*Consilience: The Journal of Sustainable Development*
Iss. 24, 2021

# Effects of and potential interventions to combat climate change impacts on groundwater resources in Long Island and Shelter Island

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## Abstract

Climate change is predicted to increase the temperature, precipitation, and sea level in the northeastern United States. For coastal communities, these impacts present challenges to maintaining the necessary quantity and quality of groundwater resources. On Long Island and Shelter Island, groundwater is the main source of freshwater for public supply, industrial uses and agriculture. This groundwater is recharged solely from precipitation that percolates into the unconfined aquifers below the ground. A growing population, increased development and urbanization, an expanding sewer system, and more intense storm events all pose threats to the regional groundwater recharge. Data from the Timescale decomposition tool, developed by the International Research Institute for Climate and Society (IRI), substantiate a regional trend of warmer temperatures and increased precipitation. Climate change will likely alter the behavior of climate modes, including the Pacific Decadal Oscillation (PDO), East Pacific/North Pacific (EP/NP) patterns, and Pacific El Niño that impact the Long Island Sound region. Data from the KNMI Climate Explorer underscore a connection between PDO and land/sea global mean temperature, as well as El Niño and sea surface temperature anomalies. New York State has developed a water conservation policy concerning well-pumping practices and groundwater effluent standards. Long Island counties have also set local water management goals to improve wastewater treatment, enhance aquifer protection, and increase the transparency and availability of pumping records. These goals must be enforced and actualized. This paper recommends that Shelter Island develop a groundwater management plan like those in place throughout Long Island. The islands are advised to consider innovative water storage strategies such as Aquifer Storage and Recovery (ASR), Artificial Recharge (AR), and rainwater harvesting. These practices, along with land use and urbanization planning, will help promote local resilience and groundwater resource sustainability. Further modeling of local groundwater dynamics and enhanced knowledge of pumping practices are necessary to develop more accurate predictions of the groundwater system under future climate scenarios.

# Introduction

This paper seeks to explore the impact of climate change on the groundwater resources of Long Island and Shelter Island, New York, to better understand possible policy interventions and adaptation strategies to increase regional resilience. To achieve this goal, the islands are advised to utilize the latest observational data and climate modeling proposed in the scientific literature. Both Long and Shelter islands have distinct groundwater dynamics and water needs that will be affected by anthropogenic climate change. Climate change may be defined as significant changes in climate, including temperature and precipitation, that occur over an extended period of time and that coincide with natural climate variability (IPCC 2007). Climate change may be caused by human activities that alter the composition of the atmosphere and characteristics of the land, or natural processes, including volcanic eruptions, solar irradiance fluxes, and Earth's orbital variations (IPCC 2007). Climate variability describes the natural patterns of fluctuation in temperature and precipitation of a region over relatively shorter timescales (i.e., inter-annual or multi-decadal) that are not influenced by or related to human activities. Long Island and Shelter Island experience climate variability due to regional interactions with Pacific Decadal Oscillation (PDO), East Pacific/North Pacific (EP/NP) patterns, and Pacific El Niño. Due to climate change, these islands are predicted to experience increased temperature, higher precipitation, and a sea-level rise. These impacts, compounded with the increased consumer water demand and pressure on local sewer systems, pose a significant threat to the quality and quantity of groundwater resources. Groundwater resources are the only source of public water supply for these islands. The groundwater is recharged by precipitation that percolates to the water table. Thus, sustainable management of these groundwater resources is vital to uphold the quality of life and industry development for Long Island and Shelter Island.

