Delaware Canal
Preliminary Stormwater Study

December 2017

prepared by:

DELAWARE CANAL 21
LANDMARK *FUTURE*

HERITAGE CONSERVANCY

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Delaware Canal Preliminary Stormwater Study

An Overview

The Delaware Canal State Park (DCSP) in Pennsylvania, extends from the City of Easton in Northampton County to Bristol Borough in Bucks County. The central feature of the park is the 60-mile Delaware Canal and Towpath that parallels the Delaware River. Designated as a National Historic Landmark, the Delaware Canal retains much of its original infrastructure. In fact, its age and complexity make this facility the most technically intricate and costly Pennsylvania state park to operate and maintain.

In addition to the routine operations and regular capital maintenance of the canal, the park staff must also contend with periodic river flooding and land-based stormwater runoff that cause substantial impacts to the structure and operability of the canal and towpath.

This study focuses on stormwater issues that primarily originate outside the State Park boundaries and beyond the direct control of the Pennsylvania Department of Conservation and Natural Resources – the Commonwealth steward agency.

Throughout the length of the park, stormwater impacts are chronic and threaten the integrity and stability of the canal and towpath. Without the ability to manage stormwater at its source, DCSP treatment of these problems has been limited to short-term and frequent reactionary measures, costing the Commonwealth and taxpayers millions of dollars and diverting funds from regularly scheduled maintenance and programming within the park.

The Delaware Canal intercepts surface waters travelling down the mountainsides, through natural streams and man-made channels that collectively drain over a 40,000-acre watershed west of the state park boundaries. This landscape has undergone drastic changes since the canal was built nearly two centuries ago. Urban development and suburbanization transformed much of the natural landscape into a built environment including impervious surfaces that generate higher volumes and rates of stormwater runoff. The canal was not designed to accommodate the great demands of modern stormwater, but in fact, the historic resource has served as a de facto stormwater management facility that intercepts much of the surrounding surface flows before they eventually are released to the Delaware River.

Common impacts to the canal caused by stormwater runoff are siltation and erosion that obstruct the flow of water in the canal, weaken its walls / structures, damage its ecological integrity, and limit the recreational opportunities expected by the public.

To address these modern challenges, there is great opportunity for improved, proactive stormwater management that can help reduce destructive and costly impacts to the Delaware Canal. This study begins to identify opportunities to reduce stormwater impacts to the Delaware Canal through sound stormwater management practices – both structural and administrative.

A goal of this study is to generate and support new ways of thinking about managing stormwater impacts to the canal – both inside and outside the state park jurisdiction.

Contents

1 Introduction

1.1 Purpose

The purpose of the *Delaware Canal Preliminary Stormwater Study* is to begin to assess stormwater-related impacts that continue to damage the character and integrity of the Delaware Canal. Over its historic existence, the canal has sustained damage from the effects of increased drainage volumes, outdated stormwater infrastructure, and slow responses to structural upgrades needed to maintain is hydrologic integrity.

This study presents a preliminary assessment of localized stormwater issues impacting the Delaware Canal; recommends strategies for mitigating some of these impacts; and suggests a proactive palette of best management practices (BMPs) to maintain and support the Delaware Canal.

1.2 Approach

Given the expanse of the study area; variations in land use and density; local terrain and soils; diversity of stakeholders, owners, and jurisdictions – a nontraditional and innovative approach to developing effective stormwater management is needed to protect the Delaware Canal. This study presents a strategic initial approach to stormwater management for the Delaware Canal, including the following components:

Stormwater BMP Pilot Projects. A major focus of the study was dedicated to analyzing and selecting an appropriate suite of BMPs to demonstrate potential solutions to achieve reduced velocities, volumes and pollutant/sedimentation loads that can help to minimize impacts to the Delaware Canal. The study identifies multiple locations along the Delaware Canal where serious stormwater impacts occur and recommends at least one BMP opportunity unique to each selected "pilot" site. These pilot projects are intended to serve as demonstration sites that can be replicated by a variety of governmental entities and private landowners throughout the Delaware Canal watershed.

Assessment of Delaware Canal as a Stormwater Management Facility. This study includes a preliminary investigation regarding the question of whether the Delaware Canal might sustainably function and be maintained as a key component of a regional stormwater collection system for surface water drainage.

Assessment of District Stormwater Management Agency Structure. The Delaware Canal travels through 18 municipalities that are located in two counties. Coordination among diverse and widespread stakeholders is imperative to achieve successful long-term management of this resource. Accordingly, this study examines examples of district stormwater management partnerships and suggests a cooperative framework for multiple public agency partners to collaborate throughout the Delaware Canal watershed.

major tasks

Watershed Analysis
- 1.1 - Review HC findings
- 1.2 - Conduct preliminary analysis

Access Canal Hydraulic System
- 2.1 - Calculate static volumes
- 2.2 - Calculate estimated flow rates
- 2.3 - General assessment of hydraulic mechanisms
- 2.4 - Estimate average freeboard dimensions

Review BMP Alternatives
- 3.1 - Review HC list of selected SW BMP sites
- 3.2 - Prepare memo / comment

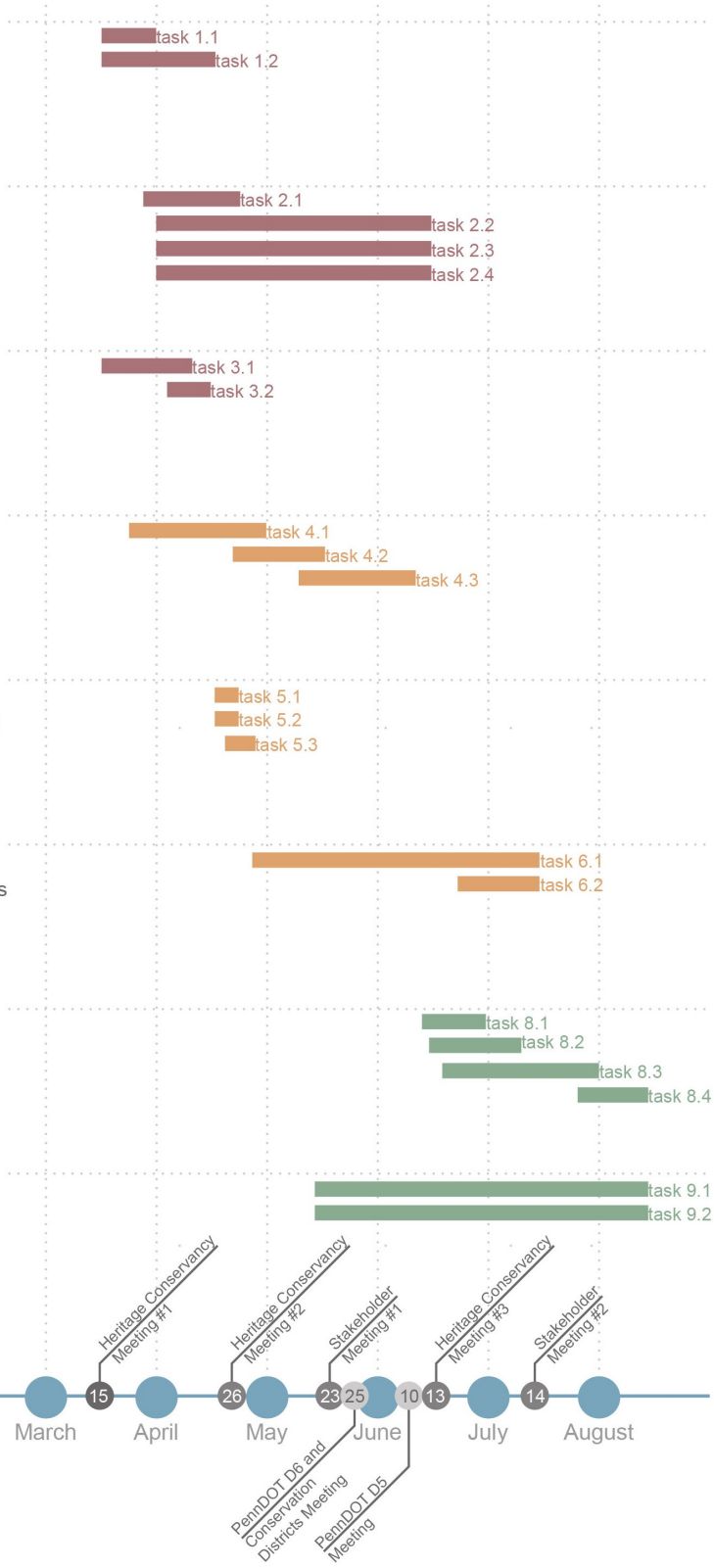
Identify Potential Non-Act 167 BMP Sites / Types
- 4.1 - Collect existing agency, utility data
- 4.2 - Review data for SW BMPs
- 4.3 - Prepare supplemental list of BMPs

Observe Potential BMP Sites (in field)
- 5.1 - Observe HC - identified BMP site in the field
- 5.2 - Observe potential agency jurisdiction BMP sites
- 5.3 - Update Task 3.2 memo

Prepare Memo of Issues + Opportunities
- 6.1 - Prepare memo for ACT 167 demo projects
- 6.2 - Prepare memo for PennDOT/DCNR jurisdictions

Contribute to Report
- 8.1 - Review HC report outline
- 8.2 - Review HC report draft
- 8.3 - Prepare SC/HEA sections of the report
- 8.4 - Revise draft for final report

Develop GIS Mapping
- 9.1 - Mapping allowance for ACT 167 BMP Sites
- 9.2 - Mapping allowance for agency jurisdiction sites



project timeline

2016

1.3 Project Partners

This project was conceived by Delaware Canal 21 (DC21) and conducted in partnership with Heritage Conservancy. In addition to these nonprofit partners, the Project Team responsible for the completion of this study included professional consultants Simone Collins Landscape Architecture and Hanover Engineering Associates who performed technical analyses and developed the recommended BMPs.

A Steering Committee comprised of representatives from the Project Team and the Pennsylvania Department of Conservation and Natural Resources (DCNR) met periodically to review initial findings and provide guidance.

In addition to DCNR, the Project Team consulted with stakeholders including PennDOT Districts 5 and 6 and Bucks and Northampton County Conservation Districts. These entities maintain control and/or governance over activities related to stormwater that directly impact the canal.

Simone Collins prepared mapping and analysis that were presented to various audiences including the Lower Delaware Wild and Scenic Management Council and Delaware Canal Advisory Board. Presentations were intended to inform the public about the project and seek early support for implementation of recommendations. Public feedback was also gathered from these meetings.

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The principal focus of DC21 is on forming private-public partnerships to develop substantial new sources of revenue for funding the repair, maintenance, and operation of the canal infrastructure. The organization's goal is to create a perpetual planning and funding system outside the state parks budget to ensure the canal's ongoing routine, preventive, and strategic maintenance. DC21's top priorities are getting and keeping a reliable flow of water in the Delaware Canal; keeping the wonderful 60-mile-long recreational path in first-class shape for bikers, hikers, dog-walkers, and cross-country skiers; and improving public access to this beautiful natural, recreational, and historic resource.

HERITAGE CONSERVANCY

Heritage Conservancy's mission is to preserve and protect our natural and historic heritage. Based in Doylestown, PA, and serving Bucks and Montgomery Counties, Heritage Conservancy is a community-based organization dedicated to the preservation and protection of significant agricultural and natural areas as well as historic resources. A champion of conservation best practices, Heritage Conservancy believes that everyone is responsible for stewardship and seeks to enlighten, engage, and empower others to help achieve this vision.

1.3.1 Consultants

In addition to work performed by Heritage Conservancy and DC21, the study process included specialized analyses by professional landscape architecture and engineering consultants.

The consultant selection process began with organization of a Selection Committee comprised of representatives from Heritage Conservancy and DC21 with oversight from DCNR. A Request for Proposals was distributed to area firms. Proposals were reviewed and scored by the Selection Committee. The proposal submitted by Simone Collins Landscape Architecture in association with Hanover Engineering received the highest score. Upon interviewing with the Selection Committee, the Simone Collins / Hanover Team was selected for their recognized expertise as landscape architects and their in-depth knowledge of the issues affecting the Delaware Canal.

Simone Collins Landscape Architecture is a planning and design firm with a portfolio of visionary and award-winning projects in the areas of parks, trails/greenways, streetscapes, heritage, bridge design, transportation, land use/zoning, institutional/schools, commercial landscapes, and estate garden design. Simone Collins specializes in developing partnership funding strategies and public involvement programs for community projects. Simone Collins offers a full range of landscape architecture and planning services "from conception through construction." Simone Collins has performed multiple projects on the Delaware Canal, including the *2017 Delaware Canal Vision Study.*

Hanover Engineering Associates, Inc. is a Pennsylvania corporation formed in January 1970 and has grown to a staff of 85 employees since that time. Hanover Engineering currently maintains eight office locations in Pennsylvania, with corporate headquarters located in Bethlehem. The firm specializes in municipal, civil, structural, mechanical, and environmental engineering. Hanover Engineering Associates provides professional environmental and surveying services to clients within the public, private, and energy sectors.

1.4 Study Area

The geographic context for this study comprises two primary areas: the Delaware Canal State Park (generally the canal, towpath and berm) and the approximate 40,000-acre sub-watershed that directly feeds the Delaware Canal.

1.4.1 Delaware Canal State Park

Delaware Canal State Park extends from the City of Easton in Northampton County to Bristol Borough in Bucks County. The Lehigh Coal and Navigation Company transferred ownership of the canal to the Commonwealth of Pennsylvania in 1940. The park is operated and maintained by the Pennsylvania Bureau of State Parks.

For most of its length, Delaware Canal State Park is a narrow, 60-foot wide linear corridor that encompasses the canal and adjacent towpath. The Park also includes 11 islands and The Giving Pond for a total of more than 800 acres. While this study focuses primarily on the canal and towpath, it is important to recognize the expanse of the park and acknowledge competing administrative and budget demands within its own jurisdiction.

The central feature of the park is the 60-mile Delaware Canal and towpath (aka the Delaware & Lehigh National Trail), that parallels the Delaware River. Built between 1827 and 1832, the canal operated as southeastern Pennsylvania's main commerce transportation corridor until 1931.

The Delaware Canal was built as a man-made hydraulic transportation channel by manipulating two rivers and adjacent creeks to water its course. The primary sources of water feeding the canal include dams in the Lehigh River in Easton, Northampton County and in the Delaware River near New Hope, Bucks County. The canal also intercepts many local streams that contribute to its base flow.

Throughout much of its course, the canal directly abuts or closely aligns with the shore of the Delaware River. In other sections, it is set back from the river's edge – separated by parcels outside State ownership and control. Several segments of the canal were built directly between the river and state highways. This is particularly true in Northampton County where PA Route 611 tightly traces the western edge of the canal. In Bucks County, the canal intermittently crosses PA Route 32 (River Road), a two-lane scenic highway that runs between Morrisville Borough and the village of Kintnersville, Nockamixon Township. PA Route 611 runs parallel to the Delaware Canal between Kintnersville and Easton. In Falls Township, lower Bucks County, the canal turns farther inland for approximately seven miles before reaching Bristol Borough.

