NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

SCIENCE ADVISORY BOARD

FINAL REPORT

CLIMATE CHANGE AND WATER RESOURCES

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Prepared by:

Climate and Atmospheric Sciences Standing Committee

Approved by:

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Executive Summary

The Climate and Atmospheric Sciences Committee of the New Jersey Department of Environment Protection (NJDEP) was asked to respond to the following question:

> *Request the SAB look at* ***climate*** *more broadly in terms of having SAB focus on* ***drought, streamflow and flooding*** *in terms of recent weather patterns (past), broad weather patterns (e.g., El Niño and La Niña), and expected climate change (future). Streamflows are an important component in the safe yield models of the water supply of northern New Jersey. How will these streamflows change as the climate changes? What are the impacts of climate change on fluvial flooding? What are the impacts of climate change on areas that experience both coastal and fluvial flooding?*

This report provides a review of the available knowledge on past and future changes in climate with an emphasis on the hydrologic cycle, including predictions for precipitation and the implications for streamflow and water supply.

New Jersey has become wetter in recent decades relative to the long-term climate record. Future projections from climate models indicate that an increase of ~10% in average annual precipitation would be expected by the end of the century, with the largest increases in winter and spring and little change in summer and autumn. Temperatures in New Jersey have risen, and this increase is expected to continue, with temperatures in the late 21st century exceeding the range of past variability. Higher temperatures will affect the water balance by increasing evaporative demand. The combination of increased evaporative demand and little change in summer and autumn precipitation is expected to result in more frequent "flash droughts." Changes in the frequency of precipitation-bearing coastal storm systems affecting the state are uncertain.

Studies have indicated that an increase in annual streamflow is expected, resulting from higher precipitation and less storage of water in snowpack. Observations from the Catskill Mountains show that the spring runoff peak has been happening earlier in the year. An analysis of streamflow data is underway that will look for possible trends; a report on this analysis is expected in 2021. Climate change is not the only driver of changes in the hydrologic cycle; changes in land use and their effects on stormwater runoff will also affect future conditions.

Research on trends in extreme precipitation that such events have been happening more frequently. A recent study found that extreme precipitation events, by one metric, have more than doubled in the northeastern United States since the mid-20th century. Design standards for extreme precipitation are currently based on past records that do not adequately capture the effects of climate change, thus updating of such standards in warranted. Flooding in coastal regions will be affected by changes in precipitation and increases in sea level, which would be expected to range from 2.3-6.3 feet along the New Jersey coast under a high emissions scenario.

Precipitation

Overview and Extremes

New Jersey has four relatively well-defined seasons, with clashes between cold and warmth that trigger occasional severe weather conditions over the course of any year. However, most of the threatening weather and climate events affecting New Jersey fail to reach the extremes experienced elsewhere. This is a result of New Jersey's proximity to the Atlantic Ocean, which moderates winter cold and often keeps summer heat in check. The Atlantic Ocean also inhibits severe thunderstorms and its waters are not warm enough to sustain strong hurricanes coming from the south. The absence of major mountains usually reduces the chance of extremes in flash flooding, excessive snow, and wind. However, this does not make New Jersey immune from exceptional weather and climate events, some of which cause major harm and damage. Since recordkeeping began in 1895, New Jersey has experienced its two wettest years (2018 and 2011) in the last decade. Extreme events this decade have included Post-Tropical Cyclone Sandy, Tropical Storm Irene, a record October snowstorm, several powerful coastal storms, and multiple instances of local deluges. New Jersey has not faced major drought conditions since early this century, while on occasion short term dry and hot conditions have brought about short-lived flash drought.

The dominant feature of the atmospheric circulation over New Jersey and much of North America is the flow from west to east. These "prevailing westerlies" shift north and south and vary in strength during the year, most often exerting a significant influence on the weather and the underlying climate. Winter brings the strongest westerlies in their southernmost position. Storms form where the cold and warm air clash, and, on average, every few days a storm or frontal system is close enough to New Jersey to potentially bring about an episode of precipitation. On occasion a coastal nor'easter or other strong low-pressure system moving through the eastern US will generate heavy rain and/or snow. At other times, cold Arctic air may invade the region. Spring and fall are transition seasons when winter-type weather may occur, yet summer heat and severe thunderstorms may also make an appearance. A New Jersey summer without several weeks of above normal heat and excessive humidity is rare. Day-long storms are unusual; however, conditions are frequently ripe for thunderstorms, which may bring flooding rains, strong winds, and dangerous lightning and hail. While New Jersey landfalling tropical systems are rare, the region is no stranger to excessive rainfall and strong winds associated with these summer and fall storms, with associated tidal and river flooding, as they pass close by.

