to predict, in part because it cannot be monitored directly over large areas. Using stream flow analyses, the New Jersey Geological Survey concluded that much of the infiltration that actually recharges ground water resources occurs during periods where the ground is not frozen, but prior to or after vegetation is actively growing (Charles, et al. 1993). The question, then, is whether the potential for recharge will increase or decrease. The following considerations will play a role in this determination:

- Warmer average temperatures will, on average, result in longer periods where the ground is not frozen, providing an enhanced potential for recharge.
- Warmer average temperatures will, on average, increase evaporation and will result in a longer growing season where plants will capture water for transpiration; both would decrease recharge. Nationally, the growing season has been increasing and is expected to continue doing so (Melillo et al., 2014).

- Increased rainfall would tend to increase recharge, especially to the extent that the rainfall is sufficient to overcome soil moisture deficits, at which point ET impacts become a smaller portion of total rainfall.
- Increased rainfall intensity would tend to decrease infiltration and therefore recharge, as most soils have a limited capacity to absorb water rapidly, resulting in more runoff.
- Increased drought frequency would tend to reduce recharge during both the growing season and the non-growing season.

We do not have sufficient information to predict the long-term implications of climate change on ground water recharge rates. Therefore, the optimum approach is to develop scenarios that provide a range of possible results. This approach is discussed in "Scenario Evaluation for Source Water Trends and Implications."

Runoff Rates

Increased rainfall intensity would result in higher runoff rates. If increased total precipitation also occurs, then runoff rates would be further exacerbated (and *vice versa* if total precipitation decreases). Increased runoff has both positive and negative impacts. On one hand, runoff helps fill reservoirs during periods when the reservoir levels have dropped due to summer demands or dry periods. On the other hand, runoff tends to bring water of poorer quality into streams, especially in developed areas. Reservoirs could experience impaired water quality, as could run-of-the-river withdrawals (where water withdrawals are directly from rivers); in both cases these supplies will need greater treatment. Runoff, of course, is directly related to the flooding issues previously discussed.

Runoff is also reduced by higher ET rates, which create soil moisture deficits that result in greater absorption of rainwater before runoff is created. Runoff reductions of over 10% have been estimated if temperatures increase by 3^{o}C in the Northeastern states (CCC, 2009).

Drought Potential

Global Circulation Models (GCMs) on average indicate that our region of the nation may experience more frequent short summer and fall hydrologic droughts (Horton, et al., 2014). The water supply implications of this forecast are complicated. The models are telling us that future droughts will be more frequent, but not necessarily more severe. While all droughts impose some level of stress on water supplies, some will have limited long-term effects. If the projected more frequent droughts are spaced out over time, then our existing water supply systems should be capable of recovering between droughts. After all, our reservoir systems were originally constructed to provide water during major droughts, and have since been augmented with additional reservoirs and interconnections intended to help provide sufficient supply for a repeat of the 1960s drought, which is the drought of record (NJDEP, 1996). All surface water supply systems are required to calculate a safe yield based on a repetition of the drought of record.

However, more frequent droughts raise the potential for sequential droughts that do not allow for recovery of reservoir levels or aquifer storage, resulting in a scenario where moderate droughts could have aggregate results that severely test our water supply capabilities. As with recharge, scenario testing can be used to determine the sensitivity of our supplies to new conditions.

Temperature Changes

As with the globe as a whole, temperatures in New Jersey have been rising since 1900, with a "long-term upward trend of 2.2°F per century" (RCI, 2013). These are long-term trends within considerable variability within the trend period. Temperatures are expected to continue increasing both on average and in terms of extreme highs (Horton, et al., 2014), with unusually warm months predominating (RCI, 2013). There are two issues related to temperature changes, beyond the impacts on ET rates. One is that warmer temperatures can change water chemistry without any further addition of pollutants. The other is that higher temperatures can change the terrestrial ecosystems in ways that affect water resources.

Water Quality Impacts

Warmer water is less able to absorb oxygen, capping maximum diurnal oxygen levels. New Jersey will see some of its trout maintenance and trout production waters shift to non-trout status as average temperatures and the frequency of peak temperatures increase. Decreased oxygen levels and increased temperature can also cause other changes in water chemistry, such as the increased mobility and bioavailability of heavy metals (John and Leventhal, 1995). Because higher atmospheric CO_2 levels create higher carbonic acid levels in water, pH in surface waters may also be reduced, further affecting metal mobility. Turbidity is likely to increase due to more intensive storms, which can increase treatment costs and reduce effectiveness. Higher stream temperatures also can lead to higher pathogen levels, as bacteria and viruses will remain viable longer. Elevated temperatures also will support algal blooms, which require more extensive water supply treatment to address taste, odor and toxicity issues; that treatment of organic materials can lead in turn to increased disinfection byproducts that are harmful to human health.

Landscape Changes

New Jersey's forests, fields, wetlands and riparian areas support ecosystems that have evolved to survive and thrive under historic climate patterns, including temperature. Significant shifts in temperature will alter these ecosystems. In general, we can expect plants that are at the southern edge of their range to lose area in New Jersey, being replaced with more southern species that migrate north. Species that are currently within the middle of their range will likely remain.

The result will be a gradual shift in terrestrial, riparian and wetland habitats to more resemble those of states south of us. The shift will be slower for long-lived species, such as trees, except where southern pest species migrate north and destroy forests. This concern exists for Pinelands forests, for example, which are threatened by the Southern Pine Beetle, *Dendroctonus frontalis*. Short-lived species should be able to shift territories more quickly.

Two concerns occur regarding these shifts. First, there is no guarantee that new species will shift into an area at the same rate that old species shift out. The result could be ecosystems that are less robust and provide reduced benefits for ground water recharge, runoff controls and stream quality. Second, the new ecosystems could have different, and perhaps higher, ET rates than the current ecosystems, resulting in a reduction in infiltration and recharge.

Sea Level Rise

Sea level rise is a reality and the rate of change recently increased. Hay et al. (2015), suggest that the rate of global mean sea level rise has increased from a 1901-1990 rate of 1.2 +/- 0.2 millimeters per year to a post-1990 rate of 3.0 +/- 0.7 millimeters per year (both at a 90% confidence interval). New Jersey also is affected by land subsidence due to what is called isostatic rebound, a shifting of the continental crust after the last ice age where land that had been under the glacial ice sheet (and therefore depressed in elevation) is rising and land south of that area is sinking. South Jersey is also affected by land subsidence from reduced pressure levels within the confined aquifers of the coastal area, due to ground water withdrawals. Ground water used for potable supply is not restored to the aquifers; rather, nearly all the resulting treated wastewater is discharged to the ocean. This condition is a direct result of past policy decisions to use centralized sewer systems rather than a decentralized approach. Beneficial reuse of wastewater to maintain aquifer pressure is feasible but expensive.

The net rise of relative sea level (the land surface relative to the sea) anticipated for New Jersey will depend heavily on global factors, but will be higher than the global average due to land subsidence. Estimates for New Jersey range from 13 to 28 inches (best estimate 18 inches) by the year 2050, and by 30 to 71 inches (best estimate 42 inches) by the year 2100 (RCI, 2013); both are within the lifespan of new water infrastructure constructed during the next 20 years. Even within the low part of the ranges given, there are major implications of such relative sea level increases for water supply systems.

