Municipal solutions to climate change; a case study of stream daylighting in Suffolk County, New York

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Municipal Solutions to Climate Change; A Case Study of Stream Daylighting

In Suffolk County, New York

by

Madison L. Hrysko

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Abstract

During the 1950’s and 1960’s Suffolk County, New York experienced rapid urbanization and development. To pave way for infrastructure, hydrological modifications were made to the land including the burial of naturally flowing streams. Daylighting streams is the nature-based process of bringing buried streams back to the surface. In turn, restoring ecosystem services, increasing local resilience to climate change impacts, and expanding biodiversity. Minimal research has been done using GIS technology alongside a set of criteria to select best fit streams for daylighting. This thesis aims to fill that gap by identifying best and second-best fit streams for daylighting in Suffolk County, using a set of criteria and hydrologic modeling. The criteria selected is that potentially buried streams must be connected to an already existing waterbody, range between 250 and 1,000 feet in length, increase local resilience in vulnerable areas in Suffolk County, and must be more than 50 percent in the parks and recreation land use type. The criterion for this project is based on previous case studies, published guidelines, and management strategies for daylighting projects. It was found that a total of 67 stream segments are best fit for daylighting and 28 stream segments are second best for daylighting, totaling 95 stream segments (75,627.8471 feet). This information provides Suffolk County with a starting point for which stream segments are best suited for daylighting.
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Introduction

I. Study Area

Suffolk County, New York, is the easternmost county on Long Island, bordered by the Long Island Sound on the North Shore and the Atlantic Ocean to the South Shore, as shown in figure 1. Rapid urbanization of Suffolk County took place between 1950 and 1960, with the heaviest development occurring on the North and South Shores, capitalizing on Suffolk County’s coastal location (New York Water Science Center, 2017). During this time, the population in Suffolk County experienced a 141% increase (New York Water Science Center, 2017). This growth can partially be attributed to the rapid transit system which moved people and goods in and out of New York City, creating suitable living space on Long Island for year-round residents or summer residents escaping city life (New York Water Science Center, 2017).

Figure 1. Full map view of Long Island, New York encompassing Brooklyn, Queens, Nassau County and Suffolk County. Image from USGS, public domain (https://www.usgs.gov/centers/new-york-water-science-center/science/long-island-location-and-physical-setting).
The first major subdivision, known as Levittown, was built in 1947 just outside of New York City on Long Island (Marshall, 2015). A new concept at the time, Levittown was the product of Levitt and his sons. Together they specifically designed middle class houses for veterans and their families post World War II, which became the catalyst for modern day suburbia (Marshall, 2015). This type of development is referred to as urban sprawl and is generally considered unsustainable (Lehigh, n.d). Urban sprawl can be identified by the single-family units and expansive roadways separating dwellings. Urban sprawl leads to fragmented subdivisions, a reliance on personal automobiles, an increase in impervious surfaces, decreased walkability, and unproductive downtowns (Marshall, 2015 & Lehigh, n.d). What once was a natural landscape is now transformed into dispersed subdivisions, industrial buildings, strip malls, and major roadways (New York Water Science Center, 2017).

As the suburbs across Suffolk County expanded, the natural environment was shrinking. Hydrological modifications, including the draining of wetlands, and burial of streams, rivers, and other water bodies were paved over to make way for infrastructure (Elmore & Kaushal, 2008). Suffolk County, NY, is a prime example of a geographical area with a high rate of suburban development as well as a multitude of risk factors associated with low-lying regions and water quality concerns. As the impacts of climate change become more prevalent, it is beneficial to locate existing streams that have been buried during development and bring them back to the surface (Horton, et al., 2011). By doing this, Suffolk County will increase its resilience, restore lost ecosystem services, and increase biodiversity.

II. Paving the Watershed - What Happens When Riverways Become Roadways?

An overarching theme of development was that the natural environment and ecosystems were not heavily considered (Khirfan, et al., 2020). Development can have drastic effects on the
biological, social, and physical aspects of an area (New York Water Science Center, 2017), and with the recent, increased effects of a warming planet, we have seen that short-sightedness begin to have major impacts especially on coastal areas.

One effect of urbanization on the natural environment is the process of stream burial, which is the umbrella term encompassing the creation of culverting, piping, concrete-lined ditches, or paving over streams for development (Elmore & Kaushal, 2008). The exact definition of a culvert is encapsulating a waterway specifically under roads, sidewalks, or train tracks; however, in this research, the term buried stream will refer to any man-made encapsulation process that took place during the development of a city, including those that run under roadways. As these streams were being buried underground, it became easier for municipalities to expand, exponentially reducing the number of naturally flowing streams.

At the time of many cities’ development, implications of stream burial were not thoroughly understood and were, therefore, severely mismanaged. In some cases, these encapsulated streams were used to transport sewage waste out of city centers. This is the case for Tibbetts Brook in the Kingsbridge section of the Bronx. This buried stream empties into the sewer system, making the Department of Environmental Protection (EPA) treat this buried stream as it would wastewater, which in turn, wastes time, money, and resources (Youngerman, 2013). In addition, when extreme weather arises, the sewage system is not equipped to handle the amount of sewage, rainwater, and brook flow which ends up overflowing into the Harlem River Ship Canal, untreated (Youngerman, 2013).

An example of an extreme storm event was Hurricane Ida in August of 2021. The Tibbetts Brook not only overflowed into the Harlem River Ship Canal but also onto the Major
Deegan Expressway. This roadway is a major artery connecting the Bronx to upstate New York, of which many people rely on (Hu & Thomas, 2021). Burying streams leads to an underground water management system that cannot handle as much water as natural features and are overall less resilient to flooding and storm surges, exemplified by Tibbetts Brook (American Rivers, 2007). A lot of these issues associated with buried waterways arise because the infrastructure was not meant to accommodate the future impacts of climate change or the exponential population growth that is taking place on Long Island. Without updates, alterations, or adaptations to this infrastructure, they are destined to fail.