Segments of the canal were buried during the 1950s to accommodate various land development. Located in Falls Township and Bristol Borough, Bucks County, these sections make up approximately one mile in length. A stated long-term goal of DCNR is to reclaim these buried sections and reestablish the entire canal corridor.

The towpath was constructed on the river side of the canal and is a cherished public trail and character-defining feature of the park. The towpath generally remains in es-

Source: Delaware Canal State Park

sentially the same alignment and construction as when it was originally built – a grassed surface, averaging six to eight feet in width.

Once traveled by teams of mules towing barges up and down the canal, the towpath is now widely enjoyed by walkers, joggers, and cyclists, as well as nature and history enthusiasts. The Delaware & Lehigh National Recreational Trail is sited on the towpath within the DCSP and it represents a significant segment within the "Circuit Trails" system, the Greater Philadelphia regional network of over 750 miles of multi-use trails.

As stated in the *Delaware Canal State Park Realizing the Future: Post Decade of Flood Repairs* (June 2015), the primary purpose of Pennsylvania State Parks is to provide opportunities for enjoying healthful outdoor recreation and serve as outdoor classrooms for environmental education. In meeting these purposes, the conservation of the natural, scenic, aesthetic, and historical values of the parks should be given first consideration. Stewardship responsibilities should be carried out in ways that protect the natural outdoor experience for the enjoyment of current and future generations. With respect to the Delaware Canal portion of the park, DCNR's ultimate goal is to achieve and maintain a fully watered canal. A goal further supported by the *Delaware Canal Vison Study* (2017) as developed by DC21 and the Delaware and Lehigh National Heritage Corridor, in cooperation with DCNR.

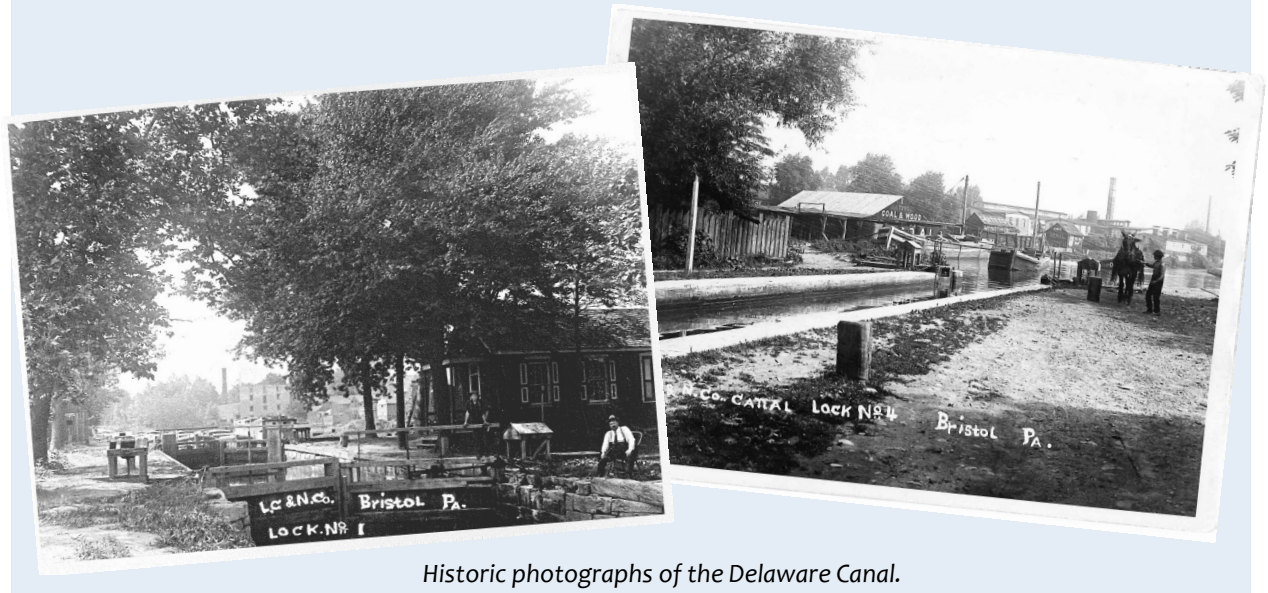
Historic Significance of Delaware Canal State Park

The canal and towpath are listed on the National Register of Historic Places and are also recognized as a National Historic Landmark, State Heritage Area, National Heritage Area and National Recreational Trail. The park is also a part of the Delaware and Lehigh National Heritage Corridor.

The Delaware Canal is the only remaining, intact man-made waterway of its kind built in the early to mid-19th century. For 99 years, it was the longest-operating canal in the country—carrying the raw materials and manufactured products that would power the Industrial Revolution. Still today, the canal and towpath retain much of their original integrity from 1831.

Given the canal's historical significance, its authenticity must be respected and upheld when making any repairs and/or improvements. Accordingly, use of appropriate techniques have been considered within the BMP selection process. These goals should be carried through subsequent design and construction development to ensure consistency with the *Secretary of the Interior's Standards for Preservation* established by the US Department of the Interior.

PennDOT recently completed a cultural resources assessment of the Delaware Canal to identify contributing elements to the National Register along the entire 60-mile corridor. The intent of the inventory is to form a programmatic agreement between DCNR, PennDOT, and Pennsylvania Historical & Museum Commission regarding future treatments by PennDOT that may potentially affect the Delaware Canal. The agencies are seeking to streamline the review and compliance process for PennDOT projects with a programmatic agreement to protect the integrity of the Delaware Canal.



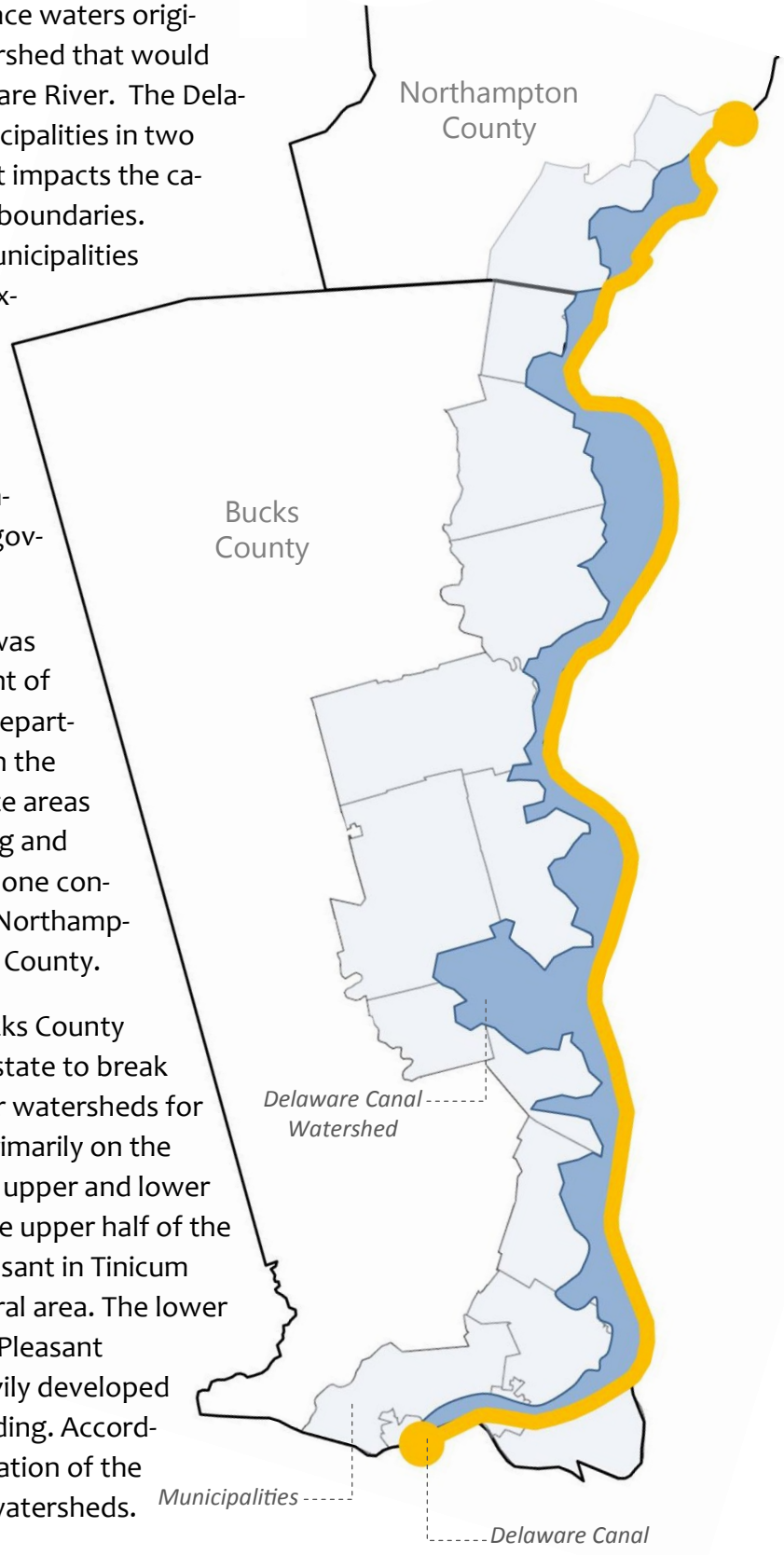
Historic photographs of the Delaware Canal.

1.4.2 Delaware Canal Watershed

In addition to diverting water from the Lehigh and Delaware rivers, the canal intercepts surface waters originating from a 40,000+ acre sub-watershed that would otherwise drain directly to the Delaware River. The Delaware Canal Watershed spans 20 municipalities in two counties. Most of the watershed that impacts the canal actually lies outside of State Park boundaries. Some portions are even located in municipalities that are not traversed by the canal. Examples include parts of Paunacussing Creek, Pidcock Creek, and Aquetong Creek. The Delaware Canal watershed is further divided among thousands of private landowners as well as various local and state government entities.

The watershed containing the canal was delineated by the then PA Department of Environmental Resources (now the Department of Environmental Protection) in the late 1970s as part of an effort to create areas for stormwater management planning and efforts. The watershed was originally one continuous unit from the City of Easton, Northampton County to Bristol Borough, Bucks County.

In the late 1990s and early 2000s, Bucks County Planning Commission petitioned the state to break the larger watershed into two smaller watersheds for planning purposes. This was based primarily on the different characteristics between the upper and lower portions of the canal's watershed. The upper half of the watershed, from Easton to Point Pleasant in Tinicum Township, Bucks County, is a fairly rural area. The lower portion of the watershed from Point Pleasant through Bristol Borough is more heavily developed and experiences frequent urban flooding. Accordingly, the state granted the re-designation of the Delaware River watershed into two watersheds.



Miles of headwaters, tributaries and streams drain the sub-watershed to the Delaware River. En route to the river, surface waters enter the canal at various points via streams, non-point sources, ravines, stormwater pipes and culverts. Runoff flowing under the canal also poses a threat to its infrastructure.

The landscape of the watershed has changed dramatically in the 185 years since the canal was built. Thousands of acres of land have been converted from a natural, undisturbed state to a relatively moderate development density that ranges from rural to suburban and urban communities. The interruption of natural hydrology and introduction of impervious surfaces has greatly increased the magnitude and frequency of high flow events. PA Routes 611 and 32, operated by the steward agency PennDOT, greatly exacerbate runoff impacts to the canal. In short, the canal was not designed to accommodate the great influx of stormwater that it now receives.

2. Preliminary Stormwater Analysis

Pilot Project Evaluation and Site Selection Process

Initially, the study goals included the selection of three pilot project locations from the following jurisdictions: the Delaware Canal State Park; a PennDOT right-of-way; and a privately-owned property. Upon initial examinations, the scope was broadened to include additional locations such as publicly-owned lands.

The Project Team assembled an initial list of critical problem areas along the canal that are caused by stormwater runoff. These sites were prioritized based on impact severity, location within the canal corridor, ownership, potential replicability of BMPs, general costs, as well as potential to mitigate stormwater impacts to the canal and towpath. After site observations and background analyses, potential management techniques were explored. Upon final pilot project location selection, site-specific BMPs were developed and recommended.

2.1. Data Collection

The initial sites evaluated for BMP demonstration sites were obtained from two sources: Delaware Canal State Park and the 20 municipalities that make up the watershed.

2.1.1. Delaware Canal State Park (DCSP) has administrative responsibility for the canal and implements ongoing maintenance measures – some are directly related to stormwater impacts on the Delaware Canal.

Early in the study process, Heritage Conservancy staff met with DCNR and DCSP staff to discuss the study and seek input. Representation from the state included: Manager of Nockamixon State Park, Delaware Canal State Park Manager, DCNR Southeast Regional Adviser, Director of the Bureau of State Parks, and Assistant Director of the Bureau of State Parks.

Important information regarding problem areas within the canal was provided by DCSP staff. Supplemental data including types of problems, frequency, resulting damage to the canal, corrective measures taken to date was also provided.

The Delaware Canal State Park Manager provided a list of 20 sites where the canal has been plagued with ongoing, serious stormwater impacts (see page 13). These problem areas involve issues of deposition of sediment and gravel bars in the canal, destruction of the towpath, and loss of slope integrity within the canal itself. There are also areas of the canal that are dry for ongoing periods. These conditions will undermine any riparian or wetland benefits that may be provided from this habitat, and also threaten the structural integrity of the canal by allowing the clay liner to dry.