Annual precipitation around New Jersey historically ranges from 52” to 54” in the Highlands of the north to a minimum of 40” to 42” along the southern coast. There is a relatively small range between monthly averages, with summer months somewhat wetter than winter ones, especially away from the coast. Wet years are those with totals more than 10” above the mean, with dry years 10” or more below the mean. Monthly extremes range from under an inch to over 10”, while totals between 2.5” to 5.0” are most common in all months. Extended dry spells with little or no rain over a multi-week period are not uncommon, while a single storm can bring a foot or more of rain to isolated locations. These totals include the melted equivalent of any snow that may fall.

Seasonal snowfall on average ranges from just over a foot in far southern areas to more than four feet over higher northern elevations. Seasonal extremes have been observed from several inches to over six feet over the past century. Individual storms may deposit over a foot to as much as 2.5 feet or a bit more in any part of the state. Usually 10" of snowfall is equivalent to 1" of liquid precipitation, but even in winter, rainfall contributes more water than melted snow. However, on occasion, upwards of 5” of water may accumulate within a long-lasting snowpack, thus increasing the flood threat should melt occur quickly, especially if accompanied by rain. One of the most noteworthy of such situations occurred in mid-January 1996, less than two weeks after a crippling snowstorm.

Variability

Significant variations in New Jersey precipitation have been observed over the past century. Both the North and South have become wetter in recent decades compared to earlier in the 20^{th} century. In the north, the 1971-2000 average precipitation was over 5” (12%) greater than from 1895 to 1970. Autumn (September-November) is the season with the greatest increase, while summer shows the smallest rise. The South became about 2” (5%) wetter late in the 20^{th} Century through present. Autumn wetness in the South increased more than in other seasons, with summer showing no change. Considerable interannual variability in precipitation is common throughout the past 125 years. This is especially evident in recent decades, particularly with respect to the number of wet years with annual totals exceeding 55”. Consecutive years with precipitation 5” or more below the long-term mean are uncommon, with the mid 1960s having three such years (1963-1966). Only once since 1895 (1902-1903) have two consecutive years been 5” above average, while 2003-2011 saw four years in that category.

Looking ahead

There have been several studies that have employed climate models to project future weather and climate conditions in the Mid-Atlantic and Northeast (e.g., Jacobson et al., 2009, Union of Concerned Scientists, 2006, 2008). None have focused solely on New Jersey, in part due to the modest dimensions of the state relative to those of model grid cells. In all cases, model ensembles (averaged results from multiple models) were used to make projections, lending considerable strength to the results. The New York City Panel on Climate Change conducted a thorough regional study (Horton and Rosenzweig, 2009), the results of which can be considered generally representative for New Jersey.

It is anticipated that as the 21^{st} Century continues, annual precipitation will remain steady and possibly increase from late 20^{th} Century values. End-of-century totals may be 10% higher (Easterling et al., 2017). It is important to reiterate that the last 30 years of the 20^{th} Century were the wettest such interval during that century. Precipitation intensity is expected to increase as the century progresses. This is partly because precipitable water vapor (PWV) increases with temperature; based on the 36 year (1979–2014) ERA-Interim reanalysis data set, a recent simulation shows that global PWV should increase in the range of 6%–13% K^{-1} (11%-23% $°F^{-1}$) accordingly with air temperature increase (Chen and Liu, 2016). In other words, even should annual precipitation fail to increase in some years, a greater percentage will likely occur in intense episodes. This would lead to more flash and river flooding.

Precipitation totals, frequency, and intensity are not the only things that must be considered in evaluating the overall water budget. It is also critical to factor in the expected warmer temperatures and the cumulative impact of precipitation and temperature on evaporation. Infrequent, heavy rains that quickly run off or evaporate may become more commonplace as this century progresses. This could actually lead to more frequent droughts, even as intense events and total precipitation increases.