Impervious surfaces like roadways and parking lots, that were built atop naturally flowing waterways, prohibit the natural infiltration of water into the ground and increase the rate and amount of runoff. Runoff is excess precipitation that flows down gradient, following gravitational forces (Water Science School, 2018). On Long Island, infiltrated water is very important because it replenishes underground aquifers. Approximately 1.5 million Long Islanders rely on aquifers for drinking water, bathing, laundry, agricultural, and many other anthropogenic uses (US Census Bureau, 2020). Long Island sources water from three main aquifers, the Lloyd Aquifer, the Magothy Aquifer, and the Upper Glacial Aquifer, which were formed by glacial retreats around 65 million years ago (Long Island Clean Water, 2017). Long Island relies entirely on these underground aquifers for their potable water and without adequate areas for infiltration there will be a lack of quantity (and quality) of water for residents (Nassau Suffolk Water Commissioners’ Association, n.d).

The infiltration process allows for precipitation or snowmelt to slowly be deposited into the aquifer, passing through plants, soils, or depressions beforehand (American Rivers, 2007). As water travels through the sediment, the water is rid of some pollutants, being naturally filtered
before it reaches the aquifer. When natural features, like vegetation, are removed for
development purposes or replaced with impervious surfaces, it lessens the amount of suitable
area to filter water into aquifers. If water is not being filtered, it ends up as runoff, carrying
pollutants to larger bodies of water, decreasing water quality downstream. (American Rivers,
2007).

In addition to the mismanagement of buried streams, flooding implications and water
quality concerns are also negative impacts of buried streams. Burying streams also changes
runoff patterns, water’s availability to downstream areas, and fragments aquatic and terrestrial
wildlife populations (American Rivers, 2007). Using nature-based solutions to increase stream
vitality and overall resilience is especially important to plan for the challenges associated with
climate change (American Rivers, 2007).

III. Climate Change and Culverted Streams

New York State has researched the trends and projections of climate change throughout
the state in a report called ClimAID. Not only does this report analyze past trends but also
projects future trends for the different regions of New York. New York State’s temperature has
historically risen .6 degrees Fahrenheit per decade since 1970 (Horton, et al., 2011). Since this
report in 2011, the projected temperature trend is 1.6 degrees Fahrenheit per decade for a total
increase of 4.0-9.0 degrees Fahrenheit by 2080 (Horton, et al., 2011). Sea-surface temperatures
are also predicted to rise between 1.8-2.5 degrees Fahrenheit by 2050, which would alter the
biologic and ecologic make up of Long Island’s water bodies (Buonaiuto, et al., 2011).

By 2080, regional precipitation will increase by 5-15% (Horton, et al., 2011). The rate of
precipitation in New York State is not the main concern, it is the increase in severity, intensity,
and frequency of these precipitation events that will cause flooding concerns (Horton, et al., 2011). Along with these extreme precipitation events, increase in storm frequency and strength will further cause flooding implications. As severe storms reach landfall from water, “low pressure and strong winds can push abnormally high water levels onto the coast” (U.S. Climate Resilience Toolkit, n.d, para. 1). In conjunction with sea level rise and increases in precipitation, storm surge has the potential to reach further inland than ever before causing major destruction economically, physically, and environmentally.

Another example of one of these intense storms that devastated New York State is Superstorm Sandy, which made landfall in October 2012. Climate scientists suspect warmer, higher seas, and unusual weather patterns made this storm more brutal than others (Freedman, 2012), illustrating what is to come in a modern world with no action to combat climate change. Hurricane Sandy affected 70,000 people, destroyed more than 600,000 housing units, over 8 million people lost power, and cost New York City at least $19 billion dollars to remedy (Gibbens, 2019 & Blake, et al., 2012). Understanding and implementing practical solutions to reduce climate intensification in Suffolk County will make it a more sustainable place to live and will, in the long run, save money, lives, and existing infrastructure.

Sea level rise is also affecting New York State and is modeled by two different projections; the general circulation model (GCM) and the rapid ice-melt scenario (Horton, et al., 2011). GCM is a more conservative approach to estimations, projecting that Long Island will experience between a 12- and 23-inch rise in sea levels by 2080 (Horton, et al., 2011). On the other hand, according to the rapid ice-melt scenario sea level is projected to rise 55 inches by 2080 on Long Island (Horton, et al., 2011). The rapid ice-melt scenario is “based on observed rates of melting and paleoclimate records,” and projects higher sea level rise than the traditional
GCM because it considers accelerating ice sheet melt in Greenland and Western Antarctica (Horton, et al., 2011, page 16).

Suffolk County’s coastal location and low elevation make it particularly susceptible to the effects of climate change (Horton, et al., 2011). Even though Long Island’s coastal areas are the most vulnerable, development pressure and coastal appeal continue to draw homeowners and developers. Low lying areas near the coast will be impacted by sea level rise, storm surges, coastal erosion, and flooding altering the livability of these areas (Buonaiuto, et al., 2011). Ultimately it is communities along the southern shore of Long Island that are impacted most heavily to these impacts because of their extremely low or even below sea level elevation, as depicted in figure 2.
Figure 2. Visualization of the south shore of Long Island experiencing 55 inches of sea level rise.

The infrastructure that currently exists on Long Island will not be able to withstand the effects of climate change. Buildings and residential homes may experience flooding up to the first floor, leaving entire buildings, industries, and commercial shops uninhabitable and unusable (Buonaiuto, et al., 2011). Another example of failing infrastructure is the municipal stormwater infrastructure that was built in the 1990’s. Stormwater infrastructure is unable to adapt to the variability and intensity of climate change. For example, in Indiana Dunes State Park, heavy rainfall caused a 200,000 square foot section of the parking lot to completely collapse despite there being an 84-inch culvert running below the surface (Indiana Department of Natural
Resources, n.d). Proving that the environmental conditions the culverts were originally made for do not account for the dynamic nature of climate change or any associated variables. Whereas naturally flowing waterways are better equipped to handle the variability in flooding events because they can expand and change in the face of stressors, especially during flooding events.