2.1.2. Delaware Canal Watershed Municipalities

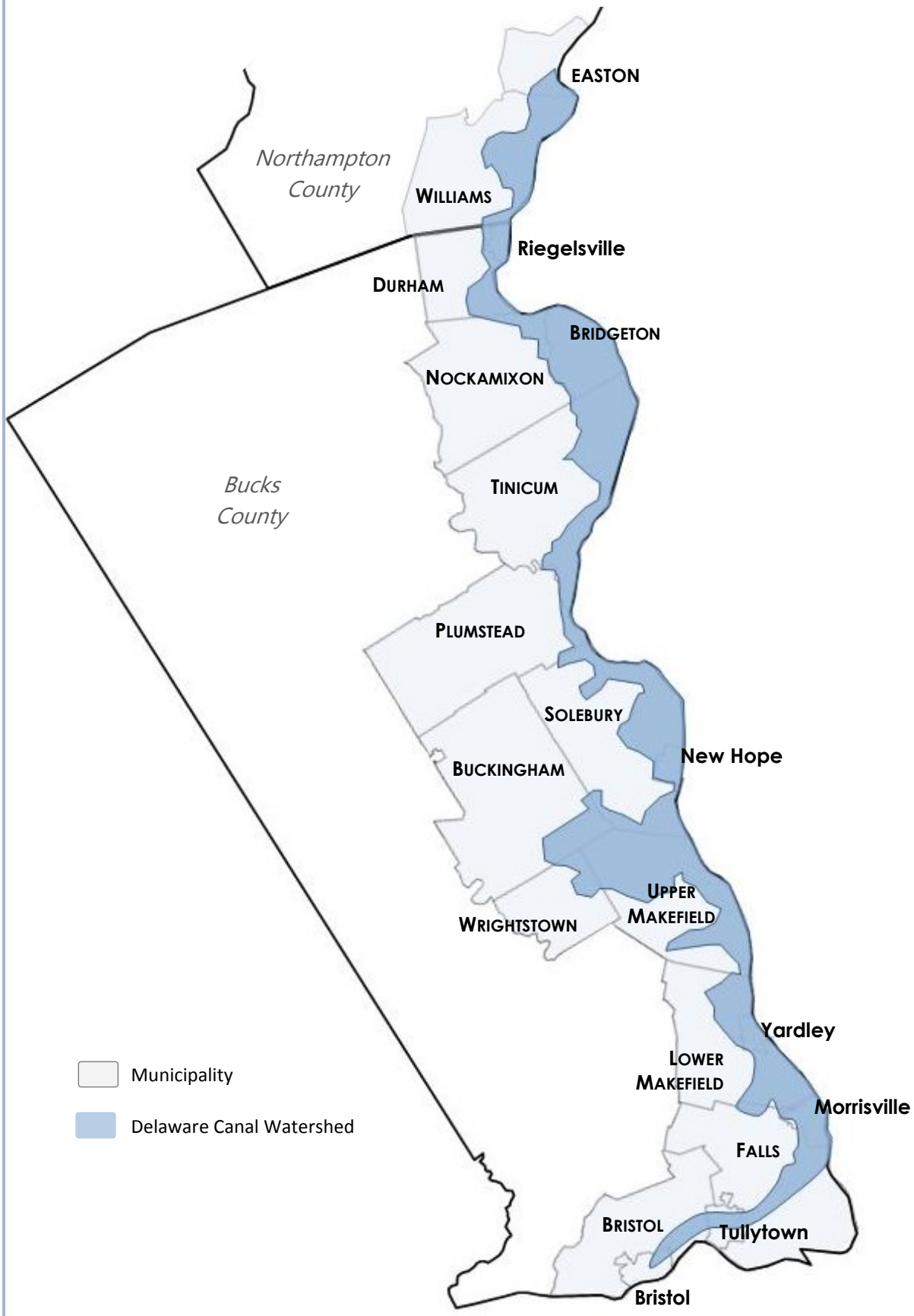
All 20 municipalities included in the Delaware Canal watershed were contacted via written correspondence on behalf of the Project Team. Municipal managers and administrators received letters explaining the purpose of this study along with tax parcel-based maps highlighting the boundaries of the watershed within their respective communities. Municipalities were asked to provide feedback regarding local stormwater problems related to the canal by identifying ongoing or recurring stormwater impacts that result in damages or losses to landowners or public right of ways within the study area. Participating municipalities marked relevant problem areas on maps and offered supplemental narrative describing the characteristics of each issue. Nine of the municipalities responded and identified a total of 20 additional problem areas.

Table 1. Delaware Canal Watershed Municipalities

Bucks County	Northampton County
Bridgeton Township	City of Easton
Bristol Borough*	Williams Township
Bristol Township	
Buckingham Township	
Durham Township*	
Falls Township*	
Lower Makefield Township	
Morrisville Borough*	
New Hope Borough*	
Nockamixon Township	
Plumstead Township*	
Riegelsville Borough*	
Solebury Township*	
Tinicum Township	
Tullytown Borough	
Upper Makefield Township*	
Yardley Borough*	
Wrightstown Township	

* Responded to survey.

Delaware Canal Watershed Municipalities

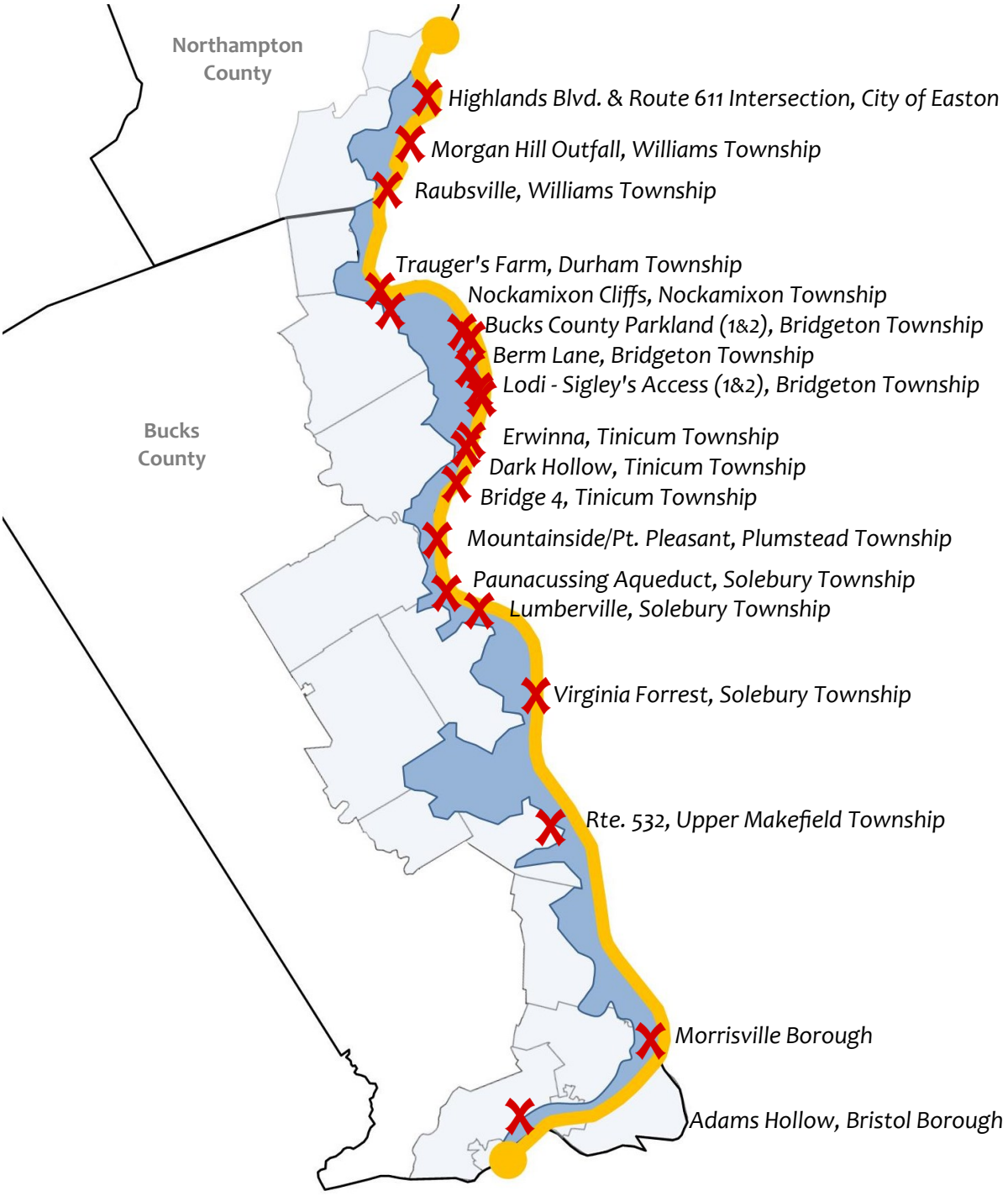


2.2 Identified Problem Areas

Problem areas identified by DCSP and municipalities were initially assessed to determine the extent and nature of impacts to the canal in the form of non-point pollutants such as sediment accumulation, flooding damages and other impacts attributed to inadequate or missing stormwater management facilities.

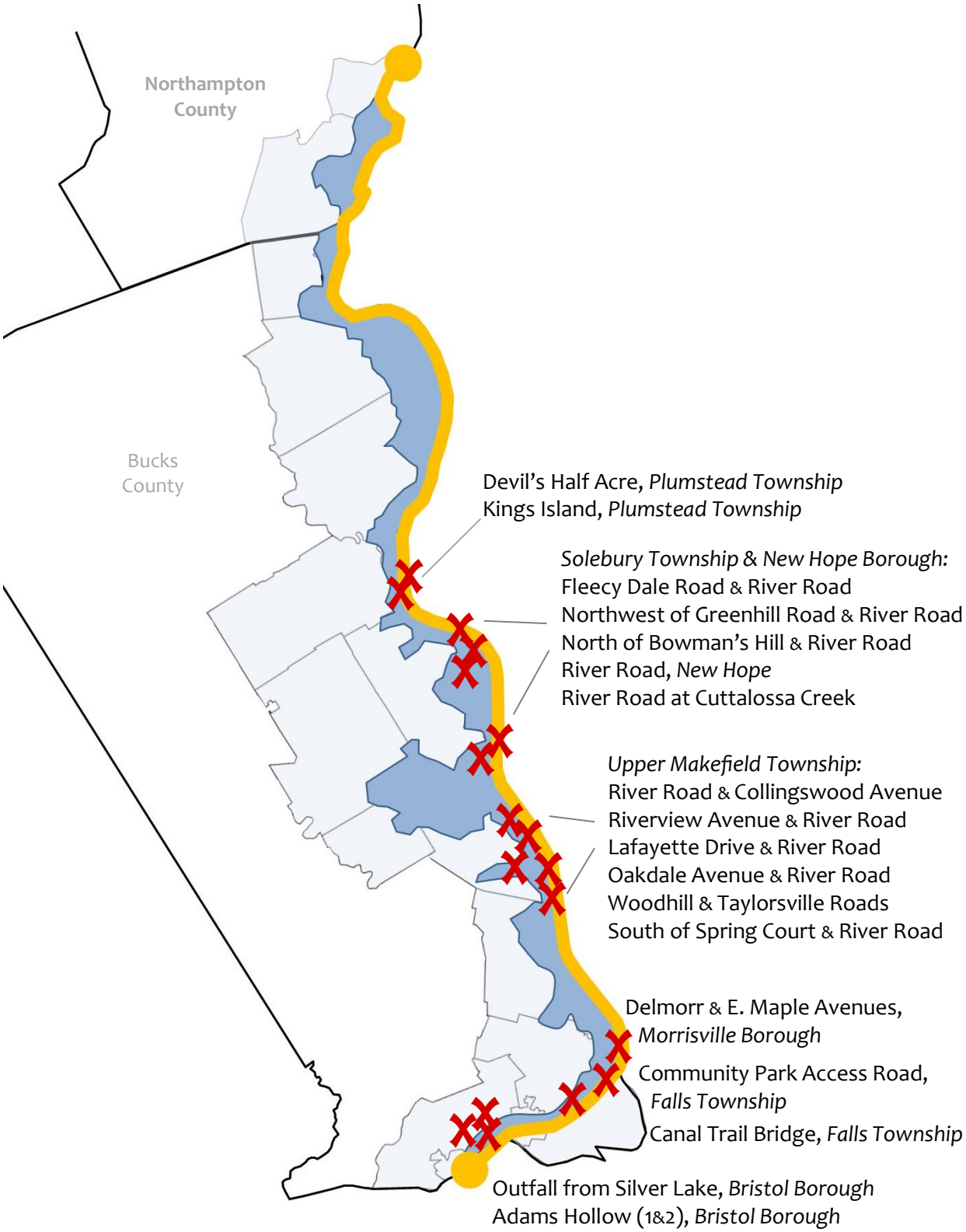
2.2.1 Delaware Canal State Park Problem Areas

The following sites were identified by DCSP as stormwater impact locations along the Delaware Canal:



2.2.2 Municipal Problem Areas

The following sites were identified by local municipalities as stormwater impact locations on the Delaware Canal:



2.2.3 Field Observations

Heritage Conservancy staff conducted site visits to each of the identified problem areas. Points of impact to the canal as well as upstream and surrounding area conditions that contribute to the runoff were observed. Sites were initially assessed to determine the extent and nature of the damaging impacts to the canal in the form of non-point pollutants such as sediment accumulation, flooding damages and other impacts attributed to inadequate or missing stormwater management facilities. Subsequent field evaluations were performed in an effort to identify areas where stormwater BMPs may reduce impacts from stormwater drainage directly impacting the canal either with volume or velocity issues or nonpoint source pollutant issues.

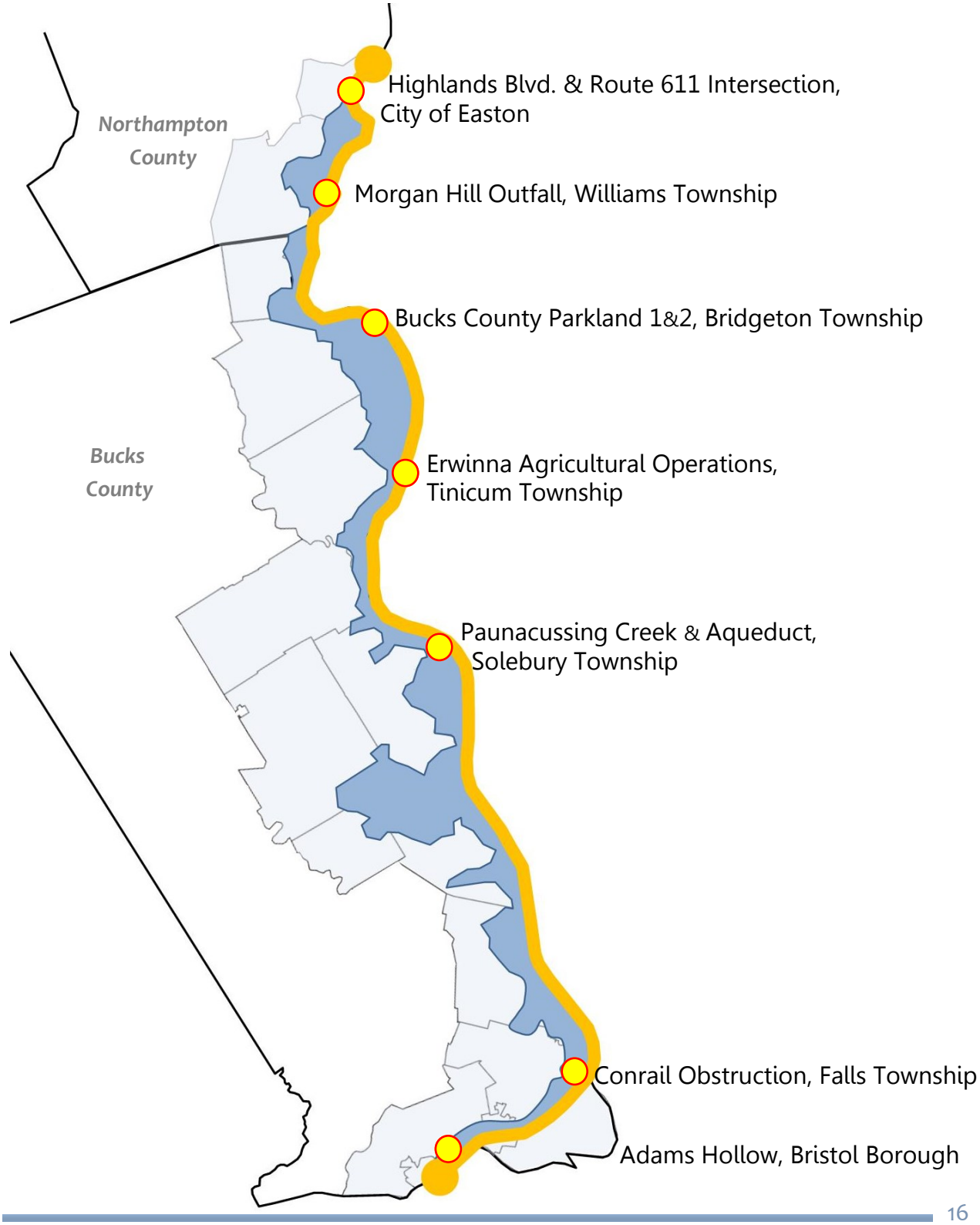
Observations by Heritage Conservancy staff revealed that sedimentation was a primary stormwater runoff problem. Because water velocity within the canal is relatively slow, sediments tend to accumulate on a consistent basis and cause ecological, recreational and economic losses to the park. Widespread sedimentation diminishes recreational activities fishing, canoeing, kayaking, mule barge rides, threatens ecological diversity (flora and fauna) and requires frequent and costly maintenance. It was also observed that some impacted conditions were more influenced by flow volumes and velocities.