Infrastructure Vulnerability

Sea level rise itself will increase erosion potential in coastal areas and will also result in more routine flooding of coastal areas that are already at risk of or are subject to tidal and storm surge flooding. These risks escalate enormously in major coastal storms where a combination of storm surge, tides and wave action can cause saline water to penetrate far in from the normal high tide mark. Hurricane Sandy and the 2016 Winter Storm Jonas both showed clearly the threat of saltwater inundation of water supply infrastructure.

Pumping stations are critical for providing water to customers in flat coastal areas. Unless the pumps are either completely protected or are fully submersible, storm inundation can result in pump failure. A few water supply wells remain that are on or very near barrier islands. As with pumps, these wells need to be protected so that saltwater does not get into the well casing or annular space. Water supply treatment plants are rarely if ever located in areas subject to coastal inundation (but see River Intake Vulnerability, below).

Finally, pipelines face the potential for damages both by erosion, where the pipes are exposed at the surface by erosion of the surrounding soils, and by inundation with saltwater that infiltrates the ground around the pipes, potentially causing corrosion. New Jersey has some coastal development where pipes are routinely exposed to saltwater, while others may be exposed during major storms.

Aquifer Vulnerability

Several aquifer locations in New Jersey are vulnerable to increased saltwater intrusion from sea level rise. Two, in the Monmouth Bayshore area along the Raritan Bay and in the Gloucester/Camden County area along the Delaware River, have already been declared Water Supply Critical Areas by the New Jersey Department of Environmental Protection and subject to withdrawal limitations to reduce the potential for saltwater intrusion. Another concern is the southern end of Cape May County, where saltwater intrusion has already resulted in abandonment (for direct use) of public wells in Cape May City and threats to wells in Lower Township along the Delaware Bay.

A fourth concern is the northern outcrop area of the Atlantic City 800 Foot Sands, a major confined aquifer, in southern Ocean County. A fifth concern is the Delaware Bay area in Cumberland and Salem Counties, where the exceptionally flat topography creates the potential for extensive saltwater intrusion through the marsh areas, potentially compromising local wells that also must be concerned about saltwater in a lower ground water unit.

In each case, aquifer models developed since the 1980s need to be updated to include potential impacts of sea level rise, so that further management of withdrawals can be based on improved estimates.

River Intake Vulnerability

The Brick Township Municipal Utility Authority has an intake on the Metedeconk Creek in Ocean County, at a location created by a small dam. Sea level rise could compromise the functionality of that dam. Delaware River intakes in the tidal sections upstream of the salt line could be more quickly affected during drought periods if sea level rise results in further penetration of the salt line upstream. The salt line is maintained artificially by releases from New York City reservoirs under the Good Faith Agreement among the city and the four Delaware River Basin states (Good Faith Agreement, 1982). Sea level rise will probably require recalculation of the necessary releases, complicating management of the region's water supplies.

Customer Vulnerability

The nature of sea level rise is that it is unidirectional and essentially irreversible within our lifetimes. Therefore, as sea level rise increases over this century to perhaps three feet or more, some areas will be protected (at considerable cost) due to their very high value, and other areas of lower economic value will be abandoned as normal life becomes untenable. The result will be a shift in a utility's customer base and revenues, along with higher costs as infrastructure in abandoned areas must be removed or decoupled from service to avoid compromising the remaining system. This increase in costs and decrease in revenue will affect customer rates. However, abandonment will also result in fewer emergency repairs and lower maintenance costs than when the area was marginally inhabitable.

Coastal Storm Intensity

The climate modeling community has not concluded whether climate change has had a material effect on coastal storm intensity or frequency to date, but the expectation is that warmer ocean temperatures will sustain tropical storm conditions further north and later into the season (Melillo, et al., 2014). Perhaps more important is that even the same frequency and intensity of coastal storms will have worse impacts on developed areas and related water supply infrastructure as sea level rises. If coastal storms also become more frequent and more severe, the potential for frequent, major damages will increase even faster.

Infrastructure Vulnerability

The potential for water supply infrastructure damages regarding coastal storms are similar to those for sea level rise – inundation, exposure, breakage, corrosion. However, where sea level rise is a gradual process, coastal storms can cause episodic, major damages. Sea level rise is inexorable, while the periodic nature of coastal storms usually allows time for some level of restoration in between storms. There is no public expectation that sea levels will decline, but there often is public hope that the most recent storm won't be repeated any time soon. Therefore, the nature of coastal storms makes them harder to incorporate in risk management approaches.

Customer Vulnerability

Hurricane Sandy demonstrated how water supply utilities can lose revenues due to residential and commercial building damages during a coastal storm. Van Abs (2016) documents how one utility saw water demand reductions of up to 60 percent in municipalities hard-hit by Sandy, using a comparison of summer demands in 2012 and 2013. Coastal storms that are more frequent, more severe or both will affect utility costs, certainly, but also utility revenues. Utilities that serve relatively small and vulnerable areas will risk a combination of costs and lost revenues that will be more damaging to their fiscal stability. Utilities with very large and diverse service areas will be less harmed.

Aquatic Ecosystem Changes

Climate change has the potential to alter aquatic ecosystems profoundly, especially in the northern parts of New Jersey where trout populations require cool waters year-round, and potentially in the Pinelands where the unique combination of geology, ground water characteristics and terrestrial ecosystems also support a very unusual aquatic ecosystem that is dependent on high-quality water with a naturally low pH. However, the focus of this evaluation is on the potential for climate change to alter aquatic ecosystems in a way that harms water supplies.

Water Quality Impacts

The primary freshwater quality impact of concern is the potential for warmer waters, quite possibly with more nutrients due to higher rates of runoff and stream erosion,[1] to support higher populations of algae and cyanobacteria (aka blue-green algae) that can release toxins into source waters (as in the 2014 Lake Erie bloom that released microcystins in the lake and prompted Toledo's "do not drink" advisory; Ohio EPA, 2014) or at the very least complicate water treatment by creating taste and odor problems. In New Jersey, algal blooms have been a concern in the Passaic River basin, which has historically had a higher phosphorus concentration than many other source waters. The Wanaque Reservoir has had instances of algal blooms as well. These concerns may increase with climate change.

Passing Flow Requirements

Aquatic ecosystems have developed in response to typical stream flow patterns. To the extent that aquatic ecosystems change, their needs for water flow may also change. Reservoir systems have passing flow requirements that mandate the release of water at a rate that supports specified, fixed flows downstream of their dams. While nearly all reservoirs are required to release flows to downstream rivers, some surface water withdrawals are not associated with a reservoir and so cannot maintain flows in the same manner. Instead, these withdrawals often must cease withdrawals when river flows below a specific level. More recently, NJDEP has imposed similar requirements on withdrawals from wells that are close to rivers and therefore affect river flows. The wells also must cease withdrawals when river flows fall too low (Hoffman and Domber, 2013), where those wells support interruptible water needs such as golf courses.

