Assessing the Effectiveness of Green Infrastructure
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Abstract
Although green infrastructure is accepted as a technique to reduce runoff and improve water quality, questions remain about its effectiveness in the field. This study has three components: a quantitative assessment of runoff reduction in two municipal parking lots, a qualitative assessment of design features, and an analysis of the history of the Tannery Brook to provide context for modern restoration. In fall 2016, two municipal parking lots in Kingston, NY were reconstructed with several green infrastructure practices. Water level within 2 rain gardens, 3 bioretention areas, and 5 dry wells was measured for 28 storms May-November 2017 to better understand runoff reduction. Although certain maintenance issues have been identified, the practices are overall performing very well. The Tannery Brook is an excellent case study of the ways that we have perceived and managed water in cities over time. Its history and present state provide context for modern stream and stormwater management. By sharing the Tannery Brook's story, we can better understand urban waterbodies and what it might take to improve them in the future.

Three Summary Points of Interest
- The bioretention areas, rain gardens, and dry wells reduce runoff very quickly, particularly the dry wells.
- After construction, the City of Kingston made several changes to improve the parking lots. Lessons learned from adaptive management can inform future green infrastructure projects.
- The history of the Tannery Brook provides context for modern-day water quality and flooding problems, along with opportunities for restoration.
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Keywords: green infrastructure, stormwater management, urban runoff, urban stream, environmental history

Introduction

Although green infrastructure has become increasingly accepted as a technique to reduce runoff and improve water quality, questions remain about its effectiveness in the field. As stormwater practices are increasingly constructed in previously developed areas as retrofits, it is important to understand how these practices function. Quantifying runoff reduction can also help communities understand expectations for stormwater practices, and help overcome barriers to more programmatic implementation (Green Nylen & Kiparsky 2015). Water quantity in particular has implications for localized and riverine flooding, managing extreme storms, reducing combined sewer overflows, and improving stream ecology and geomorphology that may be harmed by flashy runoff patterns.

The Hudson River Estuary Action Agenda 2015-2020 is a conservation and restoration blueprint for the Hudson River estuary ecosystem. Its first long-range target for Clean Water states: “Water quality in the estuary, its tributaries, and watershed is maintained and improved to support municipal drinking water supplies, swimming and other types of water-based recreation, as well as aquatic life” (NYS DEC Hudson River Estuary Program 2015). The Action Agenda also includes the 2020 outcome that: “Green infrastructure is used where feasible and cost effective to achieve more pollution reduction in the estuary, and the effectiveness of green infrastructure as a tool for improving water quality is better understood” (NYS DEC Hudson River Estuary Program 2015).

This research project assesses the effectiveness of green infrastructure at two municipal parking lots in Kingston, NY to better understand how these practices can be used to improve clean water and resilient communities in the Hudson River estuary watershed. It also assesses these stormwater practices within the context of the Tannery Brook’s watershed and history.

Site Background

The City of Kingston is located between the Rondout Creek and the Lower Esopus Creek in Ulster County, New York in the mid-Hudson Valley. As July 2016, Kingston’s population was estimated to be 23,210 people (US Census 2017).

In 2007, the New York State Department of Environmental Conservation (NYS DEC) listed the Lower Esopus Creek (from the confluence with the Tannery Brook in Kingston to its mouth in Saugerties) as having “Minor Impacts.” This segment is Class B (best use is swimming or other contact recreation), but various uses, including public bathing, aquatic life, and recreation, were considered stressed. Urban/storm runoff was also identified as a known source of pollution, particularly for phosphorus (NYS DEC 2007).

In 2012, the United States Environmental Protection Agency (US EPA) appended this segment (“Esopus Creek, Lower, Main Stem”) along with the upstream segment (“Esopus Creek, Middle, Main Stem”) to the Section 303(d) List of impaired waterbodies. The specific cause/pollutant was turbidity, and suspected source was stream erosion (NYS DEC 2016).

The City of Kingston applied to the NYS DEC’s Water Quality Improvement Program grants to improve stormwater management at three municipal parking lots, with a primary goal of the project to reduce sediment loading into the Lower Esopus Creek. The grant application included green infrastructure stormwater projects in the two municipal parking lots on North Front Street (Kingston Uptown Parking Lots) and one parking lot in the Midtown neighborhood.

NYS DEC awarded the $365,831 grant in 2013, and the City of Kingston contracted with engineering firm Barton & Loguidice to design and manage the project.