2.2.4 Existing Conditions and Reports

Project Team collected background data on land use, preserved lands, ownership, tax parcel identification (acreage and ownership), soils, Bucks County Natural Areas Inventory (2011) , US Geological Services, US Department of Agriculture, Google maps, Lower Delaware Act 167 Plans (Bucks County Planning Commission 2001), Friends of the Delaware Canal Siltation Study (Environmental Liability Management, Inc. 1999).

2.3 Final Pilot Project Sites

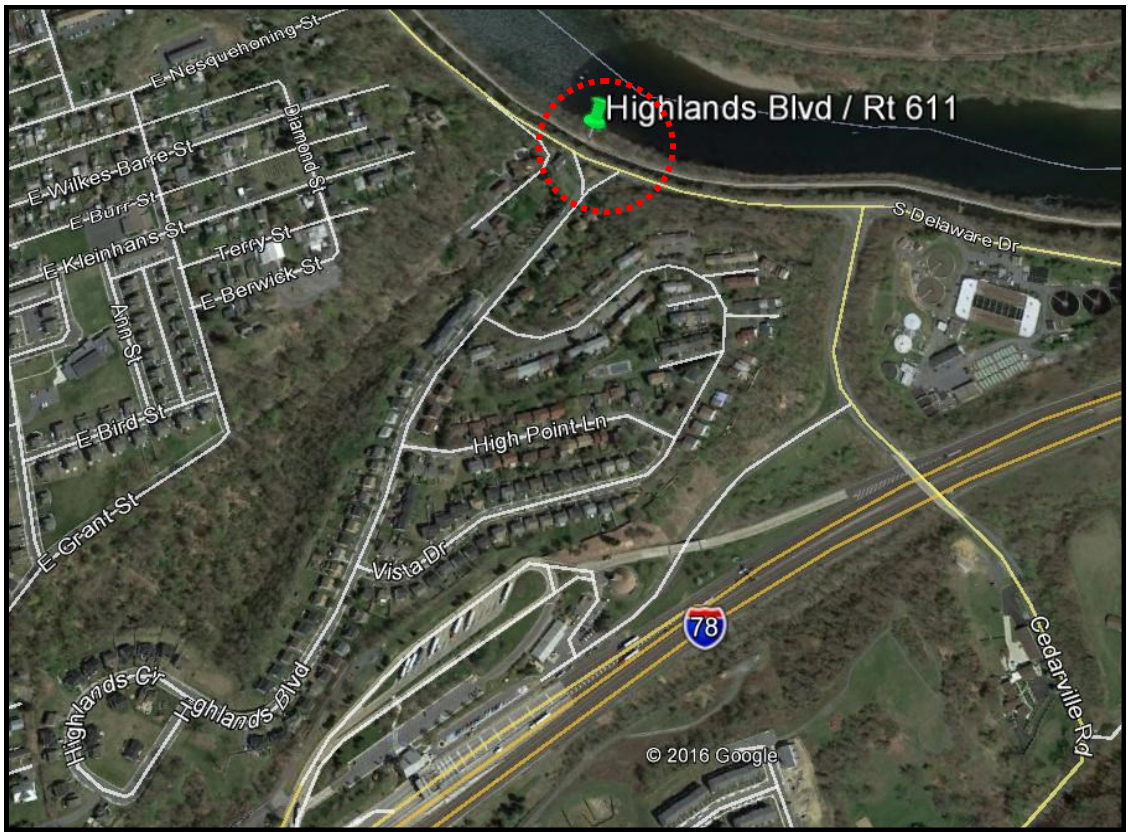
Based on site inspections and baseline conditions, the initial list of 40 problems areas submitted by DCNR and municipalities was narrowed down to seven, all of which were identified as priorities by DCNR and two of which coincide with sites identified by municipalities.



2.3.1. Highlands Boulevard and PA Route 611 Intersection

Location: Easton, Northampton Township Lat/Long 40.680891 -75.197808

Impacts to Canal: Gravel bar deposits across channel and dam up the canal. Velocity of stormwater entering the canal erodes the towpath structure.



Source: Google earth

Observations: The steep slope of Highlands Boulevard directs surface and piped water flow toward PA Route 611. In addition, the roadway appears to have little or no crown, and inlets are spaced over long distances. The result is excess water bypassing existing inlets and collecting at the intersection of Highlands Boulevard and PA Route 611. Water collected in storm inlets along Highlands Boulevard is piped down slope and conveyed perpendicular to the road, onto a private property (tax id: L10SW4D7 3 0310) north of Highlands Boulevard.

The private property has no evidence of stormwater basins or watercourses on site. However, aerials and topography of the area indicate that surface water is directed to this parcel, suggesting that the watercourse is piped underground. It is likely that water piped perpendicular to Highlands Boulevard converges with the watercourse piped under the private property.

Along PA Route 611, inlets collect water and discharge directly into the Delaware Canal. Some of the existing discharge pipes are fed by single inlets that run under PA Route 611 and empty to the canal. These undersized stormwater systems did not appear to result in

significant sedimentation or erosion damage to the canal. Inlets along PA Route 611 are in poor condition with visible sediment build-up inside the inlet boxes. Sediment deposits on the roadway at the intersection indicate ponding during storm events. Erosion on the canal side of Route 611 indicates that water crosses/floods the road and flows into the canal.


Highlands Boulevard.

At the northeastern corner of the Highlands Boulevard and PA Route 611 intersection is a large inlet box with a culvert installed on the downstream end that discharges into the canal. The location and size of the inlet box and culvert suggest that the watercourse piped under the private property is conveyed into this system. The canal has visible scouring and erosion damage to the prism bottom and prism wall opposite the culvert. Scouring and erosion damage is generally caused by high velocity discharges during storm events.


Private property north of Highlands Boulevard.

DCNR Management Efforts: DCNR currently dredges the gravel bars approximately every six months, depending on frequency and severity of storm events.

Opportunities:

- Approximately 20 acres (private and HOA open space) may be available for BMPs
- Wide streets could accommodate new storm drains and/or vegetated swales via road width reduction
- Creative grading
- Structurally fortifying towpath prism wall/ floor opposite culverts

Highlands Boulevard and PA Rt 611 Intersection.

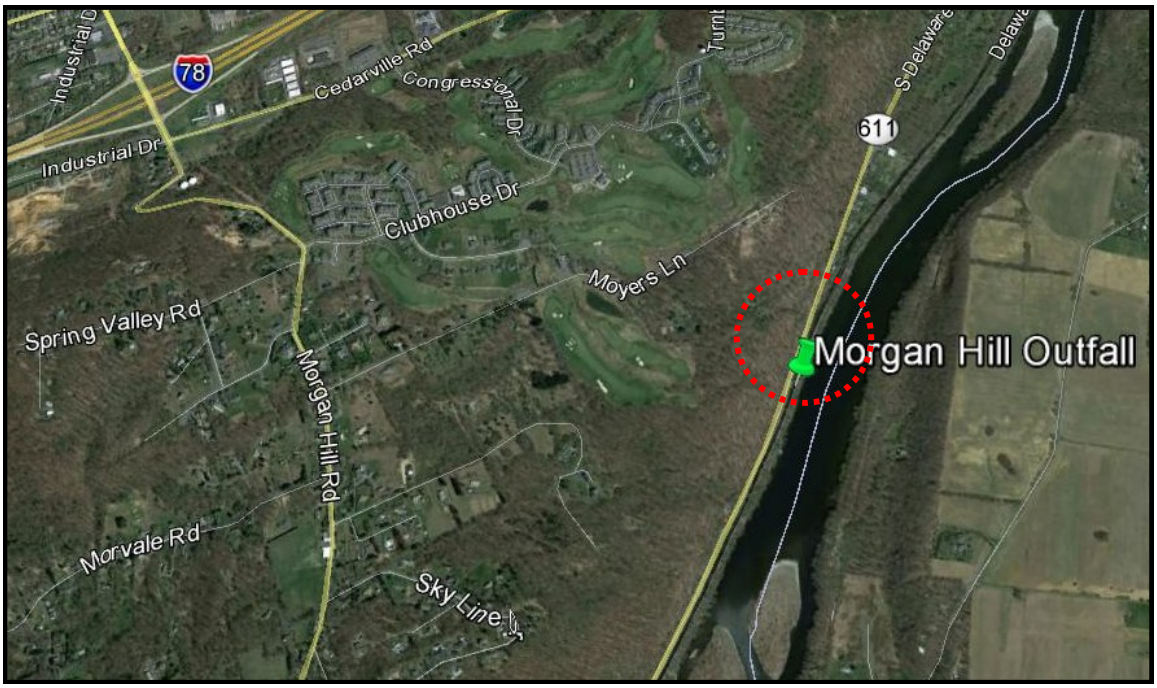
Possible Partnerships:

- Highlands Homeowners Association
- PennDOT
- City of Easton
- Private landowners
- Land trusts

2.3.2. Morgan Hill Outfall

Location: North of Raubsville, Northampton County Lat/Long 40.659523 -75.194415

Impacts to Canal: Gravel bars extend across the channel, block water flow within the canal. High velocity discharge from culvert during heavy rains causes canal erosion. While at other times, the canal bed is dry.



Source: Google earth

Observations: The recently built private golf course and residential subdivision upland from the canal has drastically increased runoff and sediment discharge. The golf course community covers 330 acres and includes 140 townhomes, 180 condominiums, and an 18-hole golf course.

A deep discharge channel downhill to a roadside swale was observed. DCNR noted high velocity discharge during storm events.

The slope that runs down from Morgan Hill to PA Route 611 has an eroded dry channel that suggests discharge from the golf course during storm events flows at a high velocity. Water flow feeds directly into a pipe under PA Route 611 and discharges into the canal.

The high velocity of this discharge has caused visible erosion and scouring damage to the canal prism bottom and prism wall opposite the outfall. In an attempt to counter these impacts, concrete was added inside the outfall end of the pipe. This is the only evidence of a control measure to slow the water velocity. A shallow roadside swale exists on the western side of PA Route 611, but is not designed to slow, collect, or hold the discharge volume from the golf course. A recent mudslide from the hillside covered PA Route 611 with several feet of earth.

Slightly north of the site, along PA Route 611, is another outfall to the canal. Here, the watercourse is a perennial stream. Water flows into a pipe, under PA Route 611 and is discharged into the canal. The canal has no visible damage from the outfall at this location. This suggests that this watercourse is not impacted from upper watershed development.

View of Morgan Hill golf course green.

DCNR Management Efforts: The canal needs to be dredged of gravel bars regularly, depending on the number and intensity of storms. Excavation hasn't occurred in this spot for several years. Broken equipment needing costly repairs prevents park staff from performing more consistent sediment removal.

Opportunities:

- Golf course - capture and reuse of stormwater and/or expansion of existing stormwater management systems
- Construct roadside swale along Route 611, allowing existing culverts to function together, alleviating the overload to the identified culvert

Possible Partnerships:

- Golf course operator
- Individual private property owners
- Northampton County Park – coordinate stormwater BMPs with enhancements to Wy-Hit-Tuk Park (i.e. expand parking area, add an observation pier, designate a scenic outlook).
- Morgan Hill Homeowners Associations
- PennDOT

View of Morgan Hill golf course green between residential units.

2.3.3. Bucks County Parkland

Location: Bridgeton Township, Bucks County Lat/Long 40.571712 -75.142957 and 40.572195 -75.142957 *(Originally two sites identified by DCSP. Given proximity, consolidated into one pilot project location.)*

Impacts to Canal: Gravel bars and canal bank erosion. Sediment deposits at confluence of creek and canal. No outlet gate to regulate creek flow to the river. Existing bridge over canal is closed.

Source: Google earth

Observations: Falls Creek runs down the mountainside and into canal, depositing silt and gravel. The stream bed begins at the top of the mountainside, runs down the slope, and under PA Route 32. The stream drops straight down in some areas causing heavy erosion. The stream has eroded the subsurface of PA Route 32 and has caused portions of the roadway edge to collapse.

At the confluence of the Delaware Canal and Falls Creek, some minor sedimentation deposits were found. These deposits were primarily within the creek and not the canal. There was no evidence of erosion in the canal and the canal prism appeared undamaged. In Falls Creek, a small settling basin is found at the confluence. The modern day confluence appears as if it was created from a breach in the canal prism wall, possibly during a storm event. This suggests that the creek might have been piped under the canal at one point. On the opposite side of the canal from Falls Creek there is no outlet gate, which may further support this theory. This also means that the entire water volume of Falls Creek is added to the water volume of the canal.

DCNR Management Efforts: This area of the canal was last dredged in 2005 and is in need of additional work. However, DCNR's equipment has been broken and in need of costly repairs since Superstorm Sandy in 2012. Park staff is unable to access problem area with existing excavator (Grade-All). Needs appropriate equipment (i.e. Menzi Muck).

Opportunities:

- Possible expansion of nearby Bucks County parkland
- Possible addition od stormwater treatment of creek flows with adjacent Bucks County parkland

Possible Partnerships:

- Township and landowner cooperation to mitigate stormwater coming down mountainside
- PennDOT to address erosion under PA Route 32
- Bucks County Parks Department
- Bucks County Conservation District

Settling Basin.

Falls Creek.

2.3.4. Erwinna Agricultural Operations

Location: Tinicum Township, Bucks County Lat/Long: 40.492923" -75.069944"

Impacts to Canal: Gravel bars and large amounts of sediment accumulate in canal. The stream threatens to erode towpath and canal walls, even with reinforcements in bank.

Source: Google earth

Observations: As evident from aerials and on-site observations, the approximately 40-acre agricultural operation near Erwinna includes a vast area of exposed bare soil. This results in excess sediment loss through run-off from bare soil crop fields. It appears that water run-off from the site is directed toward two water courses in different watersheds. The northeast portion of the site drains directly into the canal. The southwest portion of the site drains toward the Tinicum Creek watershed.