Nationally, the water needs of aquatic ecosystems are being addressed in more sophisticated ways, through a concept called the Ecological Limits of Hydrologic Alteration (ELOHA) (Poff, et al., 2009). NJDEP and USGS have cooperated on the development of ecological flow evaluation methods known as

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[1] Research indicates that soil erosion from stream banks and beds can be a major or even the major source of phosphorus in streams, as phosphorus that is bound to the soil particles is liberated in the stream. (See Sharpley, 1995.)

the NJ Hydrologic Alteration Tool (NJHAT) based on the ELOHA concept (Kennen, et al., 2007). While not yet used for passing flow requirements in New Jersey, there is at least some potential that the ELOHA concept will come into use here as it has in other states, and that changes in aquatic ecosystems related to climate change will have an effect on the resulting flow targets.

Options for Climate Change Adaptation in the Water Supply Sector

Considerable effort has been expended by USEPA, NJDEP, the water supply sector and its trade associations, and others to better prepare water supply utilities to be resilient regarding climate change impacts. As part of this project, a Basis and Background study was prepared to summarize federal and state guidance, example approaches from other states, and other ideas that may be useful in New Jersey (Millsaps, 2016). More details on many of the concepts noted here may be found in the Basis and Background study; this white paper does not attempt to provide the same level of detail.

Climate Change Risk Evaluation

Water supply utilities face a significant number of risks from climate change. Some of these risks reflect familiar risks at a heightened level (such as droughts and riverine floods), while others represent substantially different risks (such as watershed ecosystem changes and sea level rise). New Jersey has always faced problems from droughts, river floods, water quality degradation and power loss from violent storms, which may be exacerbated by climate change. Accelerated sea level rise, however, poses a new kind of threat to coastal aquifers, surface water supply intakes, and the development supported by water infrastructure.

The USEPA Climate Ready Utility Guide (2012) identified the following priorities and challenges for preparing drinking water (DW) and wastewater (WW) systems in the Northeast for the impacts of climate change:

CHALLENGES BY GROUP		DW	WW
Drought	Reduced groundwater recharge	💧	
	Lower lake and reservoir levels	💧	
	Changes in seasonal runoff & loss of snow-pack	💧💧	
Water Quality Degradation	Low flow conditions & altered water quality		💧💧
	Saltwater intrusion into aquifers	💧	
	Altered surface water quality	💧	💧
Floods	High flow events & flooding	💧💧	💧💧
	Flooding from coastal storm surges	💧💧	💧💧
Ecosystem Changes	Loss of coastal landforms / wetlands	💧💧	💧💧
	Increased fire risk & altered vegetation	💧	💧
Service Demand & Use	Volume & temperature challenges	💧💧	💧💧
	Changes in agricultural water demand	💧	
	Changes in energy sector needs	💧	
	Changes in energy needs of utilities	💧💧	💧💧

The actual risks faced by any one water supply utility will depend on its service area and infrastructure locations, source water type and location, facility technology and maintenance, energy sources, revenue base, regulatory framework and other factors. The following sections provide concepts for consideration in evaluating and responding to climate change risks.

Climate Adaptation Planning

Broadly speaking, water supply impacts of climate change can and should be addressed through several different but linked pathways, each of which will involve different roles for the various entities involved. Hazard mitigation planning can be used to address how climate change will exacerbate the impacts of natural hazards on water supply. Utility planning can be used to reduce risks identified through hazard mitigation plans, and to increase utility preparedness for the more gradual effects of climate change. These two methods are addressed in this section. In addition, planning plays a critical role in the modeling of climate change impacts on hydrology and water quality, asset risk assessment and management, utility management, and source water protection, all of which are addressed in later sections. **In all cases, engagement of critical interests and the broader publics will be important to success in the planning process.** Public involvement techniques for climate change adaptation are similar to those for other water supply and utility planning process, but have the added complication of ongoing political debates regarding climate change itself. While much of the debate is more about the relationship of political ideology to the necessary changes, rather than the science itself, the debate can slow the development of consensus regarding adaptation.

Hazard Mitigation Planning

Hazard Mitigation Plans are developed to address major disruptions caused by natural hazards, through a process developed by the Federal Emergency Management Agency, FEMA. For New Jersey water supplies and climate change, the primary concerns are increased damages from severe weather including floods and storm surge. FEMA outlines the planning process as having four steps:

> "**1. Organize Resources** – At the start, a state, tribe, or community should focus on assembling the resources needed for a successful [hazard] mitigation planning process. This includes identifying and organizing interested stakeholders, as well as securing needed technical expertise.
> **2. Assess Risks** – Next, the state, tribe, or community needs to identify the characteristics and potential consequences of hazards. It is important to understand what geographic areas different hazards might impact and what important people, property, or other assets might be vulnerable.
> **3. Develop a Risk Mitigation Plan** – Based on an understanding of risk, the state, tribe, or community then needs to determine what their priorities should be and develop long-term strategies for avoiding or minimizing the undesired effects of disasters. The product is a mitigation plan and implementation approach.
> **4. Implement Plan and Monitor Progress** – The state, tribe, or community can bring the mitigation plan to life in a variety of ways, ranging from implementing specific mitigation projects to changing aspects of day-to-day organizational operations. To ensure success in ongoing implementation, it is critical that the plan remains relevant. Thus, it is important to conduct periodic evaluations to assess changing risks and priorities and make revisions as needed." (FEMA, n.d.)

The State of New Jersey Hazard Mitigation Plan is developed through the NJ Office of Emergency Management, a unit of the State Police within the Department of Law and Public Safety. A number of natural hazards that may affect water supplies are related to climate change (NJOEM, 2014), including:

- Coastal Erosion and Sea-Level Rise
- Drought
- Flood (riverine, coastal, storm surge, tsunami, and stormwater flooding caused by local drainage and high groundwater levels)
- Geological Hazards (landslide and subsidence/sinkholes) associated with hydrologic changes
- Major Storms (Hurricanes and Tropical Storms, Nor'Easters)
- Severe Weather (high winds, tornadoes, thunderstorms, hail, and extreme temperature)
- Wildfire
- Winter Storms (snow, blizzards, and ice storms)

Similar plans exist or are being developed at the county level, usually involving a wide range of agencies and interests that are engaged in pre-disaster planning, risk mitigation, and disaster response, along with those interests that would be affected by natural hazards, including water supply utilities.

It is critical that hazard mitigation plans (or all-hazard plans, as they are also known) fully address climate change impacts that did, will or may exacerbate natural hazards. All water utilities should engage with the hazard mitigation planning process, making sure that planners are fully aware of utility system assets, ways in which existing natural hazards can compromise utility operations, and ways in which climate change will require enhanced or new efforts to protect against increased hazards.

In addition, hazard mitigation plans should avoid actions that either are not well-supported or actually exacerbate climate change impacts. As one example, proposals are frequently made to deliberately drawn down water supply reservoirs to create space for flood storage, even though doing so is not a design function of these reservoirs, the storage cannot be created in a timely manner, creating long-term storage space reduces the safe yield of the reservoirs and makes them much more vulnerable to the possible increase in short-term droughts, and the drawdown process can create a false sense of enhanced protection for downstream flood plain development.