What is not considered and may be quite important are more frequent "flash" droughts that might arise over several summer months, later to disappear should heavier cool-season precipitation occur. Also, evaporation levels are much lower during the cool season, thus contributing to a lower drought threat than in summer.

Winter and spring precipitation is projected to increase for the 21st Century; extreme precipitation is also projected to increase. The projections of increasing precipitation are characteristic of a large area of the Northern Hemisphere in the northern middle latitudes, as well as increases in heavy precipitation events. Projections of above average precipitation amounts, and more frequent extreme precipitation events may also result in increased coastal and inland flooding risks throughout the state (Dupigny-Giroux, 2018).

Precipitation Intensity

Changes to extratropical storm tracks in the North Atlantic are possible (Roberts et al., 2017), but have not been reliably established (IPCC, 2013). Changes in the frequency, intensity, and tracks of storms is an area of active research, and the New Jersey Science and Technical Advisory Panel (STAP) concluded there is no definitive consensus regarding such changes (Kopp, 2019). The need to better understand projected changes to coastal storms has spurred several areas of active research that could influence scientific understanding of future projections, including changes in the Gulf Stream, changes in sea surface temperatures, changes in blocking patterns, and possible evidence of a poleward shift in storm tracks (e.g., Colle et al., 2013; Emanuel, 2007; Harvey et al., 2015; Maloney et al., 2014; Overland et al., 2015; Reed et al., 2015; Woollings et al., 2012; Garner et al., 2017; Bhatia et al., 2018; Catalano et al., 2019; Roberts, Colle, and Korfe 2017). The STAP has advised NJDEP that planners and decision-makers should review ongoing and emerging research in these areas that may revise current projections (Kopp, 2019).

Climate change and predicted impact on temperature

Overview and extremes

While the primary focus of this report is on precipitation, when discussing associated water resources, one must include some discussion of temperature. It plays an important role in the hydrologic cycle as evaporation is closely associated with a given temperature regime. Evaporation levels increase as temperatures rise, though factors such as atmospheric humidity, and wind play a role. And this is with respect to potential evaporation, as fluxes are reduced when limited water is available to evaporate. This is to say that evaporation values are higher when water continues to be available to evaporate, and evaporation will stop once available water has evaporated.

January average temperatures across New Jersey range from the mid 20s (°F) in the North to the mid 30s in the South. The diurnal temperature range is 15° to 20° (about 10° to 15° near the coast and in some urban areas). Cold Januaries can be as much as 10° below average, with milder ones 10° above average. Warm-season temperatures do not range as widely spatially or temporally compared to those of the cold season. July means run from the low 70s in the North to mid-70s in the Southwest. The diurnal temperature range (difference between coldest and warmest temperatures in a day) is as much as 5° smaller than in January, as is the range between cool and hot summer months. On average, daytime maximum temperatures may equal or exceed 90° as many as 25 times each year in southern inland and urban areas but as few as 5 or 10 days along the immediate coast, with the highest elevations often not seeing a 90° summer reading. Also, on occasion, a summer might not bring a 90° maximum at a coastal location but in hot summers, warmer locations can have more than 40 days above 90°. Maximum temperatures may occasionally reach into the low 100s, but there are years where no location may achieve that mark. Most winters see an extreme minimum below 0°F, particularly in the Northwest and at times in the southern Pinelands, however such readings are uncommon in coastal and urban locations. Widespread occurrences of temperatures below -10°F are quite rare, especially in recent decades, though may occur atop the highest ridges or in the coldest valley locations.

Variability

New Jersey has warmed in recent decades compared to earlier in the 20th Century. Twelve of the state's 15 warmest years have occurred since 1998. The growth of cities and suburbs and local warming associated with this development does not explain these changes. In fact, the more populated North warmed less than the South.

As of November 2019, the last month with a mean temperature ranking as one of the five coldest on record for that given month was December 1989.