The entrance drive to the site is a steep, paved asphalt road with no evidence of roadside swales. At the top of the entrance drive, north of the building complex, is a small sediment basin. This basin appears to receive a significant amount of run-off from the bare soil crop fields but is significantly undersized. The condition of this basin is poor, with evidence of sediment build-up. There is no inlet or roadside swale to direct water to the basin. Rather, it appears water sheet flows from the crop fields, across the entrance road, and into the sediment basin.

A drop inlet provides a discharge point from the basin. Water is piped under the entrance road to an outfall along the northern property boundary – into an eroded dry channel

that suggests water flows at high velocity down slope towards the canal during storm events. This channel extends along the northern property boundary which collects additional water run-off from the fields.

Further up the entrance road and adjacent to the central building, is a large impervious vehicular drop-off and parking lot. Run-off from the impervious surfaces and some of the bare soil fields to the south, flow east towards the canal. A diversion berm that is installed upslope of the entrance road conveys this runoff across the entrance road. After the run-off is conveyed across the entrance road it is directed into a channel that flows down slope towards the canal. This channel is also dry and eroded, indicating high velocity discharge during storm events. At the base of the slope, water is again directed through manmade channels and discharged into the canal. The Project Team observed excessive amounts of sediment deposits that collected at the base of the slope on private property.

At the discharge point to the canal, there are no sediment control measures in place that would slow and collect the stormwater. In the canal, there are massive sediment deposits and evidence of erosion scour from high velocity discharge.

DCNR Management Efforts: Towpath-side of bank (opposite stream outlet) has been reinforced with rip-rap to stabilize bank. DCNR noted that sediment accumulates and fills canal within months of dredging.

Opportunities:

- Work with landowner of agricultural property to grow field cover species
- Work with landowner of agricultural property to retrofit and expand existing basin
- Add check dams along driveway
- Install upslope swale to direct runoff to basin
- Construct additional sediment basin at the base of the constructed diversion berm
- Prepare a soil conservation plan for agricultural property

Undersized sediment basin.

Possible Partnerships:

- DEP, DCNR
- Tinicum Township (potential MS4 activities)
- Natural Resources Conservation Services

2.3.5. Paunacussing Aqueduct

Location: Solebury Township, Bucks County Lat/Long: 40.407954 -75.041704"

Impacts to Canal: Creek deposits and eroded bedrock bars above the confluence of the canal and Delaware River require continual maintenance of rock removal to prevent adversely affecting the Paunacussing aqueduct.

Source: Google earth

Observations: The confluence of the Paunacussing Creek with the Delaware River forms an alluvial delta with sediment deposits from the Paunacussing Creek stretching far out into the Delaware River. The creation of this alluvial delta is twofold, caused by conditions on the Delaware River and the Paunacussing Creek.

On the Delaware River, just upstream of the Paunacussing Creek, is a wing dam that directs the river channel to the eastern side of the Delaware River. This causes slower flow in the Delaware where the Paunacussing Creek converges, creating an eddy where Delaware River sediments are deposited.

The other cause of the alluvial delta is the slope of the Paunacussing Creek in its steep upper watershed areas causing streambank erosion. Near the Delaware River confluence, the topography is significantly flatter, which allows the water velocity to slow and eroded sediments to deposit under the Delaware Canal aqueduct and out into the Delaware River.

Erosion along the Paunacussing Creek is evident with the periodic closings of Fleecy Dale Road. Fleecy Dale Road parallels the Paunacussing Creek from PA Route 32 and upstream through the creek valley. Erosion from storm events undermine the road and cause it to

collapse into the creek. This adds to the sediment deposits at the confluence of the Creek and Delaware River.

Under the aqueduct, sediment deposits have constricted the waterway to only about four feet of vertical clearance. Within the aqueduct, there were only a couple inches of water during site observation by the SC/HEA team. Water flow into the aqueduct was blocked on the upstream side of the canal. This structure is aging and DCNR is monitoring its condition. Flow is blocked on the upstream side to regulate the water level north of the aqueduct. The towpath on the aqueduct remains open to the public.

Paunacussing Creek.

The aqueduct over the creek is in poor condition with significant structural damage. There is evidence of spalled concrete and severed rebar. The steel beam webs contain portions with up to 100% section loss near the bearings. The bottom flange of the beam has major section loss and is exhibiting knife edging. The remainder of the structural beams have evidence of heavy pitting. The concrete portions of the wall are cracking in the same location which indicates that they are failing and the wall is shifting.

DCNR Management Efforts: The creek bed under the aqueduct and 50 feet upstream and downstream have been excavated three times in the last two years. However, the problem extends well beyond this area into private property upstream. DCNR is currently limited to work within a 50-foot buffer zone around the aqueduct. This 50-foot work limit is set by state and federal agencies including Pennsylvania Department of Environmental Protection and the Army Corps of Engineers. This study recommends that DCNR work with the appropriate jurisdictional agencies toward a solution and work with local landowners to excavate entire area and mitigate sedimentation drop.

Opportunities:

- In-stream water storage between PA Route 32 bridge and canal
- Install hydraulic apron device to help flush out sediments from under aqueduct

Possible Partnerships:

- Delaware River Basin Commission
- Individual private property owners; obtain access & maintenance easements
- Army Corp / DCNR collaboration
- Land Conservation—Land trusts

Sediment deposits under aqueduct.

2.3.6 Conrail Obstruction

Location: Falls Township, Bucks County Lat Long" 40.195503 -74.781727"

Impacts to the Canal: Physical obstruction in the canal that causes flooding upstream into Morrisville Borough.

Source: Google earth

Observations: At the Conrail Obstruction location, an elevated railroad spur embankment was built by filling in the Delaware Canal waterway and towpath directly south of the Morrisville Borough-Falls Township line. The undersized culvert installed below this obstruction at the time the canal was filled in prevents the free flow of water in the canal to move southward. A comprehensive study of the canal in Morrisville, to include design of the Borough stormwater system, adequate overflow structures, and the design of the flood protection levee is needed to determine system hydraulics.

The Conrail Obstruction also creates an unsafe trail condition for towpath users. The towpath is blocked by the Conrail line and rerouted east toward the regional and high speed Amtrak rail. Here the path runs parallel to the tracks without any physical barrier for over 300 feet. This hazard to the safety of trail users needs to be addressed prior to any injuries that may occur along the railroad. A construction contract awarded in 2017 will open up the towpath section of this obstruction, but does not address the water obstruction issues.

DCNR Management Efforts: DCNR has little to no authority in addressing the obstruction given that the obstruction is caused by the railroad. DCNR has undertaken steps to participate in a partnership project that will analyze hydraulic conditions in this area and recommend options to alleviate flooding.

Opportunities: The hydraulic analyses and schematic design project for this area will consider additional overflow and increased size of the obstruction culvert as potential solutions for river flooding of the canal in Morrisville Borough and locations north.

A combined feasibility study of the two remedies: a new waterway culvert under the railroad obstruction and a new overflow structure have been suggested. DCNR has suggested moving directly into design of the new outlet. However, this strategy assumes one solution and does not address the issue comprehensively.

DCNR completed design of a bicycle and pedestrian tunnel that would eliminate the obstruction to the towpath trail. Although it does not address the flooding hazard or environmental concerns caused by the obstruction to the canal flow, this project will provide safe, direct trail passage to the canal and reestablish the towpath through the existing 35-foot high Conrail Spur Line earthen embankment that crosses the Delaware Canal State Park in Falls Township.

Possible Partnerships:

- Falls Township – access to property and maintenance agreement
- Morrisville Borough – historically flooded community
- Amtrak, Conrail
- D&L Heritage Corridor, PEC, DC21

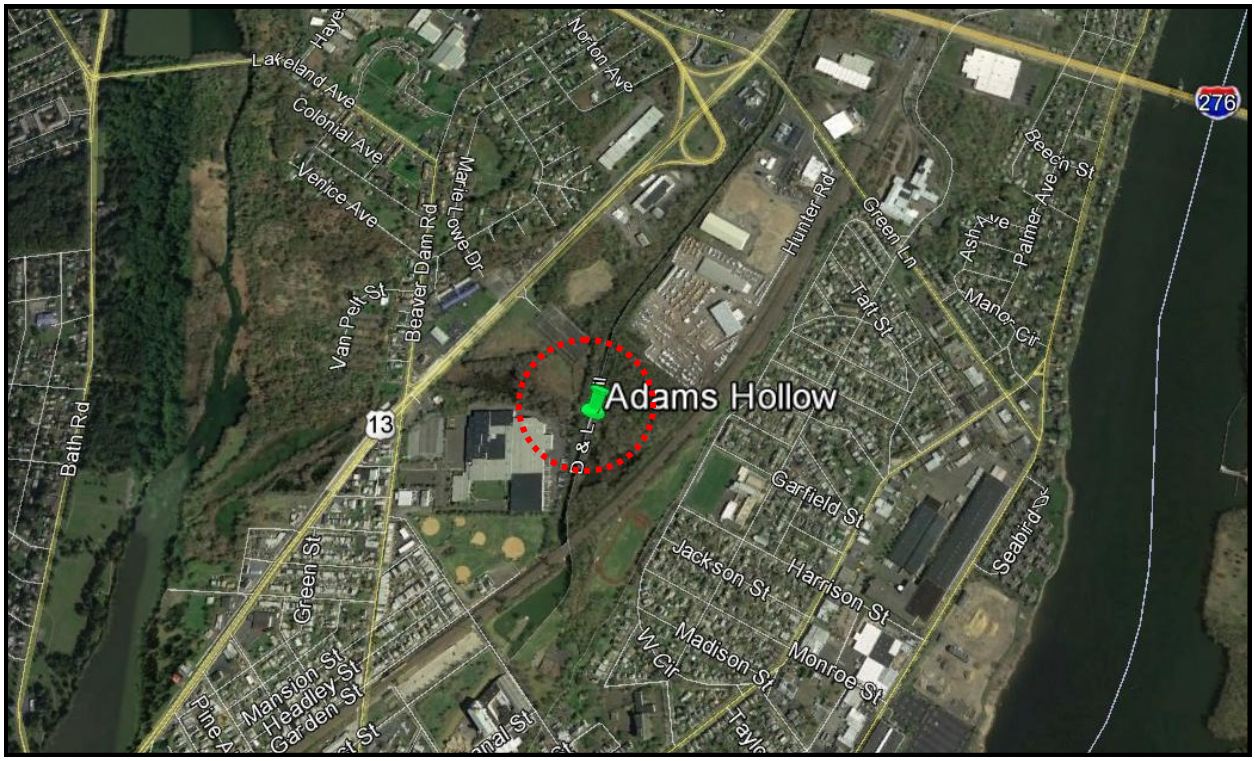
Delaware Canal and Towpath, Falls Township.

Informal pedestrian/bicycle path along railroad.

2.3.7. Adams Hollow

Location: Bristol Borough, Bucks County Lat/Long"40.109959 -74.849541"

Impacts to Canal: Sediment deposits in culvert.



Source: Google earth

Observations: The southern section of the canal, primarily south of Yardley Borough, is heavily developed with more impervious surfaces than many other areas to the north. The topography is also flat, which means the canal is built up from ground level in many instances. Near the location where Adams Hollow crosses under the canal, the water level in the canal is higher than the adjacent parking lot and finished floor elevation of the adjacent Hubbell lighting facility, and poses an issue if there were ever a breach in the canal prism wall. Current evidence of erosion of the prism wall suggests that additional structural support may be needed on the upstream side.

The Adams Hollow culvert under the canal is not visible because of excess ponding on the downstream and upstream side of the canal. A perennial forested wetland has established itself on the downstream side of the canal on Bristol Borough property. This suggests that water flow in the creek is very slow. The wetland is bordered by the canal to the west and the railroad corridor to the south and east. Water drains out of the wetland through a culvert under the railroad.

Adams Hollow is also ponding on the upstream side of the canal. This suggests that the flow through the culvert is blocked with sediment deposits, and/or the water level of Adams Hollow is higher than the culvert invert.

Currently DCNR removes sediments to reestablish proper flow. This remedy is short-lived, as this creates a "bowl" for sediments to quickly fill back into the culvert and on either side of the canal.

DCNR Management Efforts: DCNR performs maintenance activities in accordance with its jurisdictional work limits (50' along either side of the channel). The culvert and 50-foot buffer on either side have been cleaned three times in the last 10 years. According to DCNR, this has not been effective and the canal wall needs to be reinforced.

Opportunities: Surrounding vacant/underutilized lands held by various public entities including Bucks County Redevelopment Authority, Bucks County Parks Department, and Bristol Borough may be possible to serve as a stormwater detention facility for Adams Hollow storm flows.

Possible Partnerships:

- Bristol Borough – access to property and maintenance agreement
- Bucks County Redevelopment Authority - access to property and maintenance agreement

Ponding adjacent to the canal.

2.4 Types of Stormwater Impacts to the Canal

Site observations identified recurring types of impacts to the canal. These conditions affect not just the selected pilot project sites, but similar situations found throughout the canal's 60-mile corridor.

2.4.1 Water flowing under the Canal

Portions of the canal infrastructure are over 185 years old, including culverts under the canal. Not every watercourse is fed directly into the canal. Larger creeks flow under canal aqueducts. Smaller watercourses that do not feed the canal, are conveyed under the canal through pipes and stone arch culverts.

Where the canal is bridged over larger watercourses with aqueducts, stormwater flows under the aqueduct can impact the structural integrity of those structures. Aqueducts with central piers in streambeds are impacted by high velocity debris and become damaged. Sediment buildups under the aqueduct can also threaten the structure.

Where watercourses have been piped under the canal, much of the infrastructure has deteriorated over the years. Sediment deposits collect and build up in pipes, old age causes culverts and pipes to collapse, and increased development causes higher water volumes that overwhelm this infrastructure. Constant repairs and sediment removal projects are completed every year. Original stone culverts are of particular concern as susceptible to stormwater impacts.

2.4.2 Water Velocity within the Canal

Water velocity varies in different segments of the canal. Historically, water velocity in the canal had minimal effects on canal boats as they moved between locks. Without locks operating in the canal, the flow regimens have changed. Research and current measurements are needed to document flows. Changed flow regimens may cause movement of sediments along the canal prism.

2.4.3 Sedimentation Deposits in the Canal

Sedimentation deposits in the canal can impact flow and have negative implications for surrounding areas. These deposits are generally caused by sediments that wash down from upper watershed areas and deposit in the canal. The slower water velocity of the canal causes the deposits to build up and impact the canal flows and uses.

In the past, DCNR dredged the entire canal to remove sediment deposits. Today, smaller dredging projects along portions of the canal continue to occur. Unfortunately, these regular dredging demands caused by modern stormwater impacts have been accepted by DCNR as a regular operation and maintenance responsibility for the canal – based on the results of up-watershed stormwater practices.

2.4.4 Erosion / Scour of the Canal Prism

Erosion and scour is caused by high water velocity entering the canal. There is evidence of erosion at numerous outfalls into the canal throughout the 60-mile corridor. Pipes and culverts that feed the canal channelize water during storm events. This in turn increases the velocity of water entering the canal.