Utility Planning

Hazard mitigation planning generally focuses on the episodic natural events that pose specific threats to societal functions. Climate change will certainly exacerbate some of these historical natural hazard risks, such as droughts and flooding. However, climate change also poses new risk challenges such as sea level rise and source water degradation due to ecosystem changes, which cumulatively require planning and management. The responses to individual hazardous events may be different from the responses to long-term gradual changes such as sea level rise.

Utilities need to address these long-term vulnerabilities as part of their capital planning efforts, as most utility infrastructure is built to last for many decades. Combining hazard mitigation planning with long-term adaptation planning will help identify the most cost-effective approaches that address both needs.

Scenario Evaluation for Source Water Trends and Implications

While the science explaining climate change and its implications is well-established and advancing quickly, and models are likewise improving, there is an inherent level of uncertainty in all estimates of future impacts. The purpose of models is to provide a simplified conceptualization of reality that allows testing of assumptions and hypotheses to better understand a specific component of the real world; models cannot be perfect. The science and models will improve over time, but management decisions are needed now regarding infrastructure that will remain in place for 50 to 100 years. Likewise, we need to make decisions regarding source water protection – both quality and quantity – that cannot wait for an eventual improvement in certainty.

The most appropriate answer is to use the best available models to develop multiple, plausible scenarios for the future. Planning would then show how each scenario can be addressed through adaptation. If all scenarios can be successfully addressed, then resource and utility management will likely succeed if New Jersey fully implements those management approaches. Some scenarios may be beyond our current capacity. In these cases, monitoring, planning and technical efforts can be targeted to better evaluate scenario probability and to improve adaptation methods for those conditions as needed and possible. This section discusses approaches for scenario development, evaluation and planning. In each type of modeling, the climate change scenarios should be the same to allow effective planning based on common conditions.

Climate Change Scenarios

As discussed in Millsaps (2016), federal agencies collaborate through the U.S. Water Resources and Climate Change Adaptation Workgroup to downscale global climate projections and hydrological analysis from the Coupled Model Intercomparison Project Phase 5 (CMIP5-based). They are updating low flow statistics calculation methods for evaluating impacts to water quality from climate change. (USWRCCAW 2015). Though there are significant benefits to development of independent modeling that is directly relevant to New Jersey, the state could base its climate change scenarios on the national work as a way of expediting progress in the modeling efforts. As noted above, the focus of scenarios is not accuracy *per se*, as long-term, complex models have inherent uncertainties. Rather, New Jersey agencies should work with scientists in the fields of climate, hydrology and ecology, from the US Geological Survey, Delaware River Basin Commission, academia and other appropriate institutions and organizations to select plausible scenarios that cover a wide but not extreme spread of possible futures under climate change.

Surface Water Availability Models

Safe yield models of varying sophistication have been developed for all major New Jersey reservoir-based systems. Safe yield models are generally based on historic conditions, which we now understand should not be used to represent future conditions. Several steps are needed to address climate change impacts. First, safe yield models need to be upgraded and (where reservoir systems are within common river basins, such as the Passaic), made compatible so that each model can be integrated with the others. The upgraded models should be capable of accepting alternative streamflow, precipitation and ET scenarios for testing purposes.

Second, technical specialists should create alternative, long-term streamflow, precipitation and ET rates based on the common scenarios, for use in the models. Third, the models should be run based on the various scenarios, which will result in a range of possible impacts. Fourth, the impacts should be evaluated against current and forecast water needs, regulations and operating protocols to see which (if any) scenarios exceed the management capacity of our current systems. Finally, management approaches should be developed to address any scenarios that exceed our current capabilities, to the extent feasible.

Regional Aquifer Models

As with the surface water supply systems, water supply models exist for the confined aquifers of southern New Jersey, many of the unconfined aquifers of that region, and nearly all of the glacial aquifers of northern New Jersey. NJDEP has at various points worked with USGS to update the older models to more current software platforms, and some models are more recent. Again, these models are based on historic conditions, and do not account for climate change.

In the same manner as for surface water availability models, New Jersey needs to upgrade and update its aquifer models so that they are fully capable of being used to model various climate change scenarios. The results will identify which (if any) scenarios would cause harmful effects to one or more aquifers, and management approaches to mitigate those effects as much as possible.

Linked Water Availability Models

In northern New Jersey watersheds, major aquifers and major reservoir systems exist within the same geographic area. Withdrawals from aquifers can reduce reservoir yields. Reservoir storage can increase aquifer levels through leakage. New Jersey should identify areas such as the Passaic River Basin, the Raritan River Basin, and the reservoir watersheds of Monmouth County where linked water availability models should be developed, combining the surface water availability models with the aquifer models.

Source Water Quality Models

New Jersey has a wide variety of water quality models that were developed to manage and mitigate water pollution, as required by the federal Clean Water Act and state laws. The resulting models are used to develop pollutant load allocations for point and nonpoint sources, which comprise parts of the "Total Maximum Daily Loads" (TMDLs) that would achieve compliance with water quality standards. These TMDL models generally address one or a small number of pollutants (e.g., dissolved oxygen, nutrients, total suspended solids, pathogenic bacteria).

Developing similar models for a wide range of pollutants in all potentially affected streams would be an extremely laborious and expensive process. To address potential climate change impacts, therefore, it makes more sense to make use of existing models from a range of watershed conditions, modified to incorporate climate change projections, to better understand what climate change impacts are most likely to alter water quality in a clearly harmful manner.

To undertake this analysis, relevant scientists from a variety of governmental, academic and non-governmental entities should identify the range of watersheds, available models that are sophisticated enough for this purpose, and determine how the hydrologic modeling discussed above could be used to help identify the impacts of climate change on stream flows. For the selected watersheds and models, alternative stream flow, water temperature and pollutant loading information should be developed for use in modeling the scenarios. Again, the results will identify which (if any) scenarios would cause harmful effects to one or more watershed or aquifer source waters, and management approaches to mitigate those effects as much as possible.

Linked Water Availability and Water Quality Models

There are some regions of New Jersey where surface water or aquifer withdrawals (and their related passing flows, if any) could have a major effect on water quality under varying climate change scenarios. Those water quality impacts could in turn change water availability, or at least the cost of treatment. As with the linked aquifer/reservoir models, experts should identify areas where linked water availability and quality models should be developed to test the climate change scenarios and determine problems that need to be addressed through improved management.

Landscape Change Models

The next issue for modeling is that landscapes don't remain static, and certainly are expected to change both through the effects of climate change on terrestrial ecosystems and through continued land development. Ecologists should develop scenarios for ecosystem shifts based on the selected climate change scenarios, such as changes in forest type, with these ecological scenarios then being used to assess potential effects on hydrology and water quality. Where the ecological scenarios drive significant hydrologic or quality effects, management approaches should be devised to address those issues.