# Description of Problem

Increased development and population growth put stress on the groundwater systems and recharge dynamics in Shelter Island and Long Island. Impervious surfaces resulting from urbanization across the islands have altered the percentage of recharge from precipitation. Population growth leads to the rising demand for water and volume of sewage discharged to the groundwater system. This may result in intrusion of saline groundwater into the aquifers. A warmer climate may lead to more successful and longer agricultural growing seasons. As a result of the increased agricultural activity, groundwater depletion is expected to accelerate while more pesticides and other contaminants might leach into the groundwater. Increased precipitation and storm events caused by climate change may lead to more water lost as runoff and less precipitation reaching the water table. As a result, the groundwater system will be recharged less effectively. Below is a thorough exploration of the scientific literature concerning the impact of climate change on groundwater systems of regions with similar geology and climate dynamics to Long Island and Shelter Island. This will elucidate areas of vulnerability or change for the two islands' groundwater systems as the effects of global climate change begin to alter the islands' precipitation, surface temperature, and climate variability. This, in turn, will inform the type of adaptive strategies and policies the islands may implement to develop regional resilience and foster a sustainably-managed groundwater system. This exercise will also showcase areas in need of further research or modeling.

# Existing Knowledge

Long Island extends nearly parallel to the Connecticut coastline, south of mainland New York State. The average annual temperature in Long Island is 46.3°F (USGS 2000). The annual rainfall in Long Island is 44.8 inches (USGS 2000). Long Island's only source of freshwater is precipitation that has infiltrated down into the water table, as the island's groundwater system is bound below by an unconfined aquifer and on the sides by saline groundwater, bays, and the ocean (Cohen et al. 1968). There are more than 2,000 recharge basins throughout Long Island (USGS, 2000). Long Island's population was 2.8 million in 2019 and expected to grow annually by 0.1 percent (Office of the New York State Comptroller 2019). Under pre-developed conditions, approximately one-half of the precipitation Long Island receives percolates to the water table (Cohen et al., 1968). In unsewered areas of Long Island's most populous counties, 85 percent of water pumped for public use infiltrates back into the groundwater system; however, in sewered areas, only 20 percent returns (Buxton et al. 1999). Large groundwater users include the power generation companies National Grid, Pinelawn Power, Covanta, and Caithness (Meyland 2017). Other competing uses for groundwater are commercial water uses, agricultural needs, and recreational and golf course uses (Meyland 2017).

Shelter Island is a small island located at the eastern end of Long Island between the North and South Forks. The average annual temperature in Shelter Island is 41.4°F (USGS 2000). The annual rainfall in Shelter Island is 45.7 inches (USGS 2000). Shelter Island's thin upper glacial aquifer filled by precipitation is the island's only source of freshwater and is permeable to saline groundwater intrusion in nearshore areas (USGS, 1984). Freshwater supply is very limited in coastal areas, Little Ram Island, and the West Neck peninsula (USGS 1984). Nearly all precipitation either is returned to the atmosphere through evapotranspiration or becomes recharge to the groundwater system (Nemickas & Koszalka 1982). Precipitation variations affect water-table changes more than any other climatic trend (Rozell & Wong 2010). Shelter Island's population was estimated to be 2,413 in 2016 and is expected to stay relatively steady (U.S. Census Bureau 2016). Only groundwater pumped by the Shelter Island Heights Association and Dering Harbor Water District is reported to New York State. The primary groundwater use is public supply and private well pumping, as there is limited agricultural and industrial presence on the island.

Water and temperature variability in the Long Island Sound are strongly correlated with Pacific decadal oscillation (PDO), east Pacific/North Pacific (EP/NP) patterns, and the dipole index, particularly during winter (Schulte et al. 2018). The winter EP/NP behavior is also strongly correlated with spring and summer water temperature anomalies in the region (Schulte et al. 2018). Shifts in PDO and EP/NP patterns have led to regional water temperature changes in recent decades, indicating that warming is not only caused by anthropogenic intervention to the natural system but rather an element of natural variability (Schulte et al. 2018). The seasonal and decadal patterns of PDO and EP/NP can be used to predict water temperature variability. Central Pacific El Niño events are associated with regional cold events, while the end of cold events may coincide with El Niño events that are a combination of eastern and central Pacific El Niño characteristics (Schulte & Lee 2019). Water temperature variability does not appear to be related to the Gulf Stream position or changes in the North Atlantic Oscillation, despite Long Island's border with the Atlantic Ocean (Schulte & Lee 2019).

Climate change is expected to alter the magnitude and timing of groundwater recharge by changing the distribution and seasonal timing of precipitation (Liu 2011). Climate modes, such as El Niño and PDO are shown to influence groundwater levels and recharge (Klove et al., 2014). Changes to climate mode dynamics due to climate change will likely affect these island groundwater systems, as they are unconfined and shallow aquifers that are sensitive to climate variability (Lee et al. 2006). Evidence suggests that global groundwater fluxes correlate with recharge variations due to climate change (Mohan et al. 2018). This means that river flows and groundwater-dependent ecosystems will also be impacted by climate change due to the hydraulic memory of groundwater systems (Cuthbert et al. 2019). Fluctuations in groundwater recharge are predicted to be larger than the corresponding changes in precipitation (Ng et al. 2010). Global median groundwater response times are estimated to be 6,000 years, however Long Island and Shelter Island most likely experience response times on human timescales due to shallow water tables and high permeability geology (Cuthbert et al. 2019). This means that rapid groundwater flux may occur in the region in the near future. Long Island Sound fluxes in groundwater over the next century have largely not been analyzed or predicted. The shallow water tables and encroaching saline groundwater of both Long Island and Shelter Island make the islands particularly vulnerable to impending climate change impacts on groundwater fluxes that are neglected from conventional global climate models.

Warmer winter temperatures due to global warming can increase the amount of precipitation falling as rain and increase snowmelt, allowing more water to percolate into the ground and increase wintertime groundwater recharge (Klove et al. 2014). This also increases the risk of leaching of contaminants into the groundwater system during winter. However, humid regions, like the Long Island Sound, are expected to receive an increase in strong rainfall events that may reduce groundwater recharge rates as most water is lost as runoff during these events (Bates et al. 2008). A warmer winter may also mean longer growing seasons for agricultural producers on eastern Long Island. This may lead to increased groundwater pumping and leaching of contaminants and pesticides into groundwater resources (Klove et al. 2014).

Rising sea levels caused by anthropogenic climate change are predicted to negatively affect freshwater resources of small island regions, as small islands have limited ability to store water in surface streams, lakes, or groundwater (Rozell & Wong, 2010). The Intergovernmental Panel on Climate Change (IPCC) sea-level rise predictions through 2099 are between 0.18 to 0.59 m, including all future human activity scenarios (Meehl et al.

2007). IPCC precipitation predictions over this time period are between -2 percent to 15 percent for eastern North America using the most likely human activity scenario (Christensen et al. 2007). Estimates illustrate actual precipitation to be higher than IPCC predictions, which will be offset by increased evapotranspiration due to higher temperatures (Rozell & Wong, 2010).

The confining bottom layers to the aquifers below Long Island and Shelter Island may play a crucial role in the islands' response to climate change, as only the sides of the aquifer are affected by hydrological conditions (Rozell & Wong 2010). Because of this clay-confining layer, Long Island and Shelter Island may be less impacted by a sea-level rise as compared to the typical sandy islands (Rozell & Wong 2010). Sea-level rise may increase freshwater resources on the islands if shoreline inundation remains minimal (Rozell & Wong 2010). Given the elevation of the islands, even a sea-level rise greater than IPCC Fourth Assessment Report estimates would result in limited island inundation and salt-water intrusion (Rozell & Wong 2010). This prediction means that unless demand significantly increases over the coming decades, groundwater-dependent ecosystems common throughout Long Island and Shelter Island, such as wetlands, will not be greatly impacted by reduced groundwater inflow or salt-water intrusion (Drexler et al. 2013). Wetlands facilitate natural water purification processes and protect against wave and storm surge. Terrestrial ecosystems will also likely be largely unaffected by climate change, as shallow groundwater resources will allow species to access water consistently without salt-water intrusion (Klove et al. 2014). However, studies indicate that groundwater pumping has more of an effect on seawater intrusion into coastal aquifers than climate change or sea-level rise (Treidel et al. 2012).

Groundwater temperatures are expected to increase alongside surface temperature increases (Taylor & Stefan 2009). This warming may impact dissolved oxygen concentrations and ultimately affect temperature dependent reaction rates and reduction-oxidation reactions (Klove et al., 2014). These reactions are important to biogeochemical processes, including the nitrogen and carbon cycles and the transport of contaminants. Thus, global warming may negatively impact groundwater quality (Klove et al. 2014).

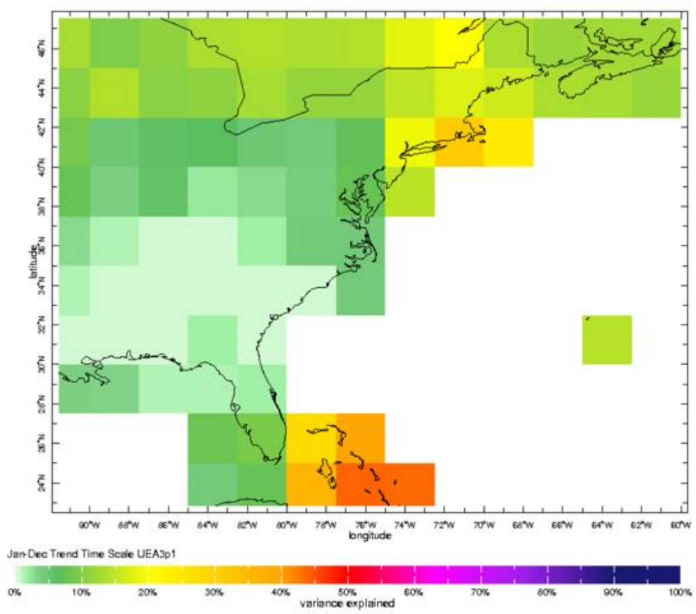


*Figure 1. Annual temperature time scales of the eastern United States from 1900-2010.*

Although no paleoclimate studies have been conducted specifically concerning Long Island or Shelter Island, studies analyzing the North Atlantic basin through shell isotopic data elucidate past oceanic conditions and oceanic/atmospheric interactions (Hudley 2012). Fossil shells demonstrate fluctuations based on sea surface temperature and the North Atlantic Oscillation during the Pliocene, offering insight into how coastal ecosystems and climate will vary in the future due to climate change (Hudley 2012).

## Data and Method

Utilizing the Timescale decomposition tool by the International Research Institute for Climate and Society (IRI), the regional annual temperature contributions of the eastern United States were analyzed from 1900-2010 (Figure 1). The temperature time scales illustrate a temperature increase, with approximately a 20 percent variance in the Long Island Sound region. The explained variance of the annual temperature time scales over this time period expresses a trend contribution of 12 percent, decadal of 14 percent, and inter-annual of 62 percent. Thus, inter-annual fluctuations appear to contribute significantly to regional climate variability (Figure 2). This is consistent with past climate studies of the region, which highlight the role of inter-annual and decadal climate modes in driving climate variability.

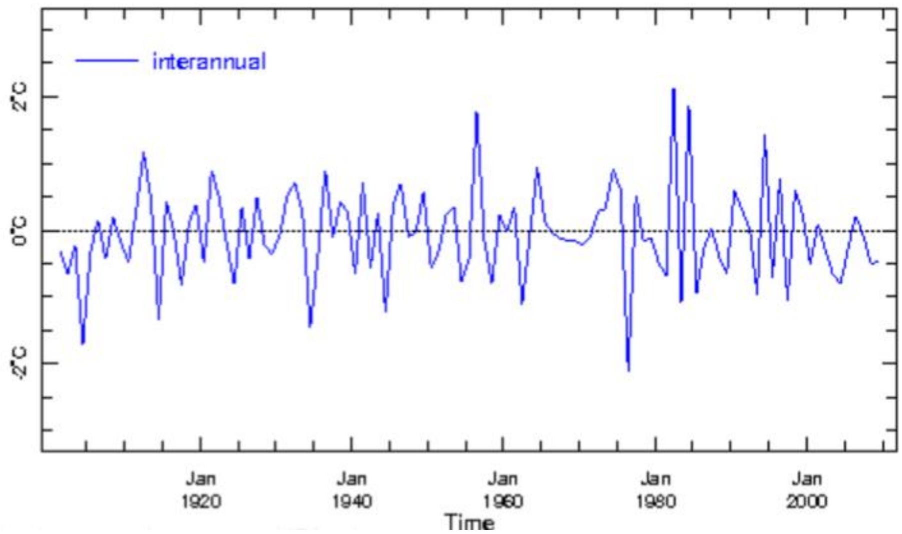


*Figure 2. Inter-annual explained variance of temperature time scales of the eastern United States from 1900-2010.*

Annual precipitation from 1900-2010 was then analyzed using the same tool. The precipitation time scales illustrate a slight precipitation increase, with a 0-5 percent variance in the Long Island Sound Region (Figure 3). The explained variance of the annual precipitation time scales over this time period illustrates a trend contribution of 3 percent, decadal of 8 percent, and inter-annual of 81 percent. Again, inter-annual fluctuations appear to be the main driver of regional climate variability (Figure 4). The temperature and precipitation time scales support the prediction that the Long Island Sound region will experience warmer temperatures and increased precipitation due to climate change.

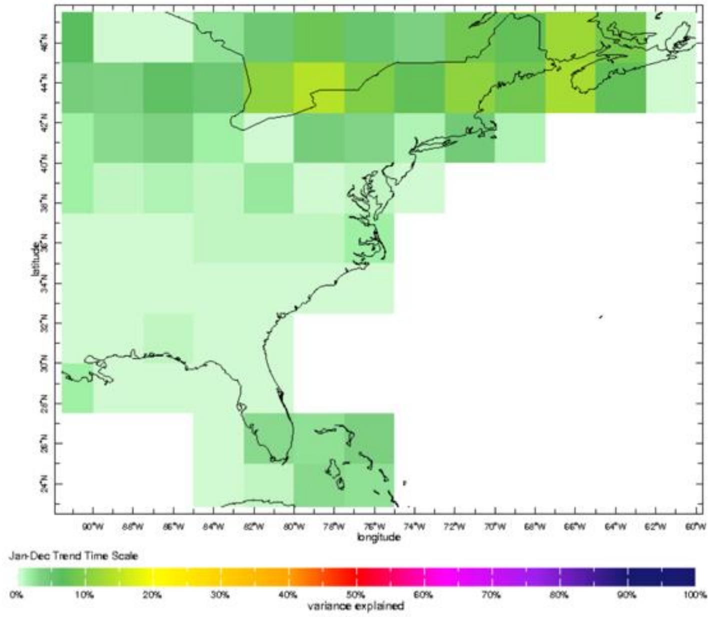


*Figure 3. Annual precipitation time scales of the eastern United States from 1900-2010.*

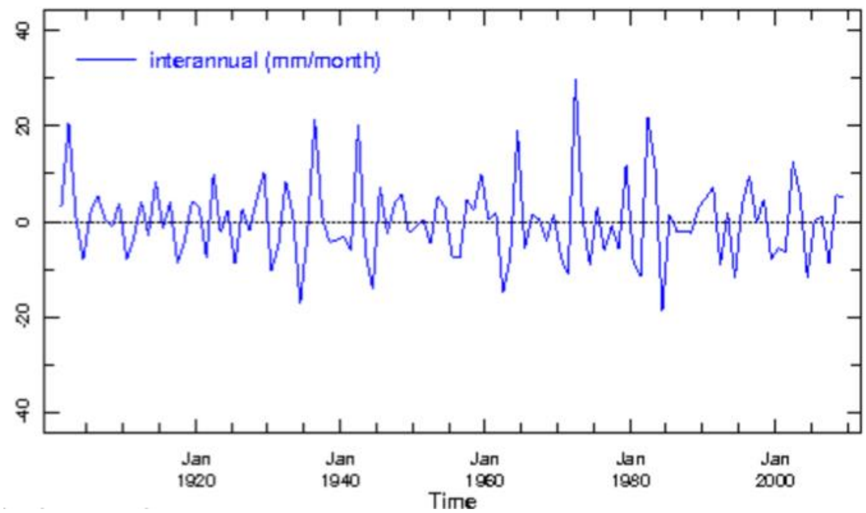


*Figure 4: Inter-annual explained variance of precipitation time scales of the eastern United States from 1900-2010.*

Using the KNMI Climate Explorer, the behavior of climate modes was analyzed. The correlation between PDO and smoothed land/sea global mean temperature was computed for 1900-2020 and indicates a connection between PDO and temperature (Figure 5). The correlation between El Niño and sea surface temperature anomalies was then computed from 1901-2017 and indicates a connection between El Niño and cold sea surface temperature anomalies along with the eastern United States (Figure 6). This supports the scientific literature that has proposed a relationship between El Niño events and cold winter events along the eastern coastline; however, the Climate Explorer did not illustrate sea surface temperature anomalies near the Long Island Sound.

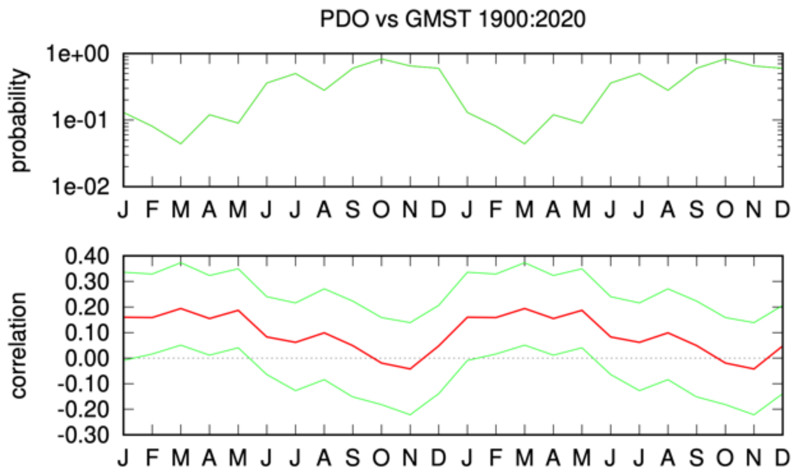


*Figure 5. Correlation between PDO and smoothed land/sea global mean temperature for 1900-2020.*

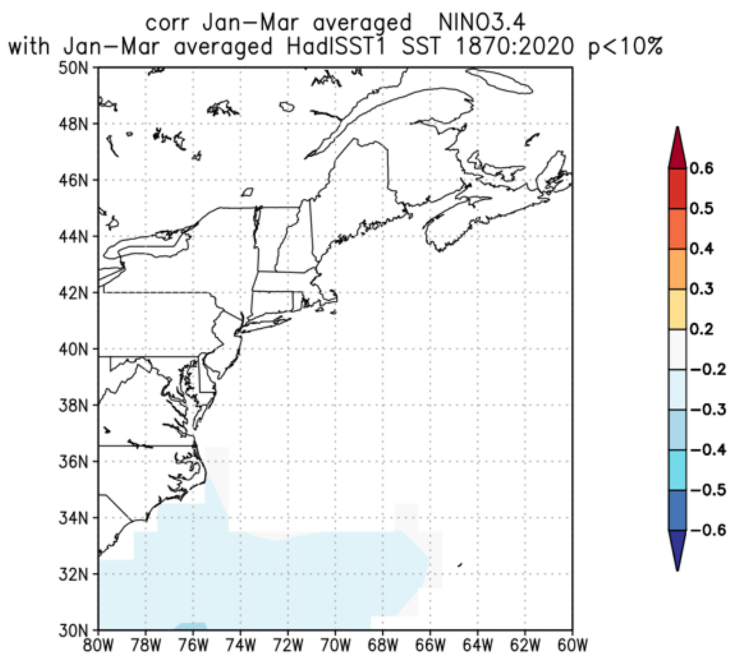


*Figure 6. Correlation between El Niño and sea surface temperature anomalies from January to March for 1901-2017.*

# Potential Solutions

Stakeholders interested in upholding the quality and quantity of Long Island and Shelter Island groundwater resources include the local populations, local policymakers and land use planning authorities, local wastewater management entities, watershed management, storm response and water management, local water utilities, industry actors, agricultural producers, educational establishments, tourism industry, conservationists interested in the health of groundwater-dependent ecosystems, and journalists and the media. These stakeholders should consider the recommendations put forth below.

Future groundwater resources of Long Island and Shelter Island will be particularly impacted by fluctuations in precipitation, pumping increases due to population growth, agricultural development, and/or economic activities, and an increase in heavy storm events. These islands' groundwater recharge is dependent on precipitation that does not leach contaminants into the groundwater system and can percolate to the water table before it is lost as runoff. The various climate modes associated with this region will likely alter over the coming century due to warmer temperatures and increased atmospheric moisture.

These islands' governments may implement a sustainable groundwater management plan to ensure groundwater resources are secure despite future climate uncertainty. This entails developing a current regional water budget and a projected water budget that accounts for a growing population, more economic development, and increased agricultural activity. Sources of significant groundwater pumping should report their use andensure over-pumping of the aquifer is not occurring. If over-pumping is occurring, a mitigation plan should be developed and enforced. A managed and sustainable yield level should be created and regularly updated for each county in the region (Meyland 2017). Contaminated plume remediation must continue, and groundwater quality must be regularly analyzed. Water demand should be reduced during the summer and times of drought.

Coastal areas throughout the United States have comprehensive groundwater conservation plans. For example, the Coastal Plains Groundwater Conservation District in Texas estimates available groundwater, predicts how groundwater resources are expected to be used, and includes joint planning with other districts and relevant actors (CPGCD Groundwater Management Plan 2014). The Coastal Plains District routinely monitors wells and aquifer conditions, in addition to analyzing precipitation and economic patterns to ensure groundwater sustainability (CPGCD Groundwater Management Plan 2014). The Coastal Plains District concludes annual reports by conducting projected water supply and demand analyses, which may include impacts of climate change, population growth, and/or economic development (CPGCD Groundwater Management Plan 2014). This proactive management plan prepares the Coastal Plains District for future groundwater variability.

New York State's Groundwater Effluent Limitations detail water quality regulations per potential contaminating substance. New York State's Standards for Water Wells encourages wells to be constructed in locations where water levels do not greatly fluctuate, individuals to implement a minimum period of stabilized drawdown during the pumping process, and the water table to recover to at least 90 percent of the initial water level within 24 hours after pumping (Public Health Law 206(18)). The New York State Department of Environmental Conservation (NYSDEC) issues 10-year well permits that require individuals to disclose monthly pumpage (LICAP 2017). Since 1988, New York State local governments must develop Water Conservation Plans with measurable short-term conservation objectives (LICAP 2017). The NYSDEC's pumpage caps, developed in 1987 to limit pumping in Long Island, have not been enforced since the early 2000s (LICAP 2017).

Long Island and Shelter Island counties have developed and implemented water management plans for decades. For example, Long Island's Suffolk County created groundwater resource management goals in 2015 to be implemented over the next 20 years. These goals include upholding New York State Ambient Groundwater standards and Maximum Contaminant Level Goals, reducing nitrogen concentrations in groundwater, minimizing other contaminants, promoting land use patterns that protect groundwater resources, and maintaining and monitoring groundwater quality and quantity (Bellone, 2015). Suffolk County also developed a Subwatersheds Wastewater Plan to manage sewer contamination and wastewater treatment. To further address and study groundwater issues, Nassau County and Suffolk County created the Long Island Commission for Aquifer Protection (LICAP) in 2013. Both the LICAP and Suffolk County's management plan call for increased or restored test well drilling, water use monitoring, and health department industrial waste inspections (LICAP 2017). In 2016, LICAP created an online database, WaterTraq, to map and monitor the water quality of public water supply. This tool emphasizes the importance of engaging the consumer, water supplier, and local governmental entities with transparent data so that coordinated sustainability efforts may be designed. Only groundwater pumped for public supply is routinely tracked and published; however, any water withdrawal of more than 100,000 gallons per day must also be reported (Meyland 2017). As of January 2017, all public water suppliers must construct a water use reduction strategy to decrease use by 15 percent in the peak season over three years(Meyland 2017).

An adaptation strategy that accommodates increased precipitation and storm events, as well as a growing population, is Aquifer Storage and Recovery (ASR), in which water is stored underground during off-peak periods so that it may be recovered during peak periods. An additional adaptation strategy is Artificial Recharge (AR). Long

Island has implemented AR to replenish water in aquifers, and this practice should be expanded if aquifers become depleted due to increased pumping (LICAP 2017). If ASR and AR are not sufficiently counteracting increased pumping due to a spike in future demand, Long Island and Shelter Island may consider alternative water sources (i.e. rainwater harvesting or re-use of reclaimed wastewater) to maintain sustainable groundwater levels (LICAP 2017). Local governments may also encourage or discourage development and community growth based on the availability of quality drinking water.

# Conclusions and Recommendations

Challenges to the implementation of the above recommendations include a lack of public engagement, the low cost of water, old infrastructure, and increased demand for water resources (LICAP 2017). Public awareness campaigns should target consumer knowledge of proper irrigation system use, leak repair, and updating aging infrastructure. These strategies will optimize water use and decrease contamination. Active community development planning would help safeguard current groundwater resources.

Water on Long Island and Shelter Island is severely undervalued (LICAP 2017). When water is relatively underpriced for the consumer, individuals are not incentivized to conserve water resources. The region has historically benefitted from inexpensive water thanks to the high supply of high-quality groundwater. However, with the increased demand, contamination, and climate uncertainty, these circumstances may change soon. Water should be priced appropriately to incentivize wise use and investment in water infrastructure replacement.

There is still uncertainty as to how  Long Island's groundwater flow will be impacted by climate change. More research, including groundwater-flow modelling and hydro-geologic mapping, is required to substantiate current climate change predictions to the groundwater system. Local governments should conduct regional groundwater models to assist policy developments and conservation strategies.

Reporting and monitoring of groundwater pumping must be enforced so that local governments have an accurate estimate of available resources. Conservation policies have already been developed in Long Island, but until their routine enforcement takes place changes in consumer behavior are unlikely. Shelter Island does not have any water conservation measures that limit water use. Its small population and lack of industry or agricultural activity will likely allow the island's groundwater resources to remain relatively unchanged over the coming decades. However, Shelter Island should consider conservation measures during the summer months and in areas that have already experienced salt-water intrusion.

Population growth patterns and land use changes appear to be the most significant influence on the region's groundwater recharge ability. Although population growth has remained relatively steady for both Long Island and Shelter Island over the past few decades, there is still uncertainty in how population will change in the future. Local governments should be proactive in land use planning to ensure groundwater recharge is still supported. Local governments should also utilize New York State conservation measures to bolster local sustainability practices. Long Island and Shelter Island may turn to the water management procedures of similar coastal communities around the United States, such as the Coastal Plains District in Texas, for examples of comprehensive monitoring, enforcement, and conservation management systems. Maintaining groundwater sustainability is an active process that requires cooperation between consumers, local governments, industry, and agricultural actors. With thorough knowledge of the climate dynamics, projected population growth and development, and impacts of climate change, local entities should be proactive about groundwater conservation efforts and promote further research or modelling to understand potential scenarios with greater certainty.

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