Moreover, water temperatures are rising due to climate change, making water bodies more conducive to harmful algal blooms (HABs). Warmer water does not mix as easily and therefore, allows HABs to grow thicker and faster, spreading across the surface (EPA, n.d). In addition to warming water, excess nutrients like phosphorus and nitrogen, contribute to the success of HABs. These nutrients are brought to water bodies via runoff, which will increase as intensity and severity of precipitation events increase, causing a decline in water quality. HABs absorb sunlight at the surface and outcompete organisms below the surface. Without sunlight reaching below the surface, organisms cannot survive, causing massive dead zones. These dead zones cause water bodies to stop providing the ecosystem services that are typically produced from healthy water bodies.

Ecosystem services are services that are either directly or indirectly derived from nature that benefit human well-being (Grizzetti, et al., 2016). Services like clean water, clean air, regulation of disease and climate, biodiversity, recreation opportunity, and spiritual benefits (Food and Agriculture Organization of the United Nations, n.d). Continued urbanization and historic burial of naturally flowing streams in Suffolk County will have devastating effects on water quality, aquifer health, and hamper ecosystem services because of impervious surface creation and the pollutants they bring downslope. Moreover, as water becomes warmer due to climate change HABs will have the necessary environment to thrive, outcompeting other organisms.
The most important climate related changes to Suffolk County to note are coastal sea level rise, increase in storm severity, and increased incidence of precipitation events, which all lead to extreme flooding. Water quality concerns are also important to consider because of increasing water temperatures and HAB production. Economically, Long Island’s water is important to preserve considering approximately “$153 billion coming from businesses that are water-reliant” (Long Island Clean Water Partnership, 2018, para. 5). Additionally, water on Long Island is valued for recreational use, like swimming, fishing, shell fishing, boating, and tourism (Opaluch, et al., 1999). Just the Long Island Sound alone is worth 5.53 billion dollars when combined with direct and indirect benefits and intrinsic value (Long Island Sound Study, 2010). When included with other key water bodies like the Atlantic Ocean and the Peconic Estuary the overall price of healthy water on Long Island skyrockets.

III. Importance of Headwater Streams

The most vulnerable streams to the process of burial are smaller streams in urban/suburban areas which are known as headwater streams. Headwater streams are the birthplace of all waterways and eventually can develop into larger streams as it moves through the natural environment (American Rivers, 2007). Headwater streams can be ephemeral, having water only after periods of heavy precipitation, intermittent, having water during the wetter part of the year, or perennial, having water flowing throughout the entire year (State of Ohio Environmental Protection Agency, 2003). Regardless of the classification of headwater streams, these water bodies influence the overall quality of larger streams they flow into and are important to preserve and monitor (State of Ohio Environmental Protection Agency, 2003).

Headwater streams are largely underrepresented in maps and are mismanaged because of their size; however, they make up over 70 percent of stream mileage in the United States (Lowe
Headwater streams allow for key ecosystem services like the rapid uptake of nutrients, for example nitrogen and phosphorus. Headwater streams also filter pollutants from getting into groundwater which is vitally important to the health of Long Island aquifers and water quality downslope (Elmore & Kaushal, 2008). Additionally, headwater streams provide a habitat for aquatic species as well as terrestrial life that rely on naturally flowing waters (Elmore & Kaushal, 2008). Their small size makes them easily influenced by local conditions and can be very different from the larger tributary it connects to downstream, supporting a wide array of biodiversity and species richness (Meyer, et al., 2007; Lowe & Likens, 2005). Certain species rely on headwater streams during specific life phases, or rely on them seasonally, or as conditions change downstream, providing a key habitat for fauna and flora (Meyer, et al., 2007). Hence, burying headwater streams for development and urbanization has unintended consequences to the existing environment and the intricacies of life within it.

V. Scope of Stream Burial

Using GIS to uncover the number of buried streams, including headwater streams, is important because of their ability to lessen climate impacts, improve water quality and increase biodiversity. Studies illustrating the implications of urbanization on streams that currently exist have been done, however, studies on buried waterways are largely understudied (American Rivers, 2007). Researchers at the University of Maryland conducted a study to illustrate the percentage of streams, including headwater streams, that have been buried in the Chesapeake Bay Watershed (Elmore & Kaushal, 2008). As it stood in 2008, the Chesapeake Bay Watershed had 20% of all streams buried while Baltimore City had buried 66% of their naturally flowing waterways (Elmore & Kaushal, 2008). Including headwater streams Baltimore City had buried 70% of all streams (Elmore & Kaushal, 2008). The research surrounding stream burial is
important because it exhibits just how often this practice was used. There is a need for education and public awareness of the implications of stream burial and the immediate need for policy intervention to address these buried streams.

VI. Daylighting and Overall Trends

Daylighting a stream is “the practice of removing streams from buried conditions and exposing them to Earth’s surface in order to directly or indirectly enhance the ecological, economic and/or socio-cultural well-being of a region and its inhabitants” as well as provide ecosystem services to an area (Khirfan, et al., 2020, sect. 5 para. 3). Marit Larson, Director of Wetlands Restoration for the Natural Resources Group of the New York City Department of Parks and Recreation is quoted in the Urban Omnibus, as stating that “restoring the structure of a stream channel and the surrounding habitat in turn improves the ecological function which is a very significant action,” (Youngerman, 2013, para 5). With the support of government entities and other stakeholders, daylighting projects are successful in restoring the ecological functioning of streams and surrounding areas.