Looking ahead

The same modeling exercises that have looked ahead at precipitation have also done so for temperature. They suggest that the next two decades (through 2030-2039) will see mean annual temperatures from 1.5° to 3°F warmer than during the last 30 years of the 20th Century. This is within the range of warmer years experienced over the past century, particularly over the past decade. The projections are for mean conditions, not extremes; still it is useful to place the projections into this sort of historical perspective. Once into the middle and latter portions of the century, as temperatures continue to rise, there are no years in the past record as warm as the projections.

It is expected that warming will be greater in winter than summer. However, given that the range of summer temperatures is not nearly as wide as that in winter, summer warming of a lesser absolute magnitude than winter could be just as significant as more substantial winter increases. The key to winter warming is the freezing point. Since temperatures presently hover near that threshold in winter, considerable warming will likely produce a marked reduction in the frequency of sub-freezing temperatures and frozen precipitation. While temperatures will continue to fall below freezing quite often during the winter, they will become less common, and cold days and runs of cold days are likely to become infrequent and less intense. Meanwhile, the number of hot days over 90°F is expected to rise considerably.

There has been considerable discussion about a possible influence of rapid Arctic warming (i.e., Arctic amplification) on temperature and precipitation extremes. Some studies (e.g., Vavrus et al., 2017) have suggested that a weaker meridional temperature gradient would result in a circulation patter with waves of higher amplitude. This hypothesis is controversial, as other studies have found evidence to the contrary (e.g., Blackport and Screen, 2020).

Streamflow and Water Supply

A significant amount of work has been completed to understand the impact of climate change upon the stream flow and water supply in the Delaware River Basin and the Kirkwood-Cohansey Aquifer. These areas are well studied by the United States Goeological Survey (USGS) and the Delaware River Basin Commission due to their significance as potable water supply sources for NY, NJ, and PA. USGS has been working extensively on the impact of climate change on streamflow and water supply. WATER (a version of Topmodel) was used to predict future changes in flow in streams of the Delaware River Basin (Williamson 2016). The model predicts higher winter runoff caused by earlier snowmelt, and lower runoff in the spring.

> "*Hydrologic simulations indicated a general increase in annual (especially winter) streamflow as early as 2030 across the Delaware River Basin, with a larger increase by 2060. This increase in streamflow is the result of higher precipitation and a major shift away from storage of precipitation as snowpack."* (Williamson, 2016)

Analysis of long-term climate measurements in the Catskills indicate a general pattern of warming temperatures and increased precipitation, runoff, and potential evapotranspiration is evident in the region (Burns et. al 2007). Peak snowmelt as approximated by the winter–spring center of volume of stream runoff generally shifted from early April at the beginning of the record to late March consistent with a decreasing trend in April runoff and an increasing trend in maximum March air temperature. This change indicates an increased supply of water to reservoirs earlier in the year. Additionally, the supply of water to reservoirs at the beginning of winter is greater as indicated by the timing of the greatest increases in precipitation and runoff—both occurred during summer and fall. These measurements also agree with work completed by the Delaware River Basin Commission (Shallcross 2017) that indicated that predicted trends in climate indicate that the basin will experience similar, but seasonally different, streamflows though severe wet or dry flows are always a possibility.

Another issue that is expected to impact potable water supplies is climate-related sea level rise. In the Delaware River there are potable water intakes located upstream of the saline/freshwater interface. Sea level rise allows for tides to propagate farther upstream and transport salt via "tidal pumping." This is especially evident during droughts when the freshwater flow into the estuary from upstream is reduced. The US Army Corps of Engineers conducted modeling that indicated that under even minor sea level rise scenarios, the saline/freshwater interface would be transported significantly inland, thus potentially endangering potable water intakes (Johnson 2010). Similar finding by the USGS indicate that sea level rise will result in the transport of salt inland into the Kirkwood-Cohansey aquifer (Fiore et al 2018).

The modeling performed up until now shows that changes in streamflow--and especially the timing due to shifts in snow melt and saltwater intrusion due to sea level rise--are expected to occur as climate change continues, particularly changes involving the timing of peak flow shifts due to snowmelt. However, these studies have a large amount of uncertainty due to other factors that may alter the hydrologic cycle. One example of such a factor that will have a major impact on the hydrologic cycle is development.

