Climate Change Stressor Indicators

CHAPTER 2: PRECIPITATION


Photo: Upper Wood River in Exeter, RI (Ayla Fox)
BACKGROUND

- Changes in global and regional patterns of precipitation stress ecosystem condition indicators such as dissolved oxygen, chlorophyll, and water clarity, as well as public health indicators including marine beach and shellfishing area closures. Precipitation also influences other stressor indicators, such as wastewater infrastructure and nutrient loading.

KEY FINDINGS

- **Trends**: Regionally, average annual precipitation as rainfall has increased 0.4 to 0.7 inches per decade since 1895, and the amount of annual precipitation falling during intense storms has increased 71 percent since 1965.

- **Projections**: Local projections include increased volume of annual precipitation, greater frequency and intensity of precipitation events, and changing seasonality with increased winter precipitation (as rain) and limited summer precipitation, prompting drought or drought-like conditions.
**Introduction**

Changes in precipitation patterns affect many aspects of ecological and public health conditions in the Narragansett Bay region. Analyzing changes in precipitation is essential to understand recent changes in the Bay ecosystem and to anticipate future changes, enabling more effective climate change adaptation practices.

The National Climate Assessment reported increases in the average annual volume of precipitation in the Northeast, severity of tropical cyclones in the North Atlantic, and frequency of extreme precipitation events (Melillo et al. 2014). Several regional analyses show an increase of 0.1 inch (0.25 centimeter) per year, or one inch (2.54 centimeters) per decade, in annual precipitation from 1905 to 2005 (Pilson 2008, Smith et al. 2010, Heffner et al. 2012, UNH 2016). An increased intensity of precipitation events has become the norm, with a 71 percent increase in the annual amount of precipitation falling in very heavy events (defined as the heaviest one percent of all daily events) from 1958 to 2012 in Rhode Island and Massachusetts (Melillo et al. 2014, Bradley et al. 2016). Increased precipitation can potentially affect organic and inorganic pollution levels from urban flooding and wastewater treatment discharge. Although there is a trend of increasing annual precipitation, shifts in seasonality of precipitation lead to longer periods of drought and drought-like conditions in summer (MAOEEA 2011).

In this chapter, the Narragansett Bay Estuary Program analyzes the status, recent trends, and future projections of precipitation patterns in the Narragansett Bay Watershed. The chapter also discusses effects of changing precipitation patterns on physical conditions of the Bay, including water clarity, dissolved oxygen, and chlorophyll, as well as the impacts on human health, such as beach or shellfishing area closures.

**Methods**

The Estuary Program analyzed data from two NOAA stations: Providence, Rhode Island (1895 to 2015) and Worcester, Massachusetts (1948 to 2015). Precipitation data and Palmer Drought Severity Index (PDSI) data were obtained from NOAA’s Climate at a Glance database (NOAA 2016). PDSI data are available only for states, not cities (e.g., Providence and Worcester), and therefore the Estuary Program used the data available for Rhode Island and Massachusetts from 1895 to 2015. This source was selected because of the long time period and completeness of the dataset.

The Palmer Drought Severity Index is a measurement of the relative dryness of an area on a standardized scale of −10 to +10 calculated from temperature and precipitation data. This parameter assumes the precipitation is readily available to be evaporated or transpired by plants, and it does not account for snow or ice, which experience delayed runoff (Dai et al. 2016).

**Status, Trends and Projections**

**STATUS AND TRENDS**

The status of rainfall in the Narragansett Bay Watershed is based on data from 2015. In 2015, both Providence and Worcester received about 40 inches of precipitation. The long-term annual averages for the entire datasets—1895 to 2015 for Providence and 1948 to 2015 for Worcester—were 45.9 inches (116.6 centimeters) and 46.9 inches (119.1 centimeters), respectively (Figures 1 and 2).