Daylighting is categorized as a nature-based solution, meaning it contains an action “to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges (e.g. climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously proving human well-being and biodiversity benefits” (Cohen-Shacham, et al., 2016, page xii). Nature-based solutions recognize the important role that nature plays in everyday life and works toward creating solutions to problems while protecting nature's already existing assets (Cohen-Shacham, et al., 2016). Using daylighting as a nature-based solution has been around since the 1950’s and continued to pick up momentum in the United States, especially in the 1970’s amongst the environmental movement (Khirfan, et al., 2020).
The practice of daylighting can occur on entire portions of waterways or just portions of those that are covered. Daylighting also comes in different forms; for example, there are naturalized, channelized, and artificial streams. Naturalized streams are the most natural in their construction, built with no aid from other material than what is already there (Brown, et al., 2004). Channelized streams have hard bank stabilization to control erosion and is employed when upstream reaches have a high velocity (Brown, et al., 2004). Artificial streams have the most innovation with non-erodible substrates and in some cases linear pipes redirecting high flow from upstream (Brown, et al., 2004). This type of daylighting occurs when the surrounding watershed contributes too much stormwater, typically from run off (Brown, et al., 2004). With any option, daylighting restores ecosystem services that were once provided by the naturally flowing water.

Daylighting also lessens the impacts of flooding from extreme storm events, helps reduce erosion at downstream basins by slowing velocity, lessens pressure on stormwater systems because they have a greater hydraulic capacity, and provides niche habitats for wildlife (American Rivers, 2007). Moreover, daylighting aids in the filtering of pollutants, because they can retain and slowly release these pollutants more quickly than larger water bodies. Thus, preventing HABs downstream and improving overall water quality in surface and groundwater (American Rivers, 2007). Even from a management perspective daylighting has benefits; managing surface streams are easier to maintain and monitor since they are clearly visible (Pinkham, 2000).

In addition to ecological benefits, there are societal and recreational benefits to daylighting as well, such as increasing property values around revitalized areas, connecting adults and children to nature, increasing the livability of suburban/urban areas, creating an
opportunity for environmental education, and attracting tourists to an area, which in turn increases revenue to local businesses and the community (American Rivers, 2007). Daylighting can be a draw to parks and natural spaces because of its unique value, especially in suburban/urban environments where there are not as many natural water features (Pinkham, 2000). Economically, maintaining and creating a daylighted streams can increase job opportunities on Long Island’s suburbs (Pinkham, 2000).

a. Daylighting Success: A Few Case Studies

Daylighting is a very interdisciplinary subject with its roots in ecology, sociology, hydrology, infrastructure, and economics (Khirfan, et al., 2020). The first known daylighting project is difficult to pinpoint but one of the earlier cases is Strawberry Creek in Berkeley California, which took place in 1985. Strawberry Creek had been buried to pave way for infrastructure which continuously failed under increased rainfall (Strawberry Creek Downtown, 1999). To alleviate flooding concerns, 200 feet of stream was daylighted and additional green space was built surrounding it, which cost about 50,000 dollars (American Rivers, 2007). Even though the cost of daylighting may seem high, there are numerous positive effects on the surrounding community. In the community around this daylighted creek, property values increased, crime decreased, and once abandoned businesses and warehouses were converted into local businesses and office spaces (Strawberry Creek Downtown, 1999).

Another daylighting project took place in Indiana Dunes State Park in 2005, where an 825-foot-section of Dunes Creek was daylighted. The free-flowing creek that flowed into Lake Michigan was buried and placed in culverts around 1930 so that a parking lot could be built above it, until it was brought back to the surface (Seven Canyons Trust, n.d). In 2008, another 700 feet of Dunes Creek was daylighted after a four-day rain event caused 16 inches of rain to
flood another parking lot. The heavy flooding caused a 200,000 square foot collapse despite there being an 84-inch culvert below it (Indiana Department of Natural Resources, n.d). Instead of repairing the parking lot, the state park decided to daylight another section of Dunes Creek. From 2005 to 2008, 1,575 feet of Dunes Creek was brought back to its natural state (Indiana Department of Natural Resources, n.d). In doing so, local flooding was reduced, water quality in Lake Michigan was improved, and more habitat was created for local species. The lost parking lot did reduce overcrowding at the park, but it did not decrease the state park’s revenue. In fact, “in 2005, the park brought in 68 cents for every dollar invested. By 2009, that had soared to $1.20” illustrating that natural features still brought people to this park despite there being less parking availability (Seven Canyons Trust, n.d, para. 4).

A more recent example of daylighting occurred on a section of the Patroon Creek in the Tivoli Park Preserve, located in Albany, New York. The Patroon Creek flows through many locations in Albany including the Pine Bush Preserve, the City of Albany, and the Corning Preserve where the creek discharges into the Hudson River (WRGB, 2020). The daylighted piece of the Patroon Creek was approximately 1,500 feet, buried and culverted over 90 years ago (Siegal, 2021). Now, the naturally flowing section of the creek features educational signage, small water features, and improved trailways (WRGB 2020). These add-on features, as well as the daylighting itself attracts nature lovers and community members alike. They enhance the outdoor recreation and educational opportunities that were once underutilized at the Tivoli Park Preserve (WRGB, 2020).

In addition to recreation benefits, the daylighting project restores ecosystem services and aids in localized flood prevention, increases water quality in both Tivoli Lake and the Hudson River, and prevents an overgrowth of algae (WRGB 2020). This project received the
Environmental Protection Agency’s (EPA) honorable mention in the Clean Water State Revolving Fund (SRF) which recognizes exceptional projects and highlights them nationally (Siegal, 2021). This accolade can only be received if the project has “one or more of the following criteria: innovative financing, system partnerships, community engagement, environmental and public protection, and problem solving” (Siegal, 2021, Para. 2). Receiving this accolade on a daylighting project reiterates this type of project’s benefits and sheds light on an underused nature-based improvement. Although this project cost $3 million dollars, the cost was divided amongst New York State Department of Environmental Conservation (DEC) as a Water Quality Improvement Grant and the Environmental Facilities Corporation as a Green Infrastructure Grant (Siegal, 2021).