The State of New Jersey is the most densely populated state in the US and the "natural" hydrologic cycle no longer exists. Impervious surfaces, development in floodplains, and streams that are confined to engineered channels have altered the hydrology and the impacts of these changes may outweigh the impacts of climate change, or they may exacerbate its effects. The impact of climate change and development cannot be studied separately if ascertaining their impact upon water supplies in the state of NJ is the goal. Further efforts towards quantifying the type and extent of development must therefore be made, preferably using interpretation of high spatial resolution imagery from airborne mapping campaigns or commercial satellite imaging, rather than 30 m Landsat, as has been traditionally done for land cover mapping. This is not a trivial undertaking but would likely help reduce uncertainties owing to the development factor.

The NJ State Water Supply Plan (NJDEP 2017) assesses availability of the resource by comparing the existing storage capacity to demands (existing and predicted in the future). However, the only discussion of climate change in the document is a reference to the January 4, 2016 NJDEP SAB Report (NJDEP, 2016). The 2017 NJ State Water Supply Plan includes the following language:

> *"There has been concern with the possibility of changing climate in the future. The NJDEP's Science Advisory Board, Climate and Atmospheric Sciences Standing Committee was asked to weigh on the potential impact of such changes on water supply. The Committee reviewed available literature and issued a report of findings. The final report cited the probability of increased frequency of extreme high temperatures, decreased frequency of extreme low temperatures, a lengthening of the frost-free season, and an increased short-term hydrologic variability. This report then lists a number of potential impacts on water supply. The report concludes "All of these studies and informational resources indicate that climate change will make extreme events, including floods, heat waves, and droughts, more likely. They stress the need to build capacity at the local, regional, and state level to develop and institutionalize strategies to cope with extreme events." NJDEP is committed to monitoring and responding to events in such a way as to preserve the water supply of the State as well as working to ensure an adequate supply into the future." (NJDEP, 2017)*

The NJDEP Water Supply Plan is a guidance document that uses the existing sources of information to make assessments of water availability. The need for additional research into water supply availability will only work to enhance this document. It is updated regularly by incorporating new information that will affect water supplies.

Streamflow measurements are collected by the USGS. In 2005, USGS released a report that described streamflow characteristics in New Jersey for the period 1897 through 2001 for streams with continuous flow gaging stations, and through 2003 for partial record stations (Watson et al., 2005). This 2005 report summarized trends at continuous record gages only. The report concluded that upward trends for high flows were related to stream regulation and development in the basin. High flows at unregulated, undeveloped sites were not found to be related to increases in precipitation.

A comprehensive update of this report is in preparation that will analyze streamflow data through 2017, and thus may show evidence of impacts of climate change. The update study, estimated to be released in 2021, will test for possible trends in streamflow at both continuous-record stream gages and partial record sites. At continuous gages, the study will investigate variability in streamflows by looking at the annual coefficient of variation, annual ratio of instantaneous peak flow to 3-day mean flow, and the ratio of 25th percentile to 75th flow durations. The study will perform statistical procedures to compare data for sites with partial records only with continuous record sites to identify possible trends at the approximately 800 sites with partial records only. Among the analyses that will be included are hydrograph separations; these will be done to determine mean annual baseflow for each year and for the period of record at continuous record stream gages. Estimates of mean annual baseflow at partial record stations will be presented as well based on statistical comparison procedures as noted above (Janowicz, 2019).

Stormwater

Land Use

As noted above, extensive development in New Jersey and the associated impervious surfaces exacerbate aspects of the hydrologic cycle by limiting recharge and enhancing runoff. Effects of development in urban basins are more pronounced for moderate storms following dry periods than they are for larger storms. With larger storms, especially during wet periods, the soil in rural basins becomes saturated and additional rainfall or snowmelt runs off much as it does in an urban basin (Konrad, 2016). More data are needed on trends in moderate storms ("subdaily precipitation") since, as noted by several studies, such storms should be more sensitive to climate warming than longer duration events (Wright et al., 2019).

Modeling

<u>Antecedent Conditions:</u>

Clearly, the amount of moisture present in soils and the quantity of water stored in catchment basins and similar structures will alter the degree of runoff resulting from a given storm. How such pre-existing moisture levels might respond, on average, to climate change, is uncertain. One study found that most current methods overestimate the degree to which evapotranspiration will be accelerated by climate change, and thus it is likely that future hydrologic wetting trends likely are being systematically and substantially underestimated in many water-resource impact analyses (Milly and Dunne, 2017).