This study focuses on the two Kingston Uptown Parking Lots on North Front Street near the intersection with Crown Street. They are located directly across the street from each other. This area has separated storm sewers,
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although much of the City of Kingston is served by a combined sewer system that discharges into the Rondout Creek.

Results & Discussion

Barton & Loguidice completed engineering designs for the parking lots and green infrastructure in August 2015. Since the project was considered a retrofit, practices were not required to meet the standards in the NYS Stormwater Management Design Manual. However, the designed practices were representative of good design practice.

Barton & Loguidice calculated runoff reduction for each practice (2-, 10-, and 100-year storms) using HydroCAD. The City of Kingston calculated pollutant load reductions using EPA Region 5 Model (STEPL, or the Spreadsheet Tool for Estimating Pollutant Load). This model estimated that bioretention/infiltration practices at the two parking lots would reduce 0.8 tons/year of sediment, 3.4 pounds/year of phosphorus, and 17.4 pounds/year of nitrogen to the Esopus Creek (City of Kingston 2013). These calculations were updated in 2015 with the microcatchments for each parking lot/practice.

Construction took place from August to October 2016. The South lot has one rain garden, two bioretention areas, three dry wells, and one section of pervious pavers. (Although there is another strip of pervious pavers between parking lanes on the west side of the lot, this section is crowned and does not seem to infiltrate runoff.) The North lot has one rain garden, one bioretention areas, two dry wells, and two sections of pervious pavers.

Figure 1: Engineering plans for the South lot, with rain gardens/bioretention areas (green), pervious pavers (orange), and dry wells (purple) highlighted (Barton & Loguidice 2015).

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Quantitative Assessment

Onset HOBO pressure transducers were installed in the dry wells on November 22, 2016 and in the bioretention areas and rain gardens on November 23, 2016. In each of the five dry wells, a 1” perforated PVC pipe was installed to house the HOBO. In each of the two rain gardens (without underdrains), a 1” perforated PVC pipe was installed and buried 3 feet under the surface to house the HOBO. In each of the three bioretention areas (with underdrains), the HOBOs were placed within the underdrain at the overflow riser. An extra transducer to measure barometric pressure was hung suspended within the overflow riser in Bioretention Area North, and these readings were used to convert pressure into water level in each of the green infrastructure practices.

The HOBOs were programmed to log pressure and temperature every minute, and data from the sensors were downloaded every 2 weeks. An Onset rain gage was installed at the site on May 5, 2017, which also recorded rainfall each minute. These data were paired for each practice and each storm.

Between May and November 2017, 28 storms were measured, along with water level in each of the 10 green infrastructure practices. A storm was defined as having more than 0.05 inches of rain, with an antecedent dry period of more than 6 hours. Depth, duration, average intensity, and peak 5-minute intensity were calculated for each storm. Most of the storms were less than 1 inch of rain, with an average storm of 0.5 inches.

Runoff characteristics were calculated for each practice. These included time and depth of first peak, time and...
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depth of maximum peak, time and depth of last peak, and time where water level was zero. Time from last peak to zero, time from maximum peak to zero, time from last peak to zero, and time from storm end to zero were also calculated to examine time for practices to infiltrate or drain. For this study, the analysis focuses on maximum depth and time from last peak to drain. This information has implications for the design and overall functioning of the green infrastructure practices.

All of the practices with HOBOs appear to reduce runoff very quickly. There are clear changes in water level when water enters and ponds in the practice, particularly in the two rain gardens, but water appears to be infiltrating very rapidly in all of the practices.

Figure 3: Example of changes in water depth from Rain Garden North (no underdrain) on 8/4/17. Values are recorded every minute, and converted from pressure to sensor depth by HOBOware software based on barometric pressure.

The two south bioretention areas (with underdrains) had no water measured within their underdrains. The north bioretention area only had a small amount after intense rains, likely because of water coming in through the overflow portion. Since I observed water ponding in these practices after storms, it can be assumed that all of the water infiltrated directly into the soil, and did not collect in the underdrain.

In the two rain gardens (without underdrains), water ponding was deeper than the other practices, but still infiltrated quickly. 76% of storms infiltrated in less than 12 hours, which is much faster than the 48 hour period recommended by design standards.

Figure 4: Maximum recorded water depth for each storm in the two rain gardens. The HOBOs were buried 1 foot below the ground surface, so the maximum ponding above the ground level was 3.2 feet.

Figure 5: Time for the water level in the two rain gardens to drop from the maximum depth to zero for each storm. The outlier (65 hours) is when another storm began before the practice finished draining.