There have not been any documented daylighting projects on Long Island, however, there is one proposed on the eastern end of the North Fork. The daylighting project is in Skipper Horton Park and would connect Moores Drain to the Peconic Bay. The Peconic Bay is noted as one of the “Last Great Places” in the western hemisphere by The Nature Conservancy for its commercial and recreational value and for the wildlife that depend on it (The Nature Conservancy, n.d). The daylighting project is included in the Bay to Sound project, which is committed to creating paths connecting parks from the Long Island Sound to the Peconic bay in Southold and Greenport. The project is not still completed, as it has been slowed down by the COVID-19 pandemic. Preemptively and purposefully locating streams for future daylighting projects can better inform policy makers and government officials where their efforts and funds should be focused on.
Methodology

I. Criteria for Selecting Streams

Locating where daylighting streams could be buried is the starting point for municipal governments to begin utilizing nature-based practices, like daylighting. To figure out best suited streams for daylighting, certain criteria is set and are then analyzed in ArcGIS. This set of criteria is selected by analyzing various case studies, manuals, and written reports about daylighting, all of which had key overarching themes. A set of criteria for daylighting has yet to be established thus these existing manuals and resources serve as justification for the following criteria. The four criteria are listed below and are only applied to contiguous Suffolk County, and therefore exclude Shelter, Plum, and Fishers Island. Possible daylighted stream segments:

1) Must be connected to an already existing water body
2) Range between 250 and 1,000 feet in length
3) Increase local resilience in vulnerable areas across Suffolk County
4) Must be more than 50 percent in the Parks and Recreation land use type

II. Modeling Streamflow

To begin, it is vital to identify, based on elevation, where potential waterways could be located. This can be modeled using a Digital Elevation Model (DEM) for Suffolk County which is obtained from NYS Clearinghouse (1995). The DEM was published by the U.S Geological Survey, has a pixel resolution of 10 meters, and was created in 1995. This layer is then added to ArcGIS and mosaiced together for consistency and continuity. Next the fill tool is used on the DEM to fill the sinks which could alter the delineation of basins and streams if not corrected for.
After the possible sinks are filled, the DEM is clipped to the Suffolk County shapefile, as seen in figure 3 (Suffolk County GIS, 2020).

**Figure 3.** This map depicts the elevation in Suffolk County, New York. The darker colors on the gradient represent the lower elevations and the lighter colors represent the higher elevations.

The following analyses employ the hydrology toolset, which relies on the corrected elevation model of the study area created prior. Flow direction is the first tool used on the data yielding a layer of all possible flow directions throughout Suffolk County. The flow direction tool creates this layer by taking the value from each pixel to its steepest downslope neighbor. After flow direction is determined, the flow accumulation tool creates a layer of the accumulated flow to each cell, as determined by the weight for all cells that flow into each downslope. Once
flow accumulation is carried out, the data is reclassified from five to two classes. Changing the symbology as well as reclassifying, better depicts the possible stream networks across Suffolk County, NY. The raster calculator is used to create a separate layer of all possible stream networks identified. To reduce confusion, this new layer in the following methods section will be referred to as possible streams or possible stream network while the existing stream network will be referred to as existing streams or existing stream network.

The next step is to add all existing water bodies (polygon shapefile) and existing stream network (line shapefile) to Suffolk County. This data is taken from the National Hydrology Dataset published by the United States Geological Survey (U.S. Geological Survey, n.d). The stream layer that is utilized includes a variety of water pathways, however, it is the perennial, ephemeral, and intermittent streams that are selected for analysis. As for the water body polygon from USGS, all available water bodies are selected for analysis including, reservoirs, playas, estuaries, ice masses, lakes, and ponds. When both layers are added there is overlap between possible stream network and existing stream network as well as possible stream network and the existing water bodies. To account for overlap, a manual correction is conducted to connect possible stream networks to all existing water as well as deleting the possible streams that are already included in the USGS layer. With this correction, smaller possible streams are depicted flowing into existing streams, as if they are a continuous network. The possible stream network is also flowing through the USGS’s water body layer. To correct this, the clip tool is used to clip all possible streams to these water bodies. The erase tool is utilized directly after to erase any possible streams overlapping within the existing water bodies. This creates a seamless interconnected network between possible streams, existing streams, and water bodies, as depicted in figure 4.
III. Length and Existing Water Connection Criteria and Justification

A 700-foot buffer is then created around the existing water bodies and the existing stream network. The intersect tool is used to identify locations where the possible streams intersect with the buffer and are split at the intersection. These steps are necessary to clip the possible streams to the buffer, creating a layer of possible streams only laying inside the 700-foot buffer for the entirety of Suffolk County, as depicted in figure 5. A 700-foot buffer is the length selected to ensure that possible stream networks connect to existing water entities and also used to reduce the length of streams to better fit the 250-1,000-foot range.
It is important to expand already existing water networks to alleviate flooding concerns, allowing the waterbody and new portions of daylighted streams to adapt and change during rain and flooding events (Schueler & Brown, 2004). With more space for water to go as it gets closer to the main waterbody, the surrounding area will be better equipped to handle excess water. An overarching theme of daylighting case studies is that daylighting took place on buried streams which connect directly to an existing waterbody. For example, the daylighting that occurred at Dunes Creek in Indiana State Park, Indiana, connecting Dunes Creek to Lake Michigan; Madrona Creek in Seattle, Washington connecting Madrona Creek to a pond on the west side of Lake Washington Boulevard; and Patroon Creek in Albany, New York connecting the creek to the Tivoli Lake. These case studies demonstrate that possible daylighted streams should be connected to an already existing water body for best results.