Design Storms and Quantity of Runoff Generated:

The methods for calculation of runoff for all NJDEP permitted projects are outlined in New Jersey Administrative Code (NJAC) 7:8-5.6 "Calculation of Stormwater Runoff and Groundwater Recharge." There are two acceptable methods outlined in this guidance. They are both based upon the application of a runoff coefficient that is applied to determine the relative contribution of that surface to the runoff. The term "runoff coefficient" applies to both the Natural Resources Conservation Service (NRCS) methodology at N.J.A.C. 7:8-5.6(a)1i and the Rational and Modified Rational Methods at N.J.A.C. 7:8-5.6(a)1i. Both of these methodologies have been employed successfully at many sites throughout New Jersey to estimate the quantity of runoff that results from a particular storm. Both of these methods are independent of the actual precipitation records or predictions that are entered into the model. As a result, it is anticipated that the applicability of these runoff models will not be impacted by climate change. However, since they require precipitation as an input, the output will be greatly impacted by shifts in precipitation patterns resulting from climate change.

Stormwater runoff calculations have been completed using the NRCS Type III Storm Distribution when using the NRCS Methodology, and the Rainfall Intensity Duration Curves based on site specific data when using the Rational Method. Both of these methods for estimating statistical design storms are based upon the availability of long-term precipitation records. The most current effort to update the NRCS Methodology design storm data was a project identified as NOAA Atlas 14, which NJDEP is now being encouraged to use.

The design storm predictions created for NOAA Atlas 14 (Bonnin et al., 2016) are based on an extreme value distribution. Based on the methodology used ("block maxima"), for a given location there is one sample per year used to determine the extreme value distribution. As a result, the amount of measurements that need to be collected to determine whether significant changes have occurred over time is large. A decadal analysis would most likely give a distribution with a relatively large uncertainty. Larger intervals start to be impacted by the measurement intervals. An analysis of the changes over time of the distribution of extreme values would require a great deal of data, most importantly a way of assessing the uncertainty of any shifts in the distribution. NOAA analysis of the record did not observe the impacts of climate change on the distributions. The report stated,

> *"The 1-day annual maximum series were analyzed for linear trends in mean and variance and shifts in mean to determine whether climate change during the period of record was an issue in the production of this Atlas. The results showed little observable or geographically consistent impact of climate change on the annual maximum series during the period of record and so the entire period of record was used. The estimates presented in this Atlas make the necessary assumption that there is no effect of climate change in future years on precipitation frequency estimates. The estimates will need to be modified if that assumption proves quantifiably incorrect." (NOAA, 2006)*

However, the longest record used was 53 years at Newark Airport and the latest record used was collected in the year 2000. Any climate change impacts that occurred since then are not accounted for.

Site-specific Rainfall Intensity Duration Curves are available based upon the same NOAA Atlas 2014 project (https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=nj). These curves also require a large quantity of data and the inherent error in these predictions is relatively large. For example, the 24-hour 100-year storm in New Brunswick, NJ has a predicted depth of 8.57 inches with a 90% confidence interval from 7.65 to 9.35 inches, which is a range of ± approximately 9-11% (Figure 1). More important, such extreme value analyses based on past observations assume that the climate in stationary. This assumption has been invalidated by the changes in climate that are underway and are expected to grow in the future (Milly et al. 2008).