Of the practices monitored in this study, the dry wells seem to be receiving the most runoff from the site. The dry wells drain very quickly, and 83% of storms infiltrated in less than one hour. Water depth did not appear to change during some storms; especially for
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larger storms, it can be assumed that the dry wells were infiltrating runoff as quickly it was entering the practice.

![Graph: Maximum Depth]

**Figure 6:** Maximum recorded water depth for each storm in the five dry wells. The HOBOs were buried 1 foot below the ground surface, so the maximum ponding above the ground level was 1.8 feet.

![Graph: Time to Drain from Max Peak]

**Figure 7:** Time for the water level in the five dry wells to drop from the maximum depth to zero for each storm.

**Qualitative Assessment**

Frequent site visits (at least every two weeks) and observations on adaptive management can provide insight into how the parking lots function over time. Detailed case studies can inform design, management, and maintenance. Although this site is not within the combined sewer system drainage area, much of the City of Kingston is, and similar practices could be implemented elsewhere in Kingston to mitigate flooding or combined sewer overflows. This case study can also contribute to green infrastructure projects in other urban areas within the Hudson River estuary watershed.

The City of Kingston has had to make several changes to improve the design of the parking lots, which have implications for the stormwater practices and their function. These have included regrading around two of the dry wells (Dry Well South 1 and Dry Well South 2), installing fences to prevent cars from driving through the bioretention areas, and creating walkways alongside the bioretention areas for pedestrians to cross from the parking lot to the business area (Bioretention Areas South 1 and Bioretention Area North).

Only one practice received mulch (Bioretention North), and weed growth has been an issue. All of the vegetated practices have been maintained by mowing. Some of the woody plants have been damaged by the mowers and snow removal in the winter.

![Image: Weed growth and ponding in Rain Garden South]

**Figure 8:** Weed growth and ponding in Rain Garden South.

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Although all of the practices appear to be infiltrating runoff quickly, performance may be compromised over time if the material gets clogged. Some sections of the pervious pavers appear to already be clogged after one year, and fine sediment/leaf litter going into the dry wells may reduce infiltration rates in the future.

**Historical Context: Tannery Brook Watershed**

Based on topography, the two parking lots should drain to the Tannery Brook. However, due to many management decisions over time, the Tannery Brook has been buried and natural flow paths have been substantially altered. Nevertheless, greater implementation of green infrastructure practices within the Tannery Brook’s watershed could help alleviate local flooding and improve water quality.

The Tannery Brook’s history of management dates from colonial settlement, when it was first dammed in 1661, through today. Although the Tannery Brook has worked hard for Kingston over the centuries – including powering mills, irrigating crops, providing water for breweries and distilleries, supporting industries, and carrying away waste – it has been increasingly fragmented and forgotten. Large sections of the Tannery Brook have been buried under the city, and the stream now flows in pipes below roads, parking lots, and houses. It hasn’t been forgotten by everyone, though; it continues to make its presence known through flooding, infrastructure failure, and other damage. In particular, the Tannery Brook contributed to a major sinkhole on Washington Avenue that closed the road for 5 years and has cost over $10 million to repair.

This project examines at the history of the Tannery Brook through 4 major themes over time:

- Land use changes,
- The process of fragmentation,
- The location of the Tannery Brook and its tributaries (morphology), and
- Uses of the stream (ecosystem services).

Methods include reviewing books on the history of Kingston, maps (dating as early as 1685), engineering plans and reports, newspaper articles (dating as early as 1889), photos, postcards, and personal communications with experts on local history. These materials either
directly discussed the Tannery Brook, or provided context for conditions or decision-making that impacted it.

To visualize changes in land use, fragmentation, morphology, and ecosystem services, Jiamin (Jasmine) Chen, a graduate student in landscape architecture, created a series of digitized maps. Jasmine matched each historic map to a base map using roads and other features from the time, and traced important content in Adobe Illustrator. The digitized maps have a consistent set of symbology to more easily compare the maps over time. Many of the digitized maps include our best assumption of where streams would be at the time, if they are not fully mapped on the original map. In some cases we have juxtaposed multiple maps to show a broader, watershed perspective on the Tannery Brook.

Figure 10: 1899 Sanborn map showing the Tannery Brook’s path and its confluence with Main Street Brook, its largest tributary. Maps like this one reveal the stream’s historic path, in addition to shedding light on the relationship of the city with the Tannery Brook.

Figure 11: Digitized map with content from 3 different subdivision maps. By juxtaposing this information, we can see where the Main Street Brook, a tributary of the Tannery Brook, was located and channelized.