The data show that although precipitation patterns have been variable, the annual average precipitation has increased steadily. Providence’s annual average precipitation increased 0.40 inch (1.02 centimeters) per decade since 1895 in a trend that was statistically significant (p=0.016) (Figure 1). Worcester’s average precipitation increased 0.73 inch (1.85 centimeters) per decade since 1948 in a trend that was not statistically significant (Figure 2). The largest periods of drought were in the 1940s and 1960s (Figures 3 and 4). In the 1970s, precipitation in Providence and Worcester shifted from being generally below to generally above the long-term average (Figures 1 and 2). This pattern has continued despite some recent years of below-average precipitation.

Despite the recent years of droughts and drought-like conditions, the Palmer Drought Severity Index agrees with the precipitation data, showing that wetter years have become more common. The Palmer Drought Severity Index has increased 0.03 per decade in Rhode Island and 0.07 per decade in Massachusetts (Figures 3 and 4), although these increases are not statistically significant.

**PROJECTIONS**

The University of Massachusetts Climate System Research Center produced climate model projections for Rhode Island and Massachusetts, as well as other states in New England and the Midwest (Bradley et al. 2016). The precipitation projections were based on two greenhouse gas emission rates, similar to the IPCC Special Report on Emissions Scenarios model (IPCC 2014). The lower emission
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Precipitation

Figure 1. Annual precipitation at Providence, Rhode Island. Dotted line is the average annual precipitation over the entire dataset. Black line represents a statistically significant increase in precipitation. Source: National Oceanic and Atmospheric Administration (NOAA 2016)

Figure 2. Annual precipitation at Worcester, Massachusetts. Dotted line is the average annual precipitation over the entire dataset. Black line is a guide to indicate an apparent increasing trend, but the trend is not statistically significant. Source: National Oceanic and Atmospheric Administration (NOAA 2016)
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Figure 3. Annual Palmer Drought Severity Index (PDSI) for Rhode Island. Yellow bars (negative values) indicate drier years. Green bars (positive values) indicate wetter years. Black line is a guide to indicate an apparent increasing trend, but the trend is not statistically significant. Source: National Oceanic and Atmospheric Administration (NOAA 2016)

Figure 4. Annual Palmer Drought Severity Index for Massachusetts. Yellow bars (negative values) indicate drier years. Green bars (positive values) indicate wetter years. Black line is a guide to indicate an apparent increasing trend, but the trend is not statistically significant. Source: National Oceanic and Atmospheric Administration (NOAA 2016)
rate scenario will occur only if there are substantial efforts to mitigate greenhouse gas emission rates during future economic development, while the higher emission rate is comparable to current greenhouse gas emissions (Bradley et al. 2016). Both emission rates resulted in similar findings regarding precipitation. The projections are similar for Rhode Island and Massachusetts, so they are included in one graph. The projections show that by 2100, precipitation will range from eleven to fifteen inches (28 to 38 centimeters) per winter season (Figure 5), which is an increase of zero to three inches (zero to 7.6 centimeters) from the 1950 to 2005 data. The overall amount of winter precipitation is projected to increase, but warming temperatures will cause more rain and less snowfall (Figure 6). These changing precipitation patterns and rising temperatures will create a climate in New England in 2100 that is similar to present-day Virginia (Bradley et al. 2016).

**Discussion**

Current climate models project that total volume of precipitation will increase by zero to three inches (zero to 7.6 centimeters) per decade locally (Figure 5) and that seasonality of precipitation will continue to change, leading to cascading negative impacts on the overall health of Narragansett Bay and its Watershed (Bradley et al. 2016). Rhode Island and Massachusetts have received at least 30 inches (76.2 centimeters) of rain annually since 1980, and the annual amount of precipitation has increased between 0.5 and one inch (1.3 to 2.5 centimeters) per decade (Figures 1 and 2; Pilson 2008, Vallee and Giuliano 2014, UNH 2016). The local increase in precipitation is due to large, slow-moving storm systems, multiple events in a short period of time, and the increase in frequency and intensity of rain events (Vallee and Giuliano 2014). The projected increase in intensity and frequency of precipitation events in places with aging infrastructure, urbanization, and poor soil quality is expected to increase the likelihood of flooding (see “Impervious Cover” chapter). This will increase pressure on local wastewater treatment facilities, causing more overflow events and introducing excess nutrients and pathogens into the rivers and the downstream estuarine waters (Melillo et al. 2014, USEPA 2016; see “Wastewater Infrastructure” chapter). This increased runoff and overflow in the Narragansett Bay Watershed is expected to affect many aspects of the health of the Watershed.