Linked Water Availability, Quality and Landscape Models

Finally, there may be some areas, such as the Pinelands, where the ecological implications of climate change are so tightly linked to water availability and quality that an effort should be made to link the relevant models to assess climate change impacts across all three issues simultaneously. If the Pinelands pitch pine ecosystems were to be lost due to pest infestations, the replacement forest type could shift the typical acidity of Pinelands waters, and could have increased or decreased transpiration rates, affecting water availability. There is no guarantee that such an effort is feasible at this point (the combined uncertainties may overwhelm the value of the detailed results) and so it is entirely possible that the most appropriate step in the near future will be a qualitative evaluation based on independent models. If the qualitative assessment indicates no additional concerns beyond what the independent models show, that finding may be sufficient for the foreseeable future.

Asset Risk Assessment and Management

The value of water utilities is linked to its assets – physical infrastructure, capabilities of its personnel and consultants/contractors, economic strength of its service area, and management capacity of its executives and governing body. Considerable attention is focused on these issues from a general perspective. The purpose of this white paper is to discuss special stresses from climate change.

System Evaluation

Asset management requires a thorough understanding of the current utility assets in terms of location, character, integrity and potential lifespan. Climate change does not change this fundamental approach, but requires that the system evaluation include how well the existing assets can address the specific risks of climate change, as discussed in the section "Background: Implications of Climate Change for Water Supply." Just as the asset inventory and evaluation must remain current, climate change risks should also be updated within the evaluation.

Key Assets Identification

The next step in asset management is to identify key (or critical) assets that would significantly compromise the utility operations should they fail to work as expected. Key assets can range from pumping stations and water mains to critical personnel for emergency response. Climate change may shift the identification of critical assets somewhat, mostly by adding assets that would be most affected by climate change but otherwise would not have been on the list.

Risk Assessment and System Improvements

The critical step is to then incorporate both the system evaluation and key assets identification into a risk analysis. The most important assets with the lowest current integrity scores would be at highest risk of failure. The risk assessment then is used to generate a risk management program with steps to address each key risk on a schedule that is likely to avoid failure or significant disruption of utility operations. The final result is implementation of the risk management program. These two steps are not altered by climate change considerations, as the climate change issues were already incorporated into the prior steps.

Water Supply Utility Management

A variety of laws and regulations already exist to achieve proper management of water utilities, primarily through the Safe Drinking Water Act and the Water Supply Management Act. It is clear from an historic lack of capital investment that these laws and regulations have not been sufficient, with estimated needs in the billions of dollars for New Jersey utilities (USEPA, 2013; AWWA, 2012). However, the purpose of this white paper is to focus on management responses that are particular to climate change issues, and not the general issue of utility management. Three issues are addressed here: how potable water supplies are used; whether and when beneficial reuse of wastewater might be appropriate; and energy supplies for water utilities. In each case, collaboration will be required between the NJDEP, which is responsible for determining appropriate standards for utility infrastructure and operations, and the two agencies responsible for oversight of utility budgets: the Board of Public Utilities for investor-owned utilities, and the NJ Department of Community Affairs for publicly-owned municipal utilities and utility authorities. These two agencies will need to allow for sufficient investments to ensure compliance with the NJDEP standards.

Water Conservation and Efficiency

Water conservation is a term used to cover a wide range of activities that maximize the ability of a utility to deliver water to customers (relative to the amount produced), from effective storage to the integrity of distribution lines within utility ownership and from the street to the customer building or facility. Conservation includes fixing leaks in dams, reducing wastewater creation during the water supply treatment process, reducing the frequency of line flushing necessary to maintain water quality and system integrity, fixing pipelines to reduce water losses, maintaining sufficient but not excessive water line pressure to minimize water losses, etc. While no system achieves 100 percent delivery of system water to customers, the current loss percentages range widely from perhaps 5 percent to large portions. Reduction of water losses increases a system's resilience to climate change impacts, as more water is delivered to the actual uses during stressed periods. Improved standards are needed regarding the measurement, evaluation and reduction of losses to the cost-effective minimum levels, known as unavoidable losses. Water conservation also includes control on wasteful behaviors (e.g., not taking long showers or allowing taps to flow when water is not being used).

Water efficiency relates to the technical capacity for minimizing use of the water by the customers, to achieve the maximum utility of that water once the customer receives it from the utility. Water efficiency is primarily achieved through a combination of improved technology (e.g., water-efficient appliances, automatic sprinkler systems with soil moisture sensors).

As defined here, water conservation is often but not entirely a utility (supply-side) activity, while efficiency is often a customer (demand-side) activity. However, there are overlaps, such as when a utility provides incentives for water efficiency improvements through inclining rate structures or appliance subsidies.

New Jersey's annual average water demand from public community water supplies has been gradually declining while summer demand has increased, indicating that water uses within buildings have become more efficient while external uses (primarily lawn irrigation) have become more prevalent. One result is that per capita consumptive demands (i.e., water that is withdrawn from the environment but not returned) has increased, linked to increased evaporation and transpiration associated with the outdoor water uses (Van Abs, 2013).

As temperatures rise, especially peak summer temperatures, summer water demands are likely to increase for both residential purposes (e.g., lawns and pools) and commercial uses (primarily make-up water for building cooling systems). These summer demands will place additional stress on water supplies during the most sensitive period, when aquifer recharge is limited due to higher ET, and reservoir storage is being depleted as demands increase while stream flows and runoff decrease due to a combination of lower ground water recharge and higher ET.

As discussed in the Basis and Background document (Millsaps, 2016), regulators, the water supply sector and its customers can reduce the vulnerability of the water supply through improved conservation and efficiency.

Current requirements of construction codes only affect new construction and rehab projects, not modifications in how people use water with existing development. Rate impacts of inclining block rates (where the cost per thousand gallons increases with increased use) and capital projects should help drive more attention to water use efficiency. Energy savings from more efficient fixtures and appliances will provide additional incentives for efficiency improvements. The plumbing and appliance markets have shifted to address these demands, abetted by federal programs such as the USEPA Energy Star (https://www.energystar.gov/) and WaterSense (http://www3.epa.gov/watersense/programs). The primary challenges are customer education and ensuring that water rates do not harm lower-income households. Utilities have a major role to play in customer education. State government will have a role regarding impacts on household finances.

The New Jersey Legislature and regulatory agencies such as NJDEP and the Board of Public Utilities can also aid in water conservation and efficiency affecting both utilities and customers, including:

- **Modernize Water Loss Regulations**: New Jersey's water regulations do not require use of the AWWA Manual M36 (AWWA, 2016) or similar approaches to estimate water losses and their causes. The Delaware River Basin Commission (DRBC) requires utilities within the basin to do so. As a result, many water utilities outside of the DRBC purview, but elsewhere in the state are still using simplistic techniques for estimating water losses. Better methods will provide clearer information to the utilities on the causes of their water losses. Statewide results should be used to determine appropriate benchmark standards for well-managed utilities that are then incorporated into regulatory requirements to drive improved utility asset management programs.

- **Updates to Construction Codes**: Existing federal and state requirements for new construction, structure rehabilitation and appliances do and will continue to drive more efficient water use as toilets, sinks, showerheads, dishwashers, clothes washers and other appliances are replaced over time. As technology improves, updates to the construction codes will be important. As noted in Millsaps (2016), the International Code Council (ICC) and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) published the *2015 WEP: Water Efficiency Provisions of the International Green Construction Code (IgCC)* (Johnson and Scott 2015). New Jersey should consider incorporating these provisions to the state uniform construction code.