Damage to the canal prism is typically found along the prism bottom and prism wall opposite a discharge point. In some instances, erosion undermines the discharge point and will erode the canal prism wall around the outfall.

Erosion is the most visible impact to the canal and causes serious structural damage to the prism that can be a safety liability. Erosion can scour the clay liner and reduce the impermeability of the Canal prism.

2.4.5 Water Volumes in the Canal

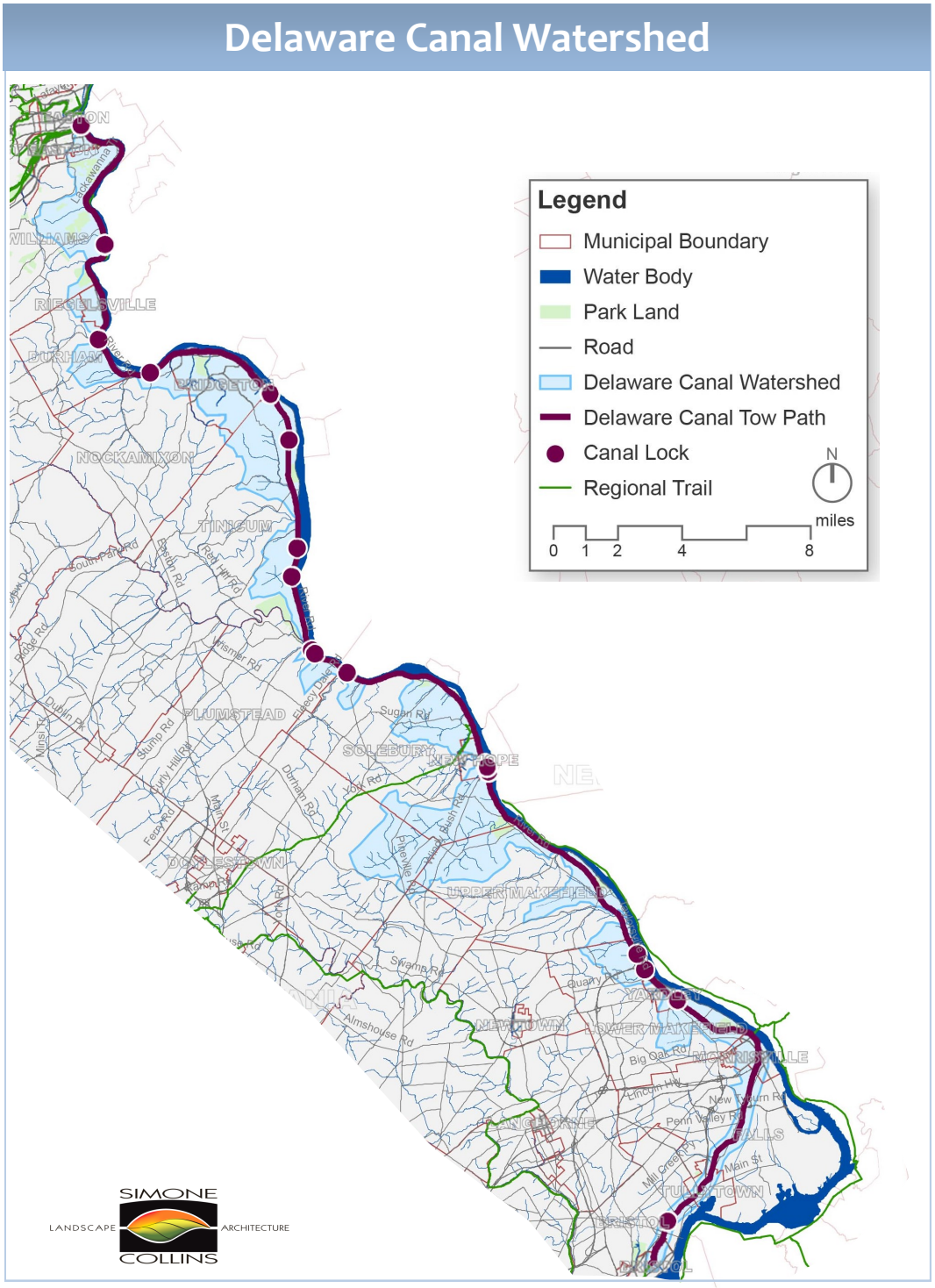
Water volume in the canal is a complex issue. A fully watered canal has been identified through the *Delaware Canal Vision Study* (2017) as a high public priority. A fully watered canal provides more recreational values and supports tourism and maintains environmental assets. A watered canal also prevents the historic clay liner from drying out, cracking, and leaking – as the most fundamental task of sustainable stewardship for DCNR. Where the liner is allowed to go dry, it leaks, water escapes the canal into the subsurface and can cause sinkholes under the canal and in adjacent areas.

Impacts to the Delaware Canal from periodic Delaware River flooding are significant and have historically created major breaches in the Canal waterway. The impacts of Delaware River flooding on the Delaware Canal must be acknowledged but analyses and alternative remedies are outside the scope of this study.

2.5 Watershed Analysis

2.5.1 Overall Watershed Hydrology

The Delaware Canal Watershed map was created as a preliminary assessment of the watershed for the canal. By establishing baseline conditions, recommendations can be made to reverse or mitigate existing stormwater impacts. A model for water flows in the Delaware Canal needs to be created as part of future stormwater planning.



2.5.2 Site Specifics for Pilot Project Locations

Each of the seven pilot BMP sites selected for this study has different watershed characteristics that impact the canal.

Highlands Boulevard and PA Route 611 Intersection

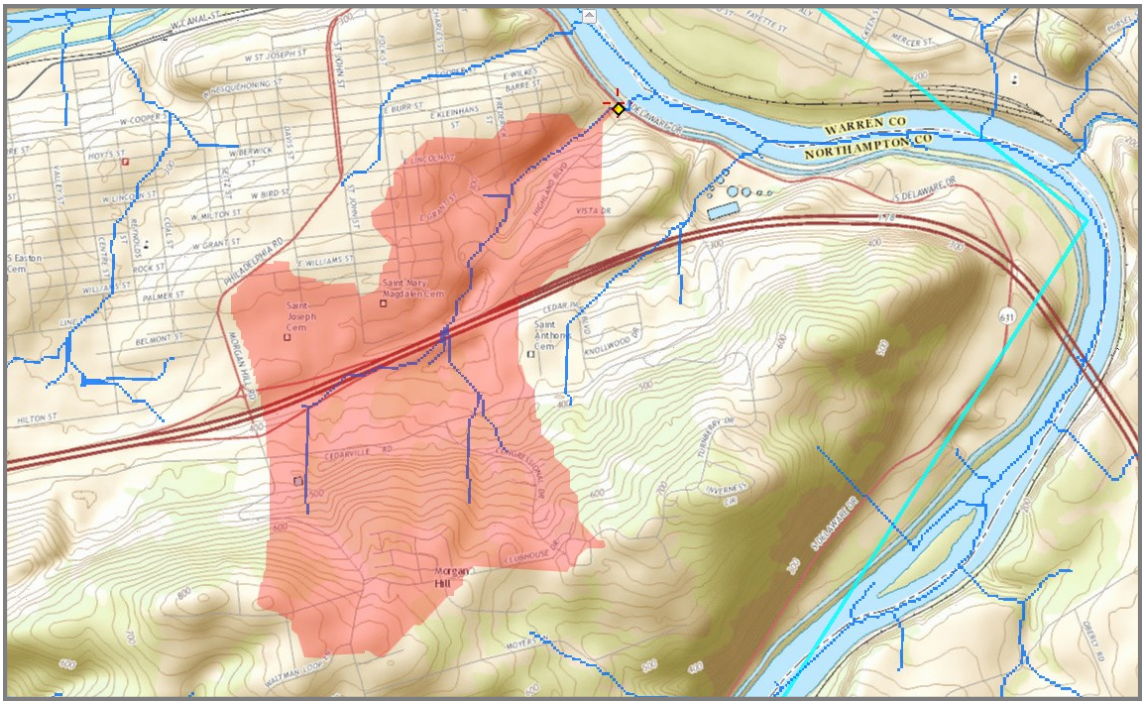
The Highlands Boulevard site is located within Sub-area 29 of the Fry's Run Act 167 Watershed. The majority of the drainage area is currently developed, comprised of residential and industrial sites. Notable locations include: Morgan Hill Golf Course, Interstate-78 corridor and a Pennsylvania Welcome Center. Some of these developed areas were constructed prior to the enactment of more stringent stormwater rules and regulations and have resulted in increased stormwater runoff rates. This includes sections of the Highlands residential subdivision, industrial properties, I-78 and the Welcome Center. Development also resulted in stormwater conveyance systems being installed that decreased stormwater travel time from previous existing conditions. Based upon a site observation it appears that an existing watercourse was piped at some point in time to the confluence with the Delaware River. These conditions may have resulted in the existing culvert installed under PA Route 611 to be undersized for present conditions. A small portion of the watershed is comprised of a wooded area. The existing culvert and PA Route 611 are located within the Regulatory Floodway, as defined by FEMA.

Watershed Calculations

Drainage Area – Approximately 422 Acres

TR-55 Analysis - Approximately 847 CFS

Highlands Boulevard and PA Route 611 Intersection watershed



Source: http://streamstatsags.cr.usgs.gov/v3_beta/viewer.htm

Morgan Hill Outfall

The outfall is located within Sub-area 24 of the Fry's Run Act 167 Watershed. The site's drainage area is comprised of the Morgan Hill Golf Course, residential single-lot properties, and forest. Stormwater management systems were installed as part of the Morgan Hill Golf course development to mitigate the increase in runoff from pre-development to post-development. However, based upon the continual overload of the downstream culvert, the stormwater systems appear to be undersized for current demands. The intermittent stream channel that leads from the Morgan Hill Golf Course to PA Route 611 is significantly steep and the increased flows have resulted in eroded hillsides.

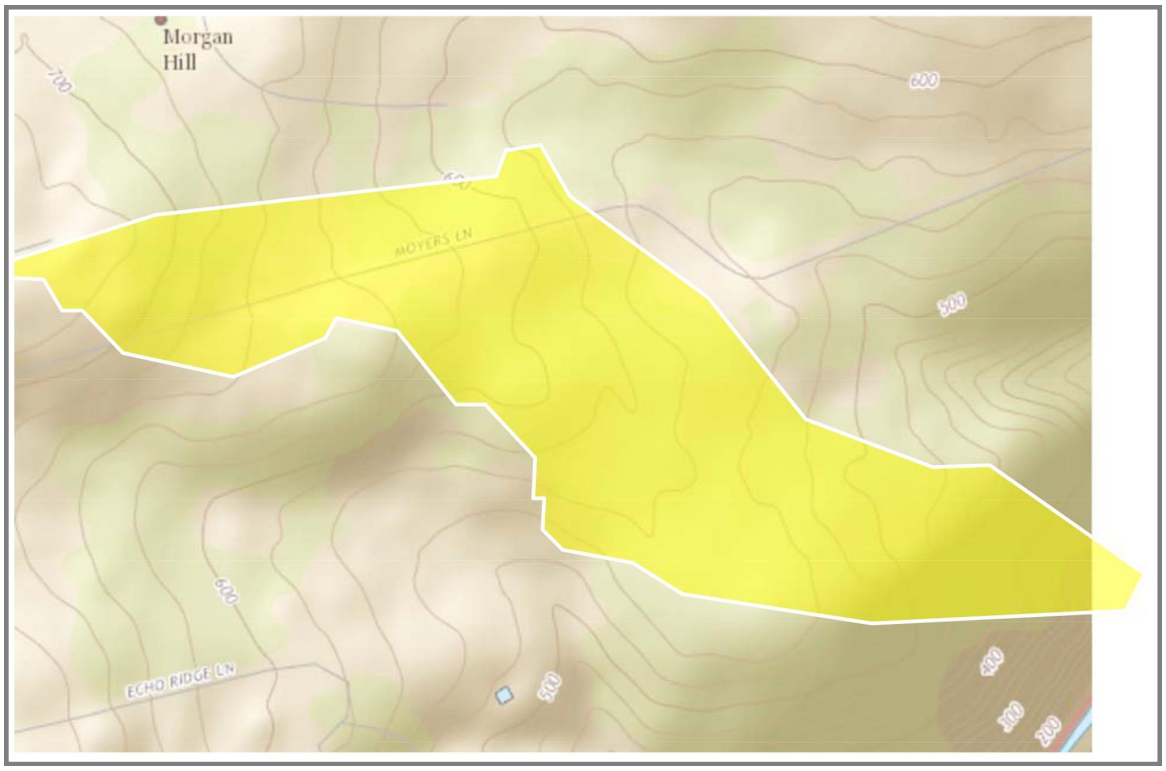
The existing culvert and PA Route 611 are located within Flood Zone AE, as defined by FEMA.

Watershed Calculations

Drainage Area – Approximately 49 Acres

TR-55 Analysis - Approximately 120 CFS

Morgan Hill Outfall watershed



Source: http://streamstatsags.cr.usgs.gov/streamstats

Bucks County Parkland

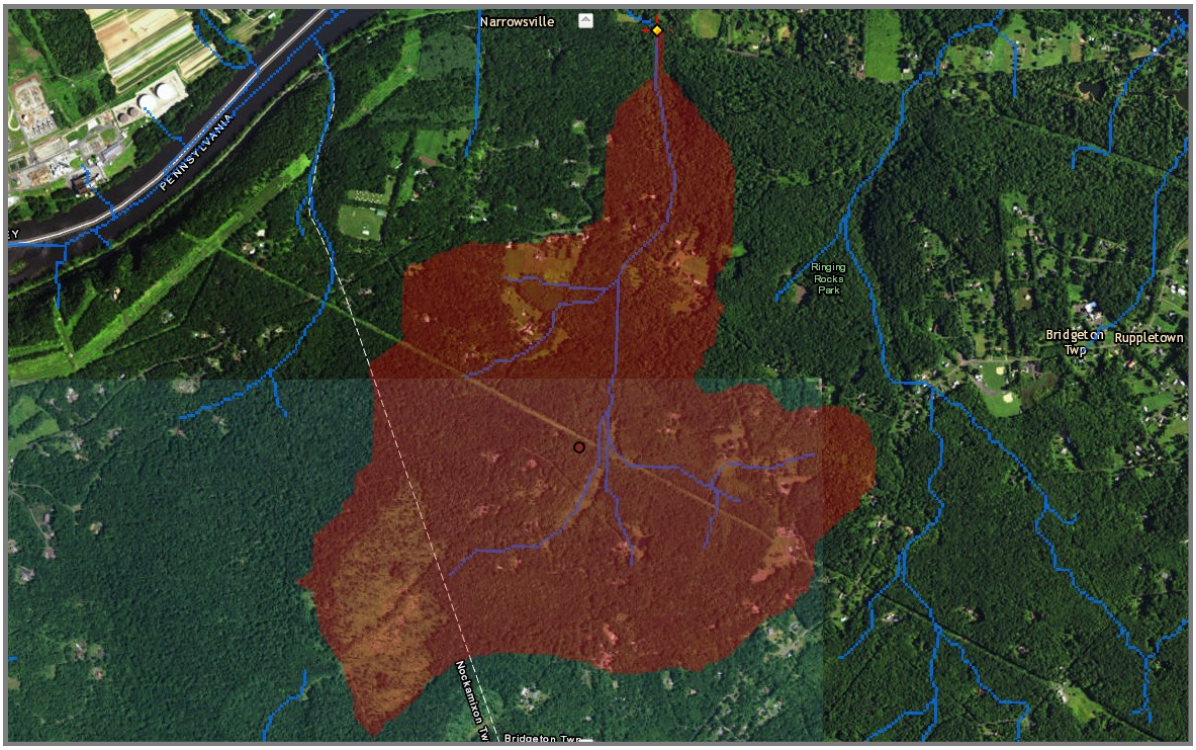
The Bucks County Parkland site is located within Sub-area 70 of the Delaware River North Act 167 Watershed, better defined as the Falls Creek watershed. The majority of the watershed is wooded, with a small percentage of residential single-lot properties. Mountainous terrain is the existing watershed topography. The site is located within Flood Zone AE, as defined by FEMA

Watershed Calculations

Drainage Area – Approximately 640 Acres

TR-55 Analysis - Approximately 1,396 CFS

Bucks County Parkland watershed



Source: http://streamstatsags.cr.usgs.gov/v3_beta/viewer.htm

Erwinna Agricultural Operations

The Erwinna site is located within Sub-area 1 of the Delaware River North Act 167 Watershed. The site's drainage area is comprised primarily of a commercial agricultural operation, above a portion of steeply wooded areas. The portion of the property located within the drainage area contains large areas of bare soil, impervious parking and drive areas, and a main building. The existing bare soil is a cause for downstream siltation. The commercial operation was developed prior to modern stormwater management rules and regulations and would not be permitted as constructed today. Site conditions observed by the Protect Team suggest that current farming practices lack sufficient groundcover, which increases the volume and velocity of runoff, as well as sedimentation. Steep channels are located within the steeply wooded portion of the drainage area that convey runoff from the upper fields and parking areas to the low lying area adjacent to the canal. The low lying area and identified impact area to the canal are located within Flood Zone AE, as defined by FEMA.