Intense flooding and overflow events, such as the severe 2010 event that dramatically affected Rhode Island, and less intense events will continue to alter the physical, biological, and human health conditions within the Narragansett Bay Watershed. Water quality is degraded when a large volume of precipitation is introduced rapidly, creating turbidity within the water column. The increased inputs of nutrients, pollutants, pathogens, and sediment decrease the clarity of the water column (see “Water Clarity” chapter). Poor water clarity impacts important habitats, such as seagrasses (see “Seagrass” chapter), and is an overall indicator of poor water quality.

Increased precipitation also affects chlorophyll concentrations and primary production by phytoplankton. Primary production occurs predominantly at the surface of the water column where nutrients (i.e., from precipitation, runoff, point-source discharge, and remineralization), sunlight, and dissolved oxygen are readily available. As the increased volume of precipitation introduces additional organic and inorganic nutrients to the Bay, it is expected that primary production may increase in surface waters, prompting eutrophication (see “Chlorophyll” chapter). As the primary producers die and settle to the bottom, this flux of organic matter decomposes, potentially resulting in decreased dissolved oxygen in the water column and negatively affecting benthic and other estuarine communities.

Another influence on dissolved oxygen levels is water column stratification. Freshwater from precipitation and runoff rests on top of the denser, saltier water. If no mixing occurs (either wind, tidal, or storm-induced), the bottom waters will become isolated and depleted of oxygen as organic matter decomposition and respiration of organisms consume oxygen. Without mixing, or advection of new water to the region, dissolved oxygen cannot be replenished (see “Dissolved Oxygen” chapter). The increase in precipitation and intense precipitation events may lead to more stratification of the water column in Narragansett Bay, depleting dissolved oxygen in the bottom water; river runoff may be a stronger climate-related driver of increased stratification than increases in temperature (Codiga 2012).

The physical and biological impacts of increased precipitation often prompt local beach and shellfishing closures due to the decreased water quality. Increased precipitation often brings pathogens, indicated by fecal coliform or E. coli bacteria, to rivers and estuaries. Precipitation amounts and correlated bacteria counts have been used to temporarily close monitored marine beaches and areas approved for shellfishing (see “Marine Beaches” and “Shellfishing Areas” chapters). Both marine beaches and shellfishing areas are opened as soon as the threat to human health passes.

While the impacts from increased flooding and overflow events are the most obvious results of
Figure 5: Climate model projection of the winter (December, January, and February) total precipitation in Rhode Island or Massachusetts to 2100. The black line represents precipitation data collected 1950 and 2005. The red line is the precipitation projection under a scenario of high greenhouse gas emission rates that are comparable to present-day emissions. The blue line is the precipitation projection under a scenario of lower emission rates that would be a result of reducing present-day emission rates through the introduction of energy-efficient technologies. Source: United States Geological Survey (USGS 2016).