From March 3 through April 29, we showed “Fragmented & Forgotten: Tracing the Tannery Brook,” at the Lace Mill in Kingston. Historic maps of the Tannery Brook were shown with Jasmine’s digitized maps, historic images, and text to visualize changes in and around the stream over time. Approximately 185 people visited the exhibit, including residents who live along the Tannery Brook, municipal officials and staff, local history experts, water management professionals, and many others who were interested in the topic. Open gallery hours were held at a variety of times throughout the two months so that as many people as possible could view the work, and on April 6, I gave a lecture on the history of the Tannery Brook.

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In addition to open viewing hours specific to the exhibit, several other events were held in the space, including two jazz concerts organized by bassist Michael Bisio and a Heal Well Kingston gathering sponsored by the City of Kingston.

On March 14, I organized a green infrastructure workshop in partnership with City of Kingston and Ulster County Department of the Environment. The workshop was held in the gallery with the Tannery Brook exhibit, and I presented both the quantitative and qualitative assessment of the green infrastructure practices. Other case studies from Kingston were also presented.

The exhibit not only shared information about the Tannery Brook and its history, but also created a space for people to gather and have conversations about opportunities for next steps. Information on the Tannery Brook’s history and ways to get involved has also been posted to a public website: [https://www.tracingtannerybrook.com/](https://www.tracingtannerybrook.com/).

**Policy Implications**

Understanding the effectiveness of green infrastructure practices can help municipalities and regulators implement practices more strategically. Quantifying runoff reduction can give us a better idea of how to give “credit” for implementing certain practices. This detailed case study allows us to share valuable lessons learned about implementing green infrastructure retrofits in an urban area. The City of Kingston can learn for future projects, and other communities can also benefit. In addition, understanding the dynamics of urban streams can help us identify where streams may actually be located. This work will be included in the City of Kingston’s Natural Resource Inventory, which will inform the Open Space Plan.
Outreach Comments

The most significant outreach was the “Fragmented & Forgotten: Tracing the Tannery Brook” exhibit. The exhibit was on display for about 2 months, and reached a diverse audience of over 185 stakeholders. Information from the exhibit has also been posted to a public website, so it can be a resource for residents and other projects: https://www.tracingtannerybrook.com/. A link to the website will be included in Kingston’s Natural Resource Inventory and on the City of Kingston’s website.

The green infrastructure quantitative and qualitative research was presented at a Green Infrastructure in Kingston workshop, which took place in the gallery with the Tannery Brook exhibit. This workshop included presentations from Ralph Swenson, City of Kingston Engineering Department; Joe Chenier, City of Kingston Department of Public Works; Amanda LaValle, Ulster County Department of the Environment, and Steve Noble, City of Kingston Mayor. The workshop was attended by 25 people, and included a rich discussion of practical implications for green infrastructure.

Figure 14: City of Kingston Mayor Steve Noble presenting at the Green Infrastructure in Kingston workshop.

I also presented the research at the Lower Hudson Coalition of Conservation Districts’ Southeast NY Stormwater Conference (October 2017), Kingston’s Climate Commission meeting (March 2017), and the Hudson River Estuary Program’s staff meeting (January 2017).

Throughout the project, I’ve been communicating with the City of Kingston’s Engineering Department, Parks & Recreation Department, and Department of Public Works. I have also reached out to Ulster County staff, other City of Kingston staff, members of Friends of Historic Kingston, and other local history and engineering experts.

Student Training

I collaborated with a Jiamin (Jasmine) Chen, graduate student in the Landscape Architecture department on the Tannery Brook history portion of the project. Jasmine created digital versions of the historic maps, overlaying content to get a more holistic picture of the stream’s morphology, land use, and uses. Jasmine also helped curate the exhibit by helping select the materials to show, organizing their layout, and sizing materials appropriately to print.

Publications/Presentations

Information has been published to the web: https://www.tracingtannerybrook.com/

Presentations include:
- Lecture on Tannery Brook History (April 2018, Kingston, NY)
- Green Infrastructure in Kingston workshop (March 2018, Kingston, NY)
- Lower Hudson Coalition of Conservation Districts’ Southeast NY Stormwater Conference (October 2017, Beacon, NY)
- City of Kingston Climate Smart Commission (March 2017, Kingston, NY)
- Hudson River Estuary Program staff meeting (January 2017, New Paltz, NY)

Additional final reports related to water resource research are available at http://wri.cals.cornell.edu/news/research-reports
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References


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