- **Mandate Improved Asset Management**: As discussed in "Asset Risk Assessment and Management," asset management is a process and a program, where one specific approach will not work for all utilities. However, improved processes and programs are certainly feasible and their structure can be described in regulations that provide a much better sense of what is required, how it is to be measured, and what findings should require utility action.

- **Lawn Irrigation Systems**: Current New Jersey law requires that lawn irrigation systems installed after September 8, 2000 be equipped with an operational rain sensor to limit irrigation based on sufficient recent precipitation. New Jersey should consider extending this requirement to any significant retrofit of pre-existing systems.

- **Household Affordability**: Water conservation and efficiency can both help lower-income households, by reducing water demand without a reduction in the benefits of water use, and harm lower-income household by increasing water costs. Some water utilities have a customer base large and diverse enough to implement affordability programs for lower-income households, but others do not. Most effective would be a statewide approach that addresses affordability, which will require new legislation. Even affordability programs at the utility level may require legislation that clarifies the legality of such efforts.

- **Public Education**: State agencies can play a significant role in public education for water efficiency, and some efforts in this direction have already been implemented. However, investment in public education tends to increase as supplies get tight, and decrease as droughts pass. More systematic efforts that drive long-term efficiencies would be useful, especially where those water efficiencies would also help the public save money on energy costs.

For water utilities, the primary approach is and should remain proper operation and maintenance of the water system. These actions include:

- **Evaluations of System Water Loss**: Regardless of regulatory requirements, utilities should use AWWA Manual M36, Water Loss Accounting, or a similar approach to determine their current level and causes of water losses within the system.

- **Asset Management Planning**: Regardless of regulatory requirements, utilities should engage in robust asset management planning and programs, as discussed in the prior section.

- **Improved Customer Metering**: Meter technology is improving rapidly, to the point where water utilities in more densely developed areas (which tend to have older buildings and therefore more leaks in customer plumbing systems) can cost-effectively install meters that automatically report water demands far more frequently than the typical monthly or quarterly approaches. Utilities with such systems report that they have been able to identify leaks on customer properties by looking for high uses in the early morning hours; the result is reduced water demand for the utility and reduced water costs to the customer. While automated meter readings of this type may not be as cost-effective for less densely-developed areas, better meters can still improve water use efficiency in these locations.

- **Water Rate Structures**: Inclining water rates, where higher levels of use result in higher costs per thousand gallons, have replaced flat rate or declining rate approaches in many areas. This shift reflects an awareness that utilities are selling a service (sufficient water to address needs) rather than a commodity (which can be provided more cheaply in large bulk amounts than in smaller amounts), and that high demands causes increased stresses to both the water infrastructure and the source waters. There are two approaches to inclining rates. One is to apply the rate based on customer demand during a fixed time, whether year, quarter or month. The other is to use improved metering technology to apply a steeper block rate at times when the utility system or the source waters are most stressed.

  Customer response to inclining block rates varies based on the customer. Lower-income households will be more price sensitive, which is why most rate structures have an ample allowance for indoor water demand at the lowest rate. Wealthy households are likely to not be price sensitive. Businesses tend to be price sensitive, especially those with major water demands. A major problem with using inclining rates as an incentive is that many utilities still bill quarterly, and so the financial impact of excessive use will be felt long after the use. Monthly billing, especially if augmented by digital notification approaches, would be more effective in driving efficiency.

  Utilities cannot rely on higher revenues from peak seasonal demands, especially in predominantly residential areas where summer demands change greatly depending on the rainfall and temperatures of each month. Utilities have used the increased revenues from peak demand periods to supplement capital investments such as leak reductions, or to fund water conservation and efficiency programs, such as customer leak reduction or appliance replacement. Both are legitimate utility costs, and are equitable in that the costs are imposed on those who are most stressing the system and the source waters. Essentially, the largest users pay for infrastructure, conservation and efficiency expenditures that benefit the same users.

- **Customer Education and Incentives**: Utilities also can be involved in the education of their specific public, the customers. Utilities nationwide have been effective in working with major users, providing technical assistance to lower demands and therefore water costs. Such programs also provide financial incentives that help businesses stay in New Jersey. Utilities could also provide financial incentives for developers to maximize water efficiency in new development and redevelopment, using the LEED program of the U.S. Green Building Council (USGBC 2015). Utilities can link customer education with incentive programs for efficiencies, such as cost-sharing for improved appliances. Utilities can also help customers understand their water demands through more frequent and detailed evaluations of water demands, using analytical software that is either emailed or made available on the internet.

In each case, the intent is to reduce the stress on the water supply and the utility system during peak use times that are exacerbated by increased temperature patterns, especially during the summer.

Finally, the public plays a critical role in water conservation and efficiency. First, they must practice it personally, through their choices of water-using technology and their uses of water. Second, they must demand it of their utilities and the relevant regulatory and funding agencies. Water demands have been decreasing over time, through a combination of regulations and market forces. More will be needed as climate change increases stresses on the water supply system.

Beneficial Reuse of Wastewater

New Jersey has enormous potential for beneficial reuse of wastewater, as roughly 80 percent of all wastewater discharges are to tidal waters and therefore are only used once. Any or all of that wastewater could be put to better use if the demand justified the expense. The reality of reuse is quite different, with very limited reuse overall. The critical question is where and when climate change will create sufficient demand. Nationally, the greatest success of beneficial reuse occurs in regions where there is no choice – reuse is the only “new” water source to meet increasing needs. In New Jersey, some electrical generating stations have needed to reuse wastewater from coastal wastewater treatment plants because the power plant withdrawals from estuaries were deemed too damaging to the ecosystems, and potable water should not be used for such nonpotable purposes and has been reducing in recent years.

Aquifer storage would most justify the expense of reusing wastewater in a major way, to provide a barrier against saltwater intrusion. Artificial recharge at or near the saltwater front would require large water volumes injected at relatively few points, providing an inherent economy of scale where prices fall as volumes increase. This approach is significantly different than providing treated wastewater for thousands of separate users through a new distribution system.

Reuse of wastewater that is discharged to inland waters is more problematic, as those discharges currently support stream flow. For example, during significant droughts, Passaic River flows at Little Falls are heavily dependent on upstream wastewater treatment plant discharges. Reuse of that effluent for consumptive purposes can cause streamflow reductions that would be harmful to the streams and the public water supply systems that rely on the river. Therefore, New Jersey should not anticipate that beneficial reuse of this type will be valuable to offset climate change impacts on inland waters.

However, there is another type of beneficial reuse that will be appropriate in all areas – reuse within individual or closely related buildings to reduce the net water supply demand of those buildings. By reusing wastewater for flushing toilets, for example, potable water that would otherwise have been used for that purpose is saved. Stormwater can be reused in a similar manner without harm to local water bodies, as developed areas discharge considerably higher volumes of stormwater than natural lands. Stormwater reuse is thus beneficial both to reduce runoff and to offset water demands. The net effect is that our standard water supplies – aquifers and reservoirs – can be reserved for more useful purposes and to offset climate change impacts.