Watershed Calculations

Drainage Area – Approximately 27 Acres

TR-55 Analysis - Approximately 231 CFS

Erwinna Agricultural Operations watershed

Source: http://streamstatsags.cr.usgs.gov/streamstats

Paunacussing Creek

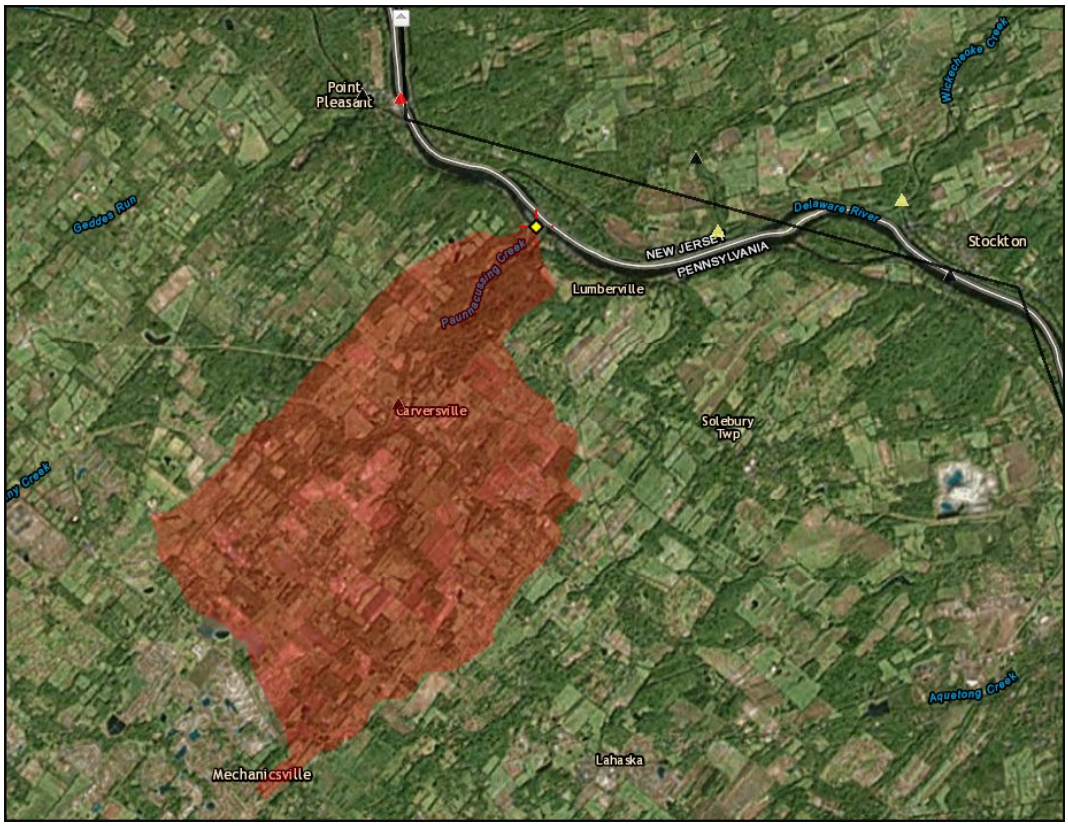
The site is located within Sub-area 10 of the Delaware River South Act 167 Watershed, which is also defined as the Paunacussing Creek watershed. The majority of the site is comprised of agricultural fields and wooded areas, with a small percentage of residential single-lot properties. The agricultural and residential areas are gradual sloping areas while the wooded portion contains steep slopes. Within the steeply wooded areas the stream is highly susceptible to erosion. Site observations identified rock deposits the length of the streambed. The eroded materials tend to deposit surrounding the two streambank constructions - the PA Route 32 bridge crossing of Paunacussing Creek and Delaware Canal aqueduct just downstream. Both structures are located within the Regulatory Floodway, as defined by FEMA.

Watershed Calculations

Drainage Area – Approximately 5,050 Acres

TR-55 Analysis - Approximately 7,417 CFS

Paunacussing Creek watershed



Source: http://streamstatsags.cr.usgs.gov/v3_beta/viewer.htm

Conrail Obstruction

The site is located within the Delaware South Act 167 Watershed. The watershed at the Conrail Obstruction is unique when compared to the other six sites studied in this report. All the other watersheds studied involved water entering or flowing under the canal. This simplifies the watershed analysis to one watershed. The Conrail Obstruction watershed involves the Delaware Canal itself. The future hydraulic analyses for this flood-prone area will include determining the locations and estimated volumes of water entering the Delaware Canal that directly contribute to historic Delaware Canal flooding in the Morrisville area.

Watershed Calculations

A separate study is recommended to accurately assess this sub-watershed. Initial calculations of water volume in the canal are found in section 6 of this report. These volumes are preliminary and will require fine tuning upon completion of a survey along the Canal.

Conrail Obstruction watershed

Source: http://streamstatsags.cr.usgs.gov/streamstats

Adams Hollow

The site is located within the Delaware South Act 167 Watershed. The watershed is comprised of heavily urbanized and residential districts. An existing local parking area was observed which does appear to be utilized and is in poor condition. The watershed also contains recreational lands, woods, and vegetated areas. Stormwater management facilities could not be seen from aerial photography for the heavily urbanized and residential districts. The drainage area is relatively flat and water is conveyed by a stream channel to an existing culvert that traverses underneath the canal. Sites within the drainage area were noted to be located at an elevation lower than the canal. The northwestern border of the drainage area is Route 13. However, there appears to a box culvert located under Route 13 which suggests that during high rainfall events, Silver Lake overflows into the drainage area. The watershed analysis calculations were performed with Route 13 as the northwestern border due to unknown capacity and overflow impacts from Silver Lake.

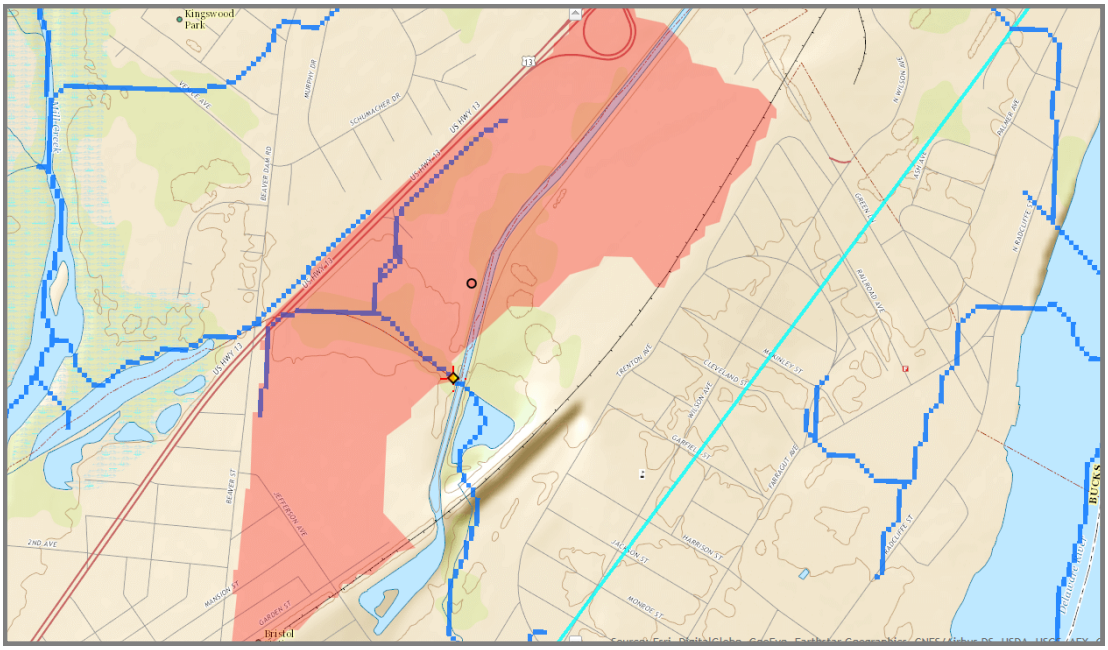
FEMA has not identified the site as being located within a flood zone.

Watershed Calculations

Drainage Area – Approximately 93 Acres (Refer to Description of explanation)

TR-55 Analysis - Approximately 353 CFS (Refer to Description of explanation)

Adams Hollow watershed



Source: http://streamstatsags.cr.usgs.gov/v3_beta/viewer.htm

3. Pilot Project BMP Recommendations

Each of the seven sites selected for this study offers potential to function as a demonstration project that may be replicated in other locations throughout the Delaware Canal corridor. Recommendations were made based on site conditions, potential for a generally universal application of the BMP in other segments of the canal, and potential for funding.

The suggested BMPs were identified with reference to the Pennsylvania Stormwater BMP Manual design guidelines. Where possible, recommendations consider multi-functional solutions that combine stormwater BMPs with public enhancement projects such as trails and parking. This strategy for future multi-use designs increases the opportunities to secure funding and public support.

The recommended BMPs vary in scale from simple vegetated roadside swales, to complex underground cisterns usable for irrigation. The recommendations made in this report reflect applicable designs for the seven selected sites, but do not cover all BMP possibilities for the canal or the selected sites. The next phases of BMP design and implementation for these sites and additional sites should consider all alternative BMPs to determine the best applications for each site. Each design project will consider land uses, topography, geology, soils, access, ownership, and funding.

3.1 Highlands Boulevard and Route 611 Intersection

Options Considered:

- Upgrade existing drop boxes to water quality collectors
- Break up long stretches of asphalt with in-road collectors or route to drop boxes
- Private landowners and HOA to implement BMPs
- Regular street sweeping
- Public education

Recommendation: Slow the water running down Highlands Boulevard and capture water to impound some of it prior to discharging into the canal. Such improvements could start at the intersection of Highlands Boulevard and Vista Drive on the northern side of Highlands Boulevard and adjacent to the private property. This area might be reclaimed as a roadside bioswale BMP. The curbline would be relocated with curb cuts that allow water to enter the BMP from the street. Due to the slope of Highlands Boulevard, the BMP would include terracing that slows the water and detains it in subsurface storage chambers.