Figure 6: Climate model projection of the winter (December, January, and February) annual snowfall in Rhode Island or Massachusetts to 2100. The black line represents precipitation data collected 1950 and 2005. The red line is the precipitation projection under a scenario of high greenhouse gas emission rates that are comparable to present-day emissions. The blue line is the precipitation projection under a scenario of lower emission rates that would be a result of reducing present-day emission rates through the introduction of energy-efficient technologies. Source: United States Geological Survey (USGS 2016).
changing precipitation patterns witnessed in the region, this is only one aspect of the changing patterns. Although the total volume of precipitation is projected to further increase, when and how the precipitation falls is also changing. According to the Massachusetts Executive Office of Energy and Environmental Affairs (MAOESEA), winter precipitation is expected to increase faster than precipitation during other seasons, often falling as rain rather than snow (Figures 5 and 6; MAMEESEA 2011). This increase of rain events in the winter months will impact local snowpack, spring snowmelt, and peak streamflow (Trenberth 2011, MAMEESEA 2011, RI EC4 STAB 2016, USEPA 2016). Historically, snowfall was immobilized on land, and warmer spring temperatures would reintroduce the now-melted snow to waterways, increasing river base flow. In comparison, when rain is delivered to a watershed, the precipitation is less delayed on its journey into the waterways. This near-immediate introduction increases base flow of streams in the winter, rather than in the spring thaw. Due to this change, low-flow periods are expected to shift earlier in the spring, extending the summer dry season. Therefore, the projected alteration of water delivery to the Narragansett Bay Watershed will alter the timing and intensity of local low-flow periods (MAMEESEA 2011).

The projected drought and drought-like conditions are expected to increase the water temperatures in small rivers and streams, degrade reservoir and groundwater reserves, and magnify the impact of environmental pollutants (RI EC4 STAB 2016). During times of reduced water availability, withdrawal of water will be felt more intensely, especially if the fresh groundwater is not replaced through precipitation. With greatly reduced groundwater replacement, saltwater intrusion can occur (USEPA 2016). This can occur most commonly around estuaries like Narragansett Bay (USEPA 2016).

Periods of drought allow pollutants to build up on land. When precipitation does fall, the first flush (first pulse of water over land) contains a very high concentration of pollutants delivered to receiving waters. The high concentration of organic and inorganic pollutants associated with the first flush has the potential to magnify the negative impacts on turbidity, water clarity and quality, chlorophyll, dissolved oxygen, and human health within the Narragansett Bay Watershed (Wright et al. 1992). In order to prevent the impacts from an event such as the first flush, or any large flooding event, the Narragansett Bay Commission and other organizations are conducting local mitigation efforts by creating a combined sewer overflow abatement program in Providence and surrounding towns to prevent approximately one billion gallons of untreated runoff and wastewater from entering Narragansett Bay annually as a result of flooding and overflow (NBC 2017). The success of the first two phases of this project has allowed the Rhode Island Department of Health to investigate opening an urban beach on the Providence River estuary and adjusting the precipitation thresholds that trigger a shellfish area closure (RIDOH 2015; see “Shellfishing Areas” chapter). The city of Fall River is also implementing a combined sewer overflow abatement program.

Overall, the changing precipitation patterns as a result of global climate change will likely alter the physical and biological conditions of the Bay and indirectly impact human health. The changing trends will pose new challenges for the health of the Bay and biodiversity, but with a proactive and innovative perspective people can work to mitigate the impacts in order to preserve the integrity of the Narragansett Bay Watershed.

Data Gaps and Research Needs

- The existing network of stream gages in the Narragansett Bay Watershed should be assessed to ascertain key gaps, and data records should be analyzed to characterize variability in rainfall across the Watershed and identify where additional rain gages may be needed (e.g., the Pawtuxet River watershed). Sustained funding for the network is critical to ensure adequate hydrologic data is available to support management decision-making.
- Extreme precipitation and drought in the Narragansett Bay Watershed need to be further investigated using a combination of approaches, such as the Palmer Drought Severity Index, the Crop Moisture Index, and Cornell University’s effort to analyze frequency and intensity of precipitation (Cornell University 2016). The results of these efforts will detail the impacts that extreme precipitation and drought have on water resources management and water quality.
- The frequency, amount, seasonality (freeze/thaw cycles), and type (rain, snow) of precipitation influence physical, chemical, and biological processes within the Narragansett Bay Watershed. The impacts of climate change on precipitation need to be further explored using downscaling of climate models or other methods. Results of these efforts will increase knowledge of how sensitive habitats will change, and how to plan for the resiliency of infrastructure.
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References