Energy for Facility Operations

Climate change is expected to increase the severity of coastal storms. Historically, such storms have resulted in the loss of electricity service to utilities, which then must provide their own service or fail to serve their customers. Hurricane Sandy was a major wakeup call for utilities and their regulators, resulting in a more thorough effort to promote and require service redundancy, on-site power generation capacity, or both. New Jersey should continue to promote and require facility self-sufficiency for energy at least during major storms.

Source Water Protection and Management

New Jersey has attempted to improve the protection of source waters over the last 30 years or more. Some improvements were not directly focused on source waters, but rather were byproducts of statewide programs to control potential or actual pollutant sources. Other efforts, such as watershed management planning and wellhead protection programs, explicitly incorporated source water protection but also had other objectives. Some programs, such as those of the NJ Water Supply Authority and Brick Township MUA, are more specifically focused on protecting source waters. The North Jersey District Water Supply Commission was involved to a certain extent in such programs as well. Finally, the Pinelands Protection Act and the Highlands Water Protection and Planning Act are both focused in part on protection of water supplies.

There are several major constraints to source water protection.

- First, source water protection requires a holistic approach to a geographic area by a variety of governments and non-governmental parties. This kind of approach is very difficult for entities that see their primary role as regulators of individual pollutant sources (NJDEP), water uses (NJDEP), or development projects (NJDEP, counties, municipalities) rather than as watershed managers. Utilities also find this approach difficult, as they are not regulators and are used to seeing their “system” as encompassing only the utility itself, not the entire landscape that contributes to and affects its water source.
- Second, source water protection inherently regulates some pollutant sources differently within the source water area than without, which is hard for regulated parties to accept.
- Third, the impacts of pollutant sources and water flow changes are cumulative; any one change may be minimal, but in combination they are problematic. Knowing which changes are cumulatively problematic requires sophisticated modeling or at least expert judgment calls. In either case, making a convincing argument is difficult.
- Finally, in most cases no one entity is “in charge.” Rather, a collaborative, cooperative approach is required but is often frustrated by the lack of a clear lead entity. In some cases, a crisis can serve as the catalyst for cooperation, but crises are by definition undesirable.

All these issues exist in the absence of climate change impacts. With climate change, we add a hard-to-understand phenomenon to a hard-to-understand approach. However, there are ways in which these issues can be addressed, as discussed in this section. Achieving success will require extensive, coordinated planning and management.

Regulatory Agency Roles

Regulatory agencies can use the climate change scenarios and models discussed above to modify regulatory standards for several key areas. In each case, doing so will protect built systems against more severe conditions. Even if the models predict somewhat more impacts than actually happen, the result is that the regulations will better protect people and property. If the models turn out to be too conservative, at least the regulations will have buffered against some of the climate change impacts.

- **Stormwater Management**: Regulatory requirements for the sizing of stormwater sewers, detention basins, retention ponds, infiltration basins, and all types of green infrastructure are based on historic precipitation records such as the 50%, 10% and 1% probability storms (aka the 2-year, 10-year and 100-year storms) for detention and infiltration, the water quality storm for control of total suspended solids, and the 4% probability (25-year) storm for pipeline size. A major problem is that the resulting infrastructure will remain in place for decades. Climate change means that these calculations, based on past records, are no longer valid even now, will become less valid over time. Therefore, stormwater systems will become less and less useful; any necessary retrofits will be costly. Based on the climate change scenarios, regulators should consider shifting from standards based on "back-cast" conditions to "forecast" conditions. In this manner, new stormwater systems can remain viable into the future. In addition, existing stormwater systems will be more stressed under conditions of more frequent severe storms, which will increase maintenance costs and the potential for system failure, with its attendant social costs.

- **Water Allocation**: The protection of water availability is a key function of source water protection. Once allocations are granted, restricting them (much less voiding them) is very difficult due to statutory constraints. Therefore, regulatory agencies should consider the potential impacts of climate change on future water availability, and maintain a buffer within water allocations for a watershed. In this manner, climate change will less likely result in conflicts over water supply allocations.

- **Flood Hazard Areas**: In a similar vein, flood hazard areas are based on models that use past events as a predictor of future conditions, a concept known as "stationarity." The assumption is that conditions will remain static, that the future will mimic the past. Recent decades of rainfall records and current climate change models upend the concept of stationarity. Because development in the flood plain will remain for very long periods, the public needs regulatory agencies to incorporate climate change scenarios into flood hazard area delineations. Suggestions that development regulations require protection beyond the current flood hazard height (e.g., two or three feet additional height to the first living floor) are a crude way of accomplishing the same purpose. However, the most appropriate correction to the current requirements will differ from watershed to watershed, and even within watersheds. Flood plain mapping takes these differences into account. Scenario-based modeling will better predict the necessary adjustments to the maps. Doing so will reduce inappropriate development within flood hazard areas that will in turn damage source water quality.

- **Saltwater Intrusion**: Three types of saltwater intrusion threats exist in New Jersey. The overarching issue is that saltwater intrusion is extremely difficult to reverse, once a section of aquifer has gone salty.

    1. <u>Confined Aquifers</u>: Withdrawals from coastal aquifers can induce the inland movement of the fresh/salt water interface within the aquifer. This effect is most common in the confined aquifers in the Monmouth/Ocean, Camden metropolitan and Cape May areas. However, it can also occur in unconfined aquifers where wells are too close the coast. This concern can be exacerbated somewhat by rising sea level, which places more pressure on the saline ground water, forcing it inland (the "push"). Increased water

demands due to climate change, such as higher summer temperatures, can induce more intrusion (the "pull"). How much of an issue this might be apparently has not been modeled but it should. Given that the areas of greatest concern, the Water Supply Critical Areas, are already subject to periodic reevaluation, it should be relatively simple to anticipate and correct for these issues. It is worth noting that more and more lawn irrigation systems rely on private irrigation wells, even where public water systems exist. Therefore, NJDEP has declining influence on ground water demands in such areas.

2. <u>Saltwater Upwelling</u>: Withdrawals from aquifers that overlie saline ground water can cause an upwelling of salt water. This issue is of concern in the Cumberland/Salem area such as the Upper Maurice River watershed. Climate change would increase the potential for connate water upwelling if aquifer recharge is reduced or water demands increase, or both. Existing ground water models should be updated and upgraded to allow for an evaluation of this concern, followed by modifications to water allocations where necessary to protect aquifer quality.

3. <u>Coastal Water Intrusion</u>: Sea level rise will result in salt water intruding further inland along coastal rivers and bays. Wells that were protected from salt water can be subject to higher salinity levels as salt water is drawn into the unconfined aquifer. The only truly viable response to this issue is abandonment of threatened wells to protect the aquifer, and replacement with new wells located farther inland where they will not induce saltwater intrusion.

- **Mitigation Requirements**: In general, the regulatory approach is to avoid impacts, minimize impacts, and then mitigate impacts where avoidance and minimization do not address all issues. As with so many other issues, mitigation projects are selected with the assumption that past conditions – of hydrology, ecology and climate – will remain essentially unchanged. Regulatory agencies can specifically incorporate climate change scenarios into the selection of mitigation projects. Not only can projects be created in a way that is more resilient to climate change, they can be selected specifically to help mitigate climate change impacts.