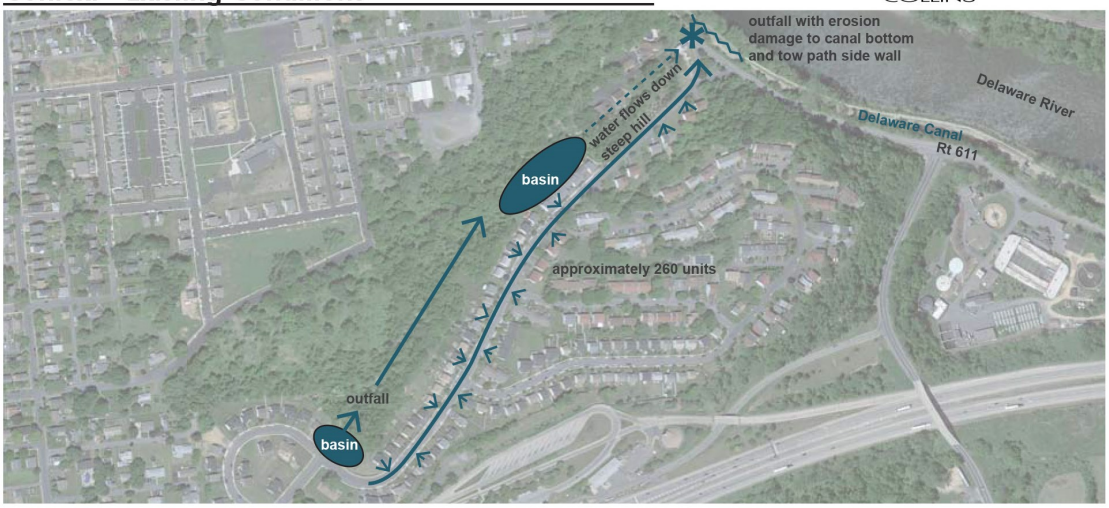
Conceptual BMP - Highlands Subdivision

SIMONE COLLINS LANDSCAPE ARCHITECTURE

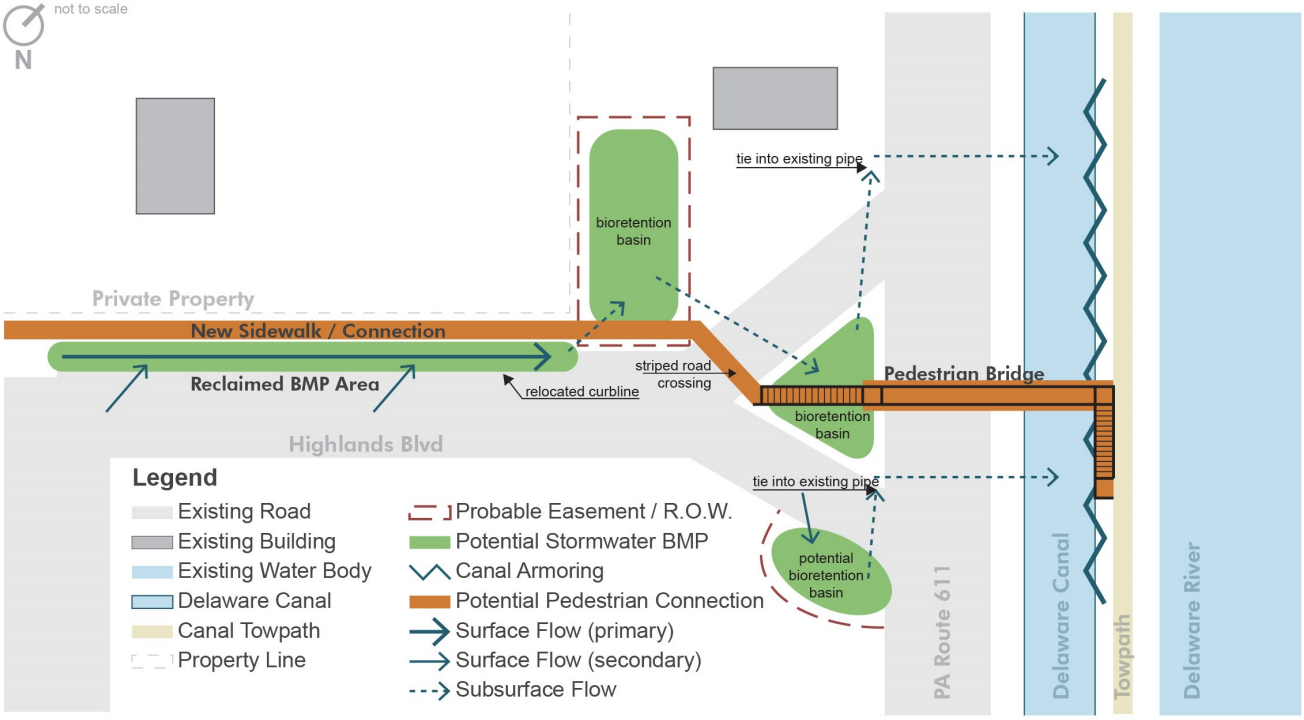
HanoverEngineering

date 08.04.2016

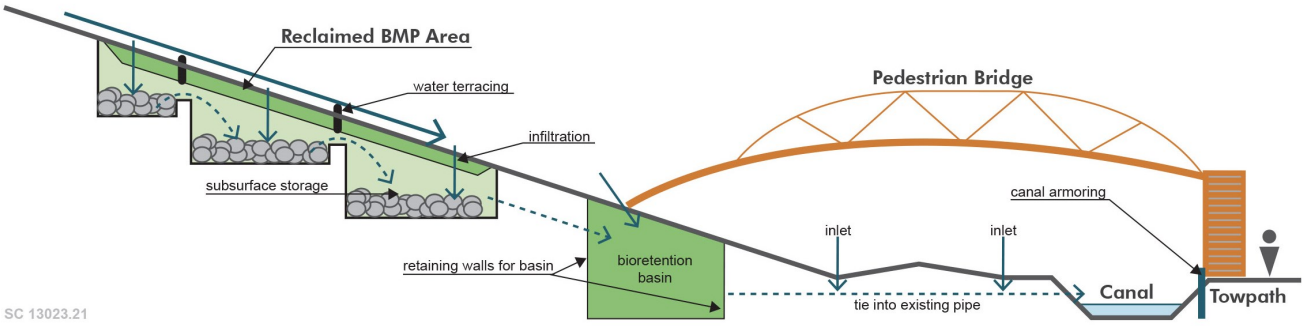
Context - Existing Conditions



Plan View



Section View



SC 13023.21

Closer to the Highlands Boulevard and PA Route 611 intersection, water might be piped from the roadside BMP to bio-retention basins, where it would be stored and released slowly. If excess stormwater fills the basins, the water outfalls into pipes that tie into the existing stormwater systems and discharge into the canal. The goal is to slow velocity and allow for longer detention than pre-design conditions.

Highlands Boulevard presents an opportunity to combine stormwater BMPs with a public enhancement project involving pedestrian connectivity that would provide approximately 260 residential units with access to the canal. There are limited recreation opportunities currently available in the area. The Delaware Canal provides a recreational asset for the community. However, with the towpath on the far side of the canal, it remains relatively inaccessible for residents living off of Highlands Boulevard. The closest canal bridge is located a quarter mile south of Highlands Boulevard across from the municipal wastewater facility. Lack of sidewalks or trails from Highlands Boulevard to the bridge limits its accessibility and appeal as a pedestrian route. These conditions offer an opportunity to combine a stormwater BMP project with a pedestrian connectivity enhancement project.

Site improvements may include extension of the Highlands Boulevard sidewalk from its current terminus at Vista Drive to the intersection with PA Route 611. The sidewalk could be designed in conjunction with roadside BMP terraces. This presents an opportunity to integrate the design of the sidewalk and BMP together and provide education opportunities for pedestrian users. Topography at the Highlands Boulevard and Route 611 intersection presents an opportunity to construct a new pedestrian bridge over Route 611 and the canal to create a safe and viable connection to the towpath.

Partners:

- City of Easton
- PennDOT District 5 - work in right-of-way. Purchase additional right-of-way. Maintenance agreement will need to be established.
- DCNR – Steward of the Delaware Canal. Maintenance agreement will need to be established.
- Northampton County Conservation District - will be involved in reviewing plans and making recommendations.
- Highlands Subdivision Home Owners Association - enhancements to HOA-owned land. Maintenance agreement will need to be established.
- Private Landowners - enhancements on or near properties.
- Land Trusts and/or municipalities acquire conservation easements.

Highlands Boulevard as a Model BMP: The Highlands Boulevard concept serves as a model stormwater BMP for reclaiming impervious area and implementing bio-retention basins – possibly in combination with pedestrian enhancement projects. This concept can and should be used for other sites along the Delaware Canal that involve similar site conditions.

3.2. Morgan Hill Outfall

Options Considered:

- Cooperative agreement w/ golf course to retain volumes and control flow.
- On-site retention of runoff to water greens in dry weather conditions.

Recommendation: Upper watershed BMPs are recommended for the Morgan Hill Outfall site and along PA Route 611 adjacent to the canal to manage the water that flows from increased development on top of Morgan Hill and down an eroded channel.

Upper watershed BMPs would help capture water and allow for natural evapotranspiration and/or reuse as irrigation. The current infiltration basin at the top of the outfall slope does not function effectively. Subsurface water flows perpendicular in this region. Any water that infiltrates, still flows downhill and adds to the outfall water volume downstream. Several BMP options could be negotiated with private land owners on top of Morgan Hill. Examples include underground cisterns to collect and hold water for golf course irrigation and wet ponds with impervious liners to provide additional storage and a water feature.

Along the outfall channel that runs down the slope of Morgan Hill toward PA Route 611 and the Delaware Canal, the water velocity is high. This is evident from the deeply eroded channels that have been cut into the steep slope and lack of vegetation. Even with upper watershed BMPs installed, discharged water volume will need to be slowed as it travels downslope. Terracing the hillside where feasible would help slow water velocity. Terraces can be designed as landscape features and aesthetic art pieces with sculpture elements. As water flows from one terrace to another, waterfalls become a visual amenity. In such an example, a stormwater BMP could be coupled with art.

As water from the outfall channel reaches the toe of the slope, it enters into a roadside swale along PA Route 611. Current conditions permit water to bypass the roadside swale and discharge into the canal at high velocity. A new roadside BMP that slows and detains stormwater should be considered. This can begin with a dissipater at the toe of the outfall channel to divert the water flow into the roadside swale rather than flow directly into the canal. The roadside swale could be widened and enhanced with raingarden vegetation to capture greater volumes of water. As a result, water would be discharged into the canal over a longer period of time and at slower velocity than existing conditions.

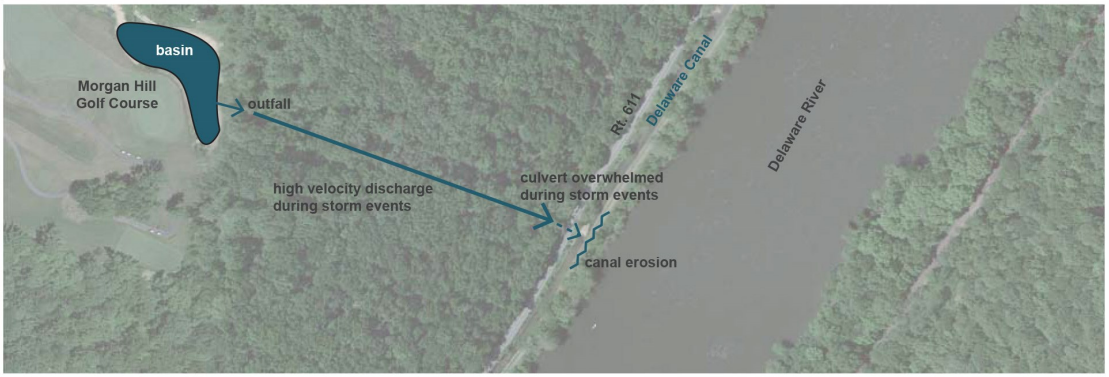
Conceptual BMP - Morgan Hill Outfall

SIMONE COLLINS LANDSCAPE ARCHITECTURE

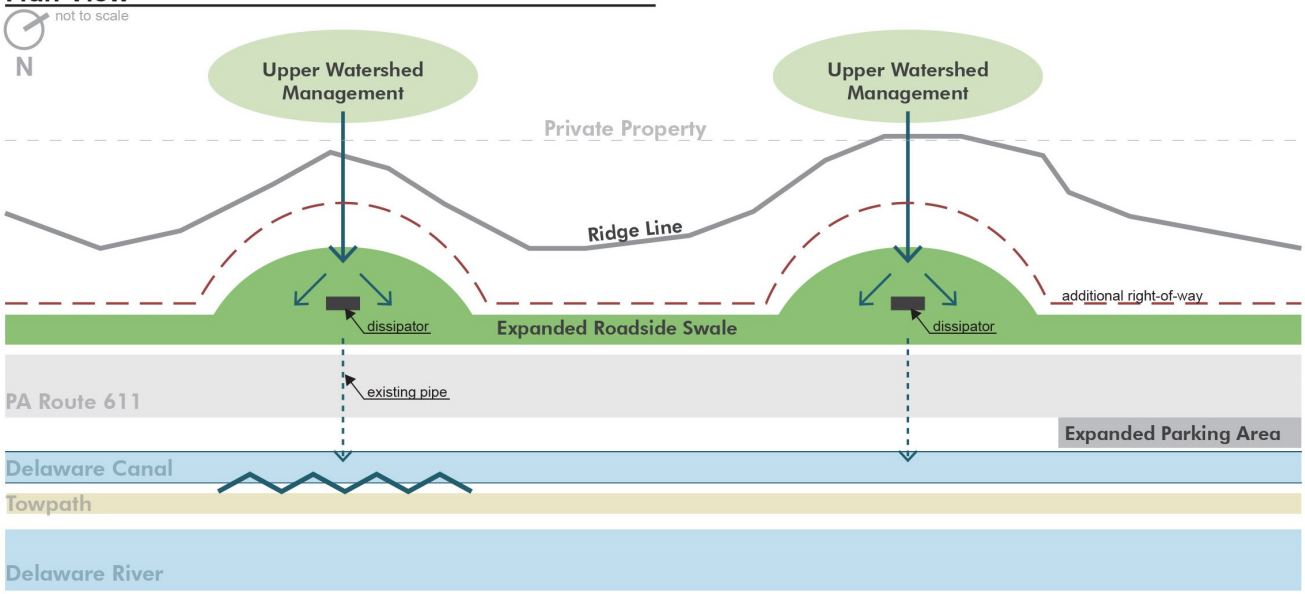
HanoverEngineering

date 08.04.2016

Context - Existing Conditions



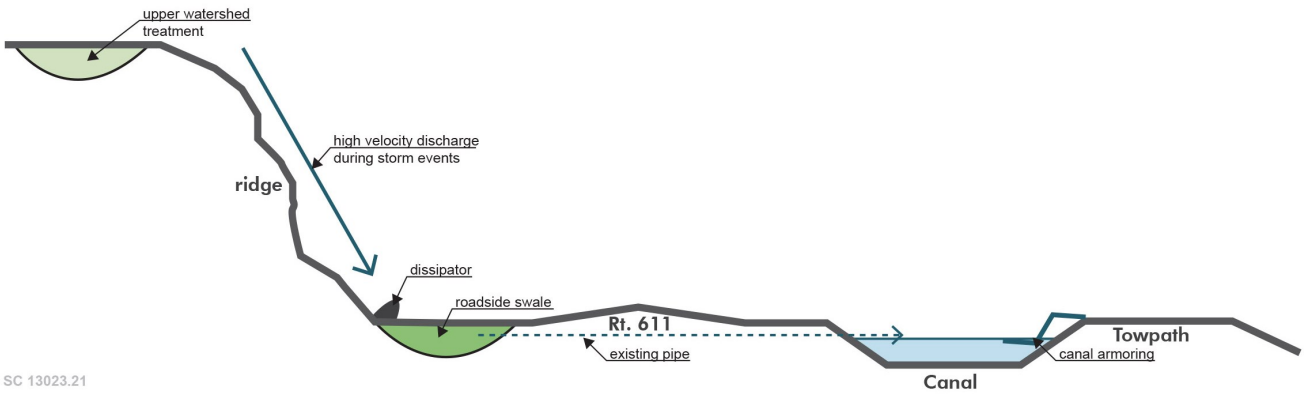
Plan View



Legend

- Existing Road
- Canal Towpath
- Existing Water Body
- Delaware Canal
- Probable Easement / R.O.W.
- Property Line
- Potential Stormwater BMP
- Upper Watershed Management
- Canal Armoring
- Surface Flow (primary)
- Surface Flow (secondary)
- Subsurface Flow

Section View



SC 13023.21

Morgan Hill Outfall, continued

Partners:

- PennDOT District 5 - Purchase additional right-of-way; work in right-of-way; maintenance agreement will need to be established.
- DCNR - Maintenance agreement will need to be established.
- Local municipality
- Private Landowners - establish upper watershed management basins. Maintenance agreement will need to be established.

Morgan Hill Outfall as a Model BMP: The Morgan Hill Outfall concept can serve as a model BMP for upper watershed management and state highway swales for other areas along the canal with similar site conditions. Maintenance agreements between government and private agencies are key to the success and implementation of this type of project.

3.3. Bucks County Parkland

Options Considered:

- County parkland potential expansion.
- Agreement to maintain as open space managed area.
- Establish significant riparian area; enforce protection.

Recommendation: The conceptual BMP recommended for the Bucks County Parkland parcels could be designed to collect sediments before they reach the canal and allow for easy maintenance. Current conditions suggest that sediments collect near the confluence of Falls Creek and the Delaware Canal. The canal prism wall in this location appears as if it may have been breached at one point in time, and now allows for free flow of water and sediment deposits into the canal. Based on site observations, conditions do not appear to be severe, but could worsen at any time upstream discharge patterns might change.