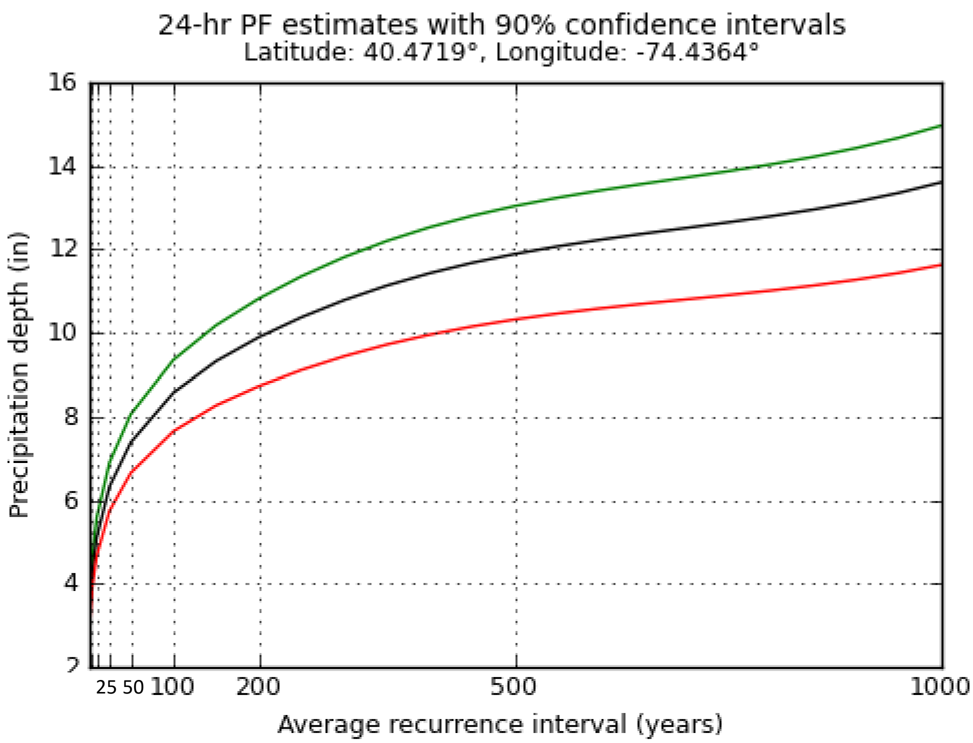

Figure 1. 24-hour precipitation frequency estimates for New Brunswick, NJ, depicting maximum 24-hour precipitation as a function of average recurrence interval. The black line is the central estimate and the red and green lines represent the lower and upper bounds, respectively, of the 90% confidence interval. These estimates are based on historical observations and do not include the effects of climate change. (Source: NOAA Atlas 14, Volume 2, Version 3)

Based upon the methodology and the observable error inherent in the precipitation predictions, it is entirely possible that the climate variation of precipitation over time is being muted by the methodology. Potential areas of inquiry are:

1. Should the methodology be adjusted to determine if the Extreme Value Distribution that is currently used is still appropriate?
2. Should regulators add into their regulations a safety factor based upon the inherent error of the predictions?

3. Are practitioners currently using the most up-to-date precipitation models? (i.e., is it specified in the latest NJDEP guidance, or are they using the ones that were published by NJ Department of Agriculture in 2005?)

Modeling Precipitation Distribution:

According to the United States Global Change Research Programs (USGCRP, 2017), the annual precipitation averaged across the United States has increased approximately 4% over the 1901–2015 period, with the autumn season exhibiting the largest and most widespread increase, exceeding 15% in much of the Northeast. In much of the Northeast, although not necessarily including New Jersey, precipitation is projected to increase more in winter and spring than at other times of the year. If greenhouse gas emissions continue to rise, the number of extreme events (exceeding a 5-year return period) is projected to increase by two to three times the historical average in every region of the U.S. by the end of the 21st century, with the largest increases in the Northeast. If greenhouse gas emissions stop increasing around 2070 and then level off, increases of extreme events are projected to increase 50%–100% by 2100. It is likely that increased water vapor resulting from higher temperatures will be the primary cause of these increases. Additional effects on extreme precipitation due to changes in dynamical processes are poorly understood (USGCRP, 2017).

Sea Level Rise

Sea level rise will be an important influence on coastal flooding. The New Jersey STAP report projected that sea level rise along the New Jersey coast for the period 2000-2100 could range from 2.3-6.3 feet under a high emissions scenario (Kopp et al. 2019). The large uncertainty in these estimates reflects recent modeling studies that account for the possibility that Antarctic ice sheets could devolve more rapidly than previous estimates (Kopp et al. 2017, Bakker et al. 2017, Wong wet al. 2017). Changes in the frequency or intensity of future coastal storms would also influence the impacts of future sea level rise.