The 250-1,000-foot range for possible daylighting is based on plausibility and the likelihood of a project being developed due to budget concerns and timelines. Additionally, this range is selected based on Virginia Polytechnic Institute and State University Blacksburg Virginia’s (2007) research regarding daylighting. Their research involves a meta-analysis of daylighting case studies and defines a medium scale daylighting project as being 250-1,000 linear feet, with an average of 480 linear feet (Virginia Polytechnic Institute & State University Blacksburg, Virginia, 2007). The average cost for medium scale daylighting projects is approximately $48,250 dollars per daylighted stream (Virginia Polytechnic Institute & State University Blacksburg, Virginia, 2007). The results from this study translate well to daylighting in Suffolk County because a well-defined medium sized daylighting fits within budgets and time constraints, making projects like daylighting feasible. Anything larger may become a political, logistical, or monetary issue.
IV. Region One: South Shore

It is then important to understand key locations on Long Island that are vulnerable to the impacts of climate change, to make these areas more resilient, which is the next criteria. Areas of Long Island that will be most vulnerable to sea level rise are low-lying areas across Suffolk County. Sea level is projected to rise 55 inches according to the rapid ice-melt scenario by 2080 on Long Island (Horton, et al., 2011). Understanding this projected sea level rise for Long Island is vital to visualize sea level rise across Suffolk County. To visualize this information the DEM is used to select and extract pixels that are less than or equal to 55 inches. Once this polygon

Figure 5. The clipped possible streams inside the 700-foot buffer. Ensuring the length criteria established.
layer is applied it is visually apparent that the South Shore is the most vulnerable location to sea level rise due to its coastal location and low elevation. The towns along the south shore that are the most vulnerable to sea level rise are East Islip, Islip, Bayport, Bluepoint, Oakdale, West Sayville, Bellport, Sayville, Bay Shore, Patchogue, Brookhaven, Shirley, Mastic Beach, and Brightwaters. These towns are then selected, added to the map, dissolved into one undivided region, and labeled ‘Region One’. Not only are these towns affected by sea level rise, the low-lying southern shore of Long Island is also vulnerable to storm surges, flooding, and coastal erosion. Streams located inside the 700-foot buffer are then clipped to region one, reducing the size of the study area. To clip these streams to region one, the intersect tool identified where the possible streams inside the 700-foot buffer and region one intersect, the segments are then split, and clipped to region one. Now streams that connect to an existing waterbody, fall within the 250-1,000-foot length, and are in a region that is vulnerable to climate change are selected for further analysis and is shown in figure 6.
Figure 6. The extent of region one as well as the possible and existing streams that fall within it.

V. Region Two: Peconic Estuary

Another area that should be focused on in Suffolk County is the area surrounding the Peconic Estuary. The Peconic Estuary is the waterbody between the twin forks on the eastern end of Long Island. The towns, incorporated villages, or hamlets that surround the Peconic Estuary are Southampton, East Marion, Greenport, Sag Harbor, Southold, Water Mill, East Quogue, Riverhead, Calverton, Laurel, Mattituck, Peconic, Hampton Bays, Orient, East Hampton, and Cutchogue. These areas are selected and dissolved into one undivided region titled ‘Region Two’. From the USGS water body layer the Peconic Estuary and a portion of the Peconic River are selected to form a new layer, as depicted in figure 7. These features are buffered by 700-feet,
merged, and dissolved to create one cohesive buffer around the selected water features. Streams that intersect this buffer are then split and clipped to the buffer. Now only the possible streams that connect to the Peconic Estuary and portions of the Peconic River are selected for continued analysis. Although the Region Two layer is not used to manipulate any streams as it was in Region One, it is still important to visualize the broader study area around the Peconic Estuary.

Figure 7. This map shows the possible streams within the selected water features inside region two.

The Peconic Estuary is known to have severe water quality issues which are attributed to nitrogen loading (Peconic Estuary Partnership, n.d). Nitrogen loading causes HABs, low dissolved oxygen, and can cause entire aquatic ecosystems to collapse (Peconic Estuary
Partnership, n.d). In addition to ecosystem collapse, HABs can make fish and shellfish unsafe to eat and water unsafe to use recreationally (Peconic Estuary Partnership, n.d). Rising water temperatures due to climate change exacerbates HAB production, makes shellfish more vulnerable to disease, and causes species to die out due to competition for dissolved oxygen (Buonaiuto, et al., 2011). Therefore, it is important to direct daylighting efforts to this area because of water quality concerns. Daylighting tributaries and headwater streams that are connected to the Peconic Estuary will create more time for nutrients to be absorbed, further filtering out pollutants and improving water quality downstream (EPA, n.d). In doing so, the Peconic Estuary ecosystem, fishing industry, and surrounding community will be more resilient especially as climate change impacts worsen.

VI. Parks and Recreation Criteria for Both Regions

Now that the possible streams have been selected in each region, the next criteria can be applied in the same manner to both regions. The last criteria is that possible streams are to be partially or fully (at least 50 percent) within the parks and recreation land use type (Suffolk County GIS, 2016). To accomplish this, the possible streams that intersect the parks and recreation land use and follow the previous criteria are selected and added to the map as a new layer. Streams that are within or partially within the parks and recreation land use type are more easily daylighted because they do not have any structures built on top of it. These areas are void of impervious surfaces and are owned by a public entity, making it easier to daylight because the land does not need to be purchased from private owners, therefore saving money overall.

VII. Quality Control

With the last criteria applied to each region, the resulting streams are the best fit for daylighting in Suffolk County, NY. For quality control, each possible stream from both regions
is manually inspected for overall quality. Streams that have most of their flow on impervious surfaces, those that cross major roadways, streams that are already in existence, or are less than 250 feet are discarded. The final output after the quality control is separated into two different classes by adding a new field in the attribute table. One class satisfying all previous criteria making them the best fit streams for daylighting in Suffolk County. The other class includes the second-best streams for daylighting in Suffolk County. The second-best streams include those that are longer than 1,000 feet or have more than 50 percent of their length outside of the parks and recreation land use type. These streams are still worthwhile to consider for daylighting because longer streams can be daylighted gradually with a larger budget and in coordination with private property owners.