The Utility Role in Source Water Protection

Water supply utilities currently have very little direct responsibility for source water protection. The result is a wide range of efforts, from Newark's near-total ownership of the source watersheds for its Pequannock reservoirs, to public wells that are surrounded by development with essentially no buffer area. Climate change has the potential to exacerbate existing problems and create new ones. For example, even for Newark's protected reservoirs, climate change can result in alteration of the forest ecosystems, additional runoff that could destabilize streams, and temperature-induced changes to stream and reservoir water quality.

Given these potential impacts to nearly all public water supplies (with the possible exception of well-protected confined aquifers), the Legislature could consider requiring that water supply utilities engage more directly and effectively in source water protection. One possibility is a requirement that utilities invest a small amount per million gallons delivered to implement NJDEP-approved source water protection plans. This approach could help avoid climate change-induced damage to water supplies, and mitigate existing threats. It has conceptual appeal over proposals for a water supply surcharge to fund open space acquisition, as it keeps the funds within the utility, fosters innovation to achieve the best results with the available funds, fosters collaborative efforts between the utilities and their source water partners, and allows for a tailored approach appropriate to each source water area.

Ecological Flows

New Jersey has begun efforts to use the ecological flows concept in regulating water allocations. Climate change will make these efforts even more important. Aquatic ecosystems will be stressed by climate change, and so maintenance of critical flow patterns (i.e., not just low flows as in most regulatory requirements, but also the pattern of other flows) will be important. Again, the climate change scenarios and models would be useful for determining what ecological flows will be needed for future conditions, so they can be accommodated now and reduce the potential for future stream degradation. Given that stream flow into reservoirs is an important part of their safe yield, and the quality of that stream flow is an important factor in reservoir quality, protection of aquatic ecosystems can play a valuable function in source water protection.

Available Funding for Water Supply Resilience Improvements

Financing will be needed to address all of the issues and processes identified above. This section provides general information about the most relevant and significant funding sources for each major topic discussed in this white paper. For all categories, general government funds may be available, as allocated through normal budgeting procedures to fund staff efforts and perhaps research projects. Many smaller funding sources may be available in each category, such as the small grants programs operated by the Sustainable Jersey program, the Association of New Jersey Environmental Commissions, and the Watershed Institute at Stony Brook-Millstone Watershed Association.[2] Foundation grants may be available to eligible entities, and online crowdfunding opportunities may exist as well. However, the sources listed below comprise the largest funding possibilities other than general government revenues.

Climate Adaptation Planning

- **FEMA Hazard Mitigation Assistance grant programs**: Flood Mitigation Assistance and Pre-Disaster Mitigation are annual, competitive grant programs for states and local governments. Grants fund eligible mitigation activities to strengthen the ability to reduce disaster losses and protect life and property from future disaster damages. Both can be used for planning activities, and the Flood Mitigation Assistance grant can also fund mitigation projects. See http://www.ready.nj.gov/programs/opb_mitigation.html for more information.
- **Water supply utilities**: Most funding for the operation of utilities is derived from customer charges for services. In a few New Jersey cases, municipal water utilities are either entirely or partially funded by property taxes. In other cases, the municipal water utility or utility authority subsidizes municipal budgets. Investor-owned and private water companies derive their revenue from customer rates and neither support or are supported by government budgets. Regardless of ownership, most utility efforts for climate change adaptation will be supported through their normal funding process.

[2] See www.sustainablejersey.com, www.anjec.org and http://thewatershedinstitute.org/, respectively.

Scenario Evaluation for Source Water Trends and Implications

- **1981 Water Supply Bond Fund**: NJDEP apparently has funds remaining from prior legislative appropriations from this bond fund, for the purpose of developing the statewide water supply plan. Climate change scenario development and modeling would be appropriate costs under this topic. If additional unallocated bond funds are available, they could be targeted to this purpose through specific authorization in the statewide plan and legislative appropriation.

- **Federal and Non-federal Research Grants**: Some aspects of this work may be eligible for funding through federal research grant programs. These grants are usually for the purpose of extending scientific methods and knowledge, rather than application of existing methods to new cases. However, non-federal research grants are periodically available that allow for a greater focus on application of existing practices to new areas. These research grants may be supported by foundations.

Asset Risk Assessment and Management; Water Supply Utility Management

- **Water supply utilities**: As noted above for Climate Adaptation Planning.

- **NJ Environmental Infrastructure Finance Program**: The NJDEP and the NJ Environmental Infrastructure Trust jointly manage this program, which combines state (bond) and federal (State Revolving Fund) funding through NJDEP with market-rate bonds through NJEIT, for a combined loan financing rate that can be significantly lower than market costs for municipal bonding. These loans are for project implementation along with associated planning and engineering costs within a set percentage. Broad-scale planning efforts are not eligible, as the focus is on implementable capital projects. See http://www.nj.gov/dep/dwq/mface.htm and https://www.njeit.org/ for information.

- **US Department of Agriculture, Rural Development**: USDA operates a Water & Waste Disposal Loan & Grant Program for rural areas and towns with fewer than 10,000 people. Among other projects, the capital costs for drinking water sourcing, treatment, storage and distribution are eligible. Engineering and other costs may also be available that are directly associated with a capital project, but general system planning is not. See http://www.rd.usda.gov/programs-services/water-waste-disposal-loan-grant-program for information.

Source Water Protection and Management

- **Clean Water Act Grants**: NJDEP receives annual Clean Water Act funding from the USEPA, including the improvement of water quality planning programs (Section 604b, see http://www.nj.gov/dep/wqmp/funding.html), and nonpoint source pollution control programs (Section 319h, http://www.state.nj.us/dep/wms/bears/319_grant_program.htm). These funds are generally re-granted to outside entities, usually non-profit organizations, local governments, municipal utility authorities or academic institutions. The funds cannot be used for permit compliance, but rather must provide a benefit in non-regulatory areas. For example, Section 604b funds have been used recently to help fund Wastewater Management Plan development. Section 319h funds were used to help fund the creation of subwatershed management plans, but now are primarily focused on implementation of adopted plans. NJDEP has significant flexibility in the use of these funds.

- **NJ Environmental Infrastructure Finance Program**: As identified above for Asset Risk Assessment and Management, and Water Supply Utility Management.

Conclusions

As noted in this white paper and its Basis and Background paper (Millsaps, 2016), our water supplies face a number of challenges due to climate change. These challenges are in addition to the current challenges posed by increasing population, increasing outdoor water uses, existing point and nonpoint source pollution within source waters, and insufficient investments in aging water supply utility systems. Given that New Jersey is already underinvesting in these issues, climate change will stress our systems even more. However, it also may provide enough critical events that the public willingness to pay will shift to a more positive stance.

Achieving successful adaptation will require recognition of the risks, agreement on the most useful adaptation approaches, and a willingness to fund implementation. There must be a recognition that we will pay for climate change adaptation sooner or later. The question is whether we act while we still have the widest range of adaptation alternatives and the longest implementation timeframe, or when our alternatives are constrained and the impacts are already damaging our water supplies. It could be argued that we are already within the latter period, but where we still have time to act.

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