Infrastructure

Current design, lifetime, and resiliency:

Although there is evidence that extreme precipitation events are increasing in frequency, engineers and risk analysts are typically concerned with rare events such as 100-year storms. Since these events are so rare, trend detection has so far proved nearly impossible using conventional methods. Wright et al. (2019) used a regional aggregation approach to boost the low signal-to-noise ratio of these rare events, and found that the trend of increasing extreme precipitation events is significant; for example, 10-year 24-hour extreme events have increased by over 130 percent from 1950 to 2017 in the Northeast. The authors concluded that this trend has potentially serious implications for the reliability of existing and planned hydrologic infrastructure and analyses, and that there is a need for prompt updating of hydrologic design standards.

Recommended considerations:

Wright et al. (2019) recommend that existing intensity-duration-frequency (IDF) estimates used for infrastructure design, floodplain mapping, and related analyses be updated. They note that efforts to update such estimates should include assessments of trends in subdaily extremes, which are important to urban infrastructure and which could be more sensitive to climate warming. Perhaps utilizing specific streamflow data based on USGS monitoring such as reported by Watson et al. (2005) and soon to be updated by USGS to cover the years up to 2017, NJDEP should consider adjusting the size of stormwater design systems to reflect the capacity and vulnerability of the receiving stream or streams.

Another item that warrants investigation, discussion, and possible revision is a prohibition that may apply to NJDOT's design of bridges. Apparently, there are New Jersey rules that prohibit expanding bridges to accommodate greater streamflow, because of the concern that this could transfer flooding from upstream to downstream neighbors. The degree to which rules that apply to transportation infrastructure present problems in the development of appropriate measures to limit the impact of floods should be investigated by both NJDEP and NJDOT. For example, if bridge openings are incapable of transmitting enough water in the face of more frequent and intense storms, roadways could flood, with potentially unacceptable consequences. It should be noted that there are typically a variety of flood impacts, which can include flooded regions adjacent to bridges or and other roadway infrastructures. And, with a variety of such impacts, a variety of solutions may be appropriate.

Methods for quantitative assessment of water resources/management

As noted above, it is recommended that IDF estimates be updated. Such updating could make use of what Wright et al. (2019) refer to as nonstationary techniques, or methods that these authors refer to as stochastic storm transposition could be used.

Wright et al. (2019) suggest that another, conservative approach would be to use the upper bound of the 90% confidence interval around mean precipitation quantities as reported in Atlas 14 as a new standard. A related approach has recently been taken by the city of Austin, Texas. In November 2019, that city approved code changes that re-designate the city's 500-year floodplain as the new 100-year floodplain, citing new rainfall data that shows greater flood risk (Huber, 2019).

There are a variety of NJDEP rules that apply to stormwater management, including detention of larger storms for flood control purposes, e.g. attenuation of 2, 10, and 100-year peak flow rates and requirements for infiltration in many areas. Some relevant parameters have been revised recently, and it is understood that NJDEP intends to revise stormwater management rules further to account for climate change. One criterion that NJDEP should consider updating is its Water Quality Design Storm (WQDS). A WQDS is a storm that drops 1.25 inches of rain in 2 hours. The WQDS is reportedly based on rainfall data collected at Trenton during the period 1913 to 1975, and may represent what was, based on the data from that period, a storm that either had a certain likelihood of occurring or that represented a certain percentage of annual rainfall. Designing a stormwater management system to accommodate a storm of this size is expected to prevent significant pollution of a typical receiving stream. However, a storm that is projected to occur as frequently today as a WQDS occurred during the period 1913 to 1975 could be a larger storm. If such a "21st century WQDS" storm drops significantly more than 1.25 inches in 2 hours, a stormwater management facility that is designed to handle the current WQDS could be undersized.

Conclusion

There are many considerations that should be included in the evaluation of water resources considering the potential climate change impacts that could affect New Jersey. New reports and literature should be continually evaluated for keys to the localized impacts New Jersey should anticipate. For example, the effects of climate change in the Highlands of northern New Jersey are likely to differ from those in the southern part of the state. The implications of climate change on water supply in regions served by surface waters versus groundwater may likewise differ. Changes in precipitation and sea level rise are potential drivers of flooding that will have different implications in upland and coastal river systems. Water resources issues should be of importance to not only NJDEP, but also other state agencies such as the Department of Transportation and the Department of Community Affairs. Effectively communicating the science across state government is recommended.

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