**Results**

Region one started with a total of 205 streams that fit within the criteria. After the visual quality control detailed in the workflow in figure 8, the final number of best fit streams with potential for daylighting is thirty-eight. There are twenty second best possible stream segments, totaling fifty-eight possible streams that have the potential to be daylighted, equating to 50,339.12811 feet. Region two started with 115 streams that fit within the criteria resulting in twenty-nine best fit streams for daylighting after a visual quality control. Within region two, there are eight second best possible stream segments, totaling thirty-seven streams that have the possibility to be daylighted, equating to 25,288.71909 feet. The results of this final analysis are depicted in figures 9 and 10.
Figure 8. Concept map (Cmap) representing the methodological workflow provided for clarity.
Figure 9. This map depicts the final stream selection in region 1 with best fit and second-best fit streams represented.
Figure 10. The final stream selection in region 2 with best fit and second-best fit streams represented.

Since the scale of this study is so large it is difficult to produce an effective static map image. Therefore, the results of this study can be explored using this link: https://arcg.is/1ezfu10. ArcGIS Online has proven to be a valuable tool to create interactive, dynamic, and exploratory maps which has significantly enhanced the practical use of results from this study.

Discussion

I. Federal, State, and Local Policy

The United Nations Convention on Biological Diversity recognizes that conservation and effective management of natural areas is an important nature-based solution for climate change
mitigation (Hannah, et al., 2020). Therefore, it is important to make these nature-based changes, like daylighting streams, to better prepare Long Island for the continued effects of climate change. The practice of daylighting not only fits into the international agenda but also fits into the United States agenda, with the passing of the Bipartisan Infrastructure Bill. This $1.2 trillion dollar bill provides the funding needed to make immediate changes in the United States, to strengthen the nation’s resilience. The two specific sections of this bill that daylighting could be supported and funded under are resilience and clean drinking water. In the resilience section, reducing the effects of flooding remains a top priority which daylighting streams accomplish. Region one would be the best location to focus daylighting efforts to relieve the south shore of Long Island of flooding attributed to climate change and low elevation. Additionally, investing, expanding, and improving clean water is outlined in this bill. Region two directly satisfies the efforts of the federal government regarding clean water efforts (DeFazio, 2021).

At the state level there are acts that improve community resilience and aim to reduce the effects of climate change. One of these acts is the Community Risk and Resiliency Act (CRRA). This act considers sea-level rise projections, the future physical climate risk, smart growth, and guidance on natural resilience (Adaptation Clearinghouse, n.d). Although not directly stated in the act, daylighting fits into this policy and can be supported through this bill. New York State is taking the initiative to research specific threats that climate change poses on the state and making efforts to mitigate climate change effects through policy. Therefore, with the trifecta of climate change being on the international, national, and state agenda, the policy window is open for daylighting to happen locally.
II. Sources of Funding

One of the major barriers to daylighting is the cost, however, daylighting can be subsidized through local, state, or federal government funds. Also utilizing volunteers to aid in the implementation can also be used to reduce some of the cost. On a federal level, funding could come from the Clean Water Act 319, Environmental Protection Agency Brownfield and Land Revitalization Program, Environmental Protection Agency Urban Waters Small Grants, FEMA Flood Relief and Flood Prevention, and Five Star Restoration Program. New York State also has grant funding available through programs like the New York Green Innovation Grant Program.

On an extremely local level Long Island Sounds Futures Fund provides funding for restoring and protecting the Long Island Sound, which daylighting streams will do. The benefits of daylighting outweigh the overall costs, especially with subsidies and grant money available at each level of government. A simple visual is found in figure 11, illustrating the costs and benefits of daylighting projects.

**Figure 11.** CMap of a simple cost benefit analysis of daylighting streams. The costs are depicted in green while the benefits are shown in blue. The arrows represent the directionality or continuation of a particular cost or benefit. This type of analysis is depicted as a thought map to encourage thinking about the larger picture when contemplating daylighting.
An example of the availability of funds for nature-based projects is the Bay to Sound trail project taking place on the eastern end of Long Island. Included in the Bay to Sound project are plans to daylight a section of a waterway in Skipper Horton Park, to create new and to improve existing hiking trails, and educational signs. However, the main goal is to create a hiking path between the Peconic Bay and the Long Island Sound using publicly owned preserves. This project has received over $250,000, proving that funding for these types of restoration projects is available to improve Long Island’s resilience (Salamanca, 2022).

III. Additional Barriers

There are some additional barriers to daylighting streams that occur on a smaller scale (stream by stream basis). One barrier is if a stream channel is buried too deep under the soil, which then becomes too costly to daylight. Moreover, there could be important utility lines that cannot be moved or altered above the channelized stream, forcing it to remain buried. Coordination of hydrologists and engineers are also necessary at individual daylighting sites for further evaluation of the hydrologic flow at each particular stream, ensuring that daylighting would be effective and plausible. Additionally, the ownership of the land on which the daylighting is to take place on could be a barrier. For example, owners on private land may not have the funding, resources, or knowledge of the process of daylighting to conduct without support. Whereas public land has more funding, experts, and time to take on ecological restoration. There are also extreme development pressures taking place throughout Long Island, which can lead to a complete disregard of existing and potential natural resources. Although funding is available for nature-based restoration, initial cost can be a barrier, as mentioned earlier. The cost for daylighting varies depending on the individual project and is therefore difficult to predict. Typically, daylighting is approximately 1,000 dollars per linear foot, but can
range between 500-5,000 per linear foot, with many projects being in the millions (American Rivers, 2007). However, if supplemented with funding, volunteers, and government support, daylighting is possible in Suffolk County.

In any area larger than Suffolk County, this type of analysis may not be effective because of the quantity of potentially buried streams located within a certain area. Even with a study area as large as Suffolk County, it is imperative that local municipalities take the time to understand which stream(s) are best for them to uncover. The criteria selected can be further expanded upon at each individual municipality in coordination with information like the depth of the buried stream, velocity of stream flow, and the amount of water being drained in the drainage basin to further select streams for daylighting. Despite these challenges, applying the above criteria to possible buried streams gives municipalities a place to begin exploration, especially as climate change continues to add stress on communities. This analysis can also be transferred to other counties for exploring potential daylighting locations. Moreover, this study can justify the use of public funds to acquire private land that have an opportunity for daylighting, in an effort to continue to preserve public space.

Conclusion

I. Insights When Daylighting: General Tools

Throughout daylighting case studies, there are overarching themes to ensure that daylighting is successfully done. Usually, to push the daylighting process along there needs to be significant local involvement and support throughout the entirety of the project. At the beginning of daylighting projects, outreach, transparency, and inclusivity are most important. These factors lead to positive reactions to the project, community volunteers down the line, and a sense of
place and belonging amongst residents. Gaining insight to what people want and expect to see can be done through visioning meetings; a place where residents can brainstorm what they want to see with a daylighting project or by taking polls around the community. Outreach needs to be directed at affected landowners to reduce complaints and appease their concerns, ensuring positive feedback.

All outreach needs to be done in conjunction with education because the general public may be unaware of the infrastructure around them. Especially in the case of daylighting because it is a historic process and streams remain unseen, underground. Education can take place during the project itself but can also continue once the daylighting project is finished through educational signage that details the implementation of the project and the benefits of daylighting. Daylighting can also foster education spaces surrounding a project through the addition of green spaces and parks that can be created during development. These locations can be utilized by organizations to educate the general public on the natural environment and serve as a place for educational signage about daylighting. In fact, the most successful daylighting projects are completed with a park or enhancement to the surrounding area. Examples include sitting areas, native plantings, or small parks.

Involving multiple stakeholders in the daylighting process is also important, as it secures a diverse set of funding and fosters long term support for the project. Stakeholders do not just have to be from the area where the project is taking place. In fact, expanding stakeholder involvement by using a watershed approach to encourage individuals or groups from upstream can increase traction, since upstream water contributes to downstream water quality. Additionally, all levels of government should be involved, including federal, state, local, tribal leaders, and nonprofits. Funding should incorporate the first two years of monitoring.
maintenance, and documentation that would take place alongside volunteer efforts to ensure the daylighting’s success.

Coordinating daylighting projects with respect to a larger plan, such as a comprehensive, sustainability, or master plan can hold politicians and elected officials accountable to their goals outlined in these plans. Linking daylighting back to a larger plan can also remind residents of the goals and ambitions of the community that they live in. If these large plans are widely adopted, have broad support, and include sustainable practices, implementing a daylighting project would be a way to implement real change with long term benefits.

II. Daylighting: Solution to Climate Change

Urbanization has had long standing effects on the landscape of Long Island. Especially through the process of stream burial. Suffolk County, specifically the South Shore and the Peconic Estuary, are vulnerable to impending impacts of climate change. Impacts like flooding, sea level rise, decreased water quality, increased storm severity and precipitation all have disastrous effects on infrastructure, public health, and public livelihood. Even if global emissions were cut immediately, the impacts of climate change will still last for many years, making it important to make nature-based changes as soon as possible (Solomon, 2009). It is then critical to ensure Long Island’s longevity and improve overall resilience to impending climate related problems.

Daylighting streams under the criterion of being connected to an already existing water body, range between 250 and 1,000 feet in length, increase local resilience, and must be more than 50 percent in the Parks and Recreation land use type are best suited streams to daylight in Suffolk County. Applying this criterion to Suffolk County using GIS identifies the best locations
for daylighting, providing municipalities a valuable starting point for the implementation of nature-based solutions to combat the realities of climate change in particularly vulnerable regions.
References


https://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf


https://serval.unil.ch/resource/serval:BIB_93FD38C8836B.P001/REF


Food and Agriculture Organization of the United States. (n.d). Ecosystem Services Biodiversity (ESB). FAO.


https://www.theguardian.com/cities/2015/apr/28/levittown-america-prototypical-suburb-history-cities


https://www.nswcawater.org/water_facts/our-long-island-aquifers-the-basics/

https://www.dec.ny.gov/lands/31842.html

https://www.usgs.gov/centers/new-york-water-science-center/science/long-island-population?qt-science_center_objects=0#overview

http://t.peconicestuary.org/reports/f53c82ee382e1c988058ee2ae8e47db855b1517e.PDF

https://www.peconicestuary.org/projects/clean-waters-2/#:~:text=One%20of%20the%20most%20serious,oxygen%20and%20degraded%20aquatic%20habitats,&text=and%20human%20health.-One%20of%20the%20most%20serious%20issues%20affecting%20water%20quality%20in%20Estuary%20is%20excess%20nitrogen%20loading


Seven Canyons Trust. (n.d). *Dunes Creek*. Seven Canyons Trust.
https://sevencanyonstrust.org/blog/dunes-creek


https://doi.org/10.1073/pnas.0812721106


Strawberry Creek Downtown. (1999). *City of Berkeley*.
https://www.cityofberkeley.info/uploadedFiles/Planning_and_Development/Level_3_-_DAP/StrawberryCreekReport.pdf


https://opendata.suffolkcountyny.gov/datasets/SuffolkGIS::landuse-2016-polygon/about


https://www.census.gov/quickfacts/suffolkcountynewyork

United States Environmental Protection Agency (EPA). (n.d). “Climate Change and Harmful
https://www.epa.gov/arc-x/climate-impacts-water-quality#:~:text=In%20many%20areas%2C%20increased%20water%2C%20due%20to%20extreme%20storm%20events

https://www.epa.gov/cwa-404/streams-under-cwa-section-404

https://toolkit.climate.gov/topics/coastal/storm-surge


https://vtechworks.lib.vt.edu/bitstream/handle/10919/49482/VWRRC_sr200735.pdf?sequence=1


WRGB. (2020). Patroon Creek Restored to Natural Condition in Tivoli Park Preserve. 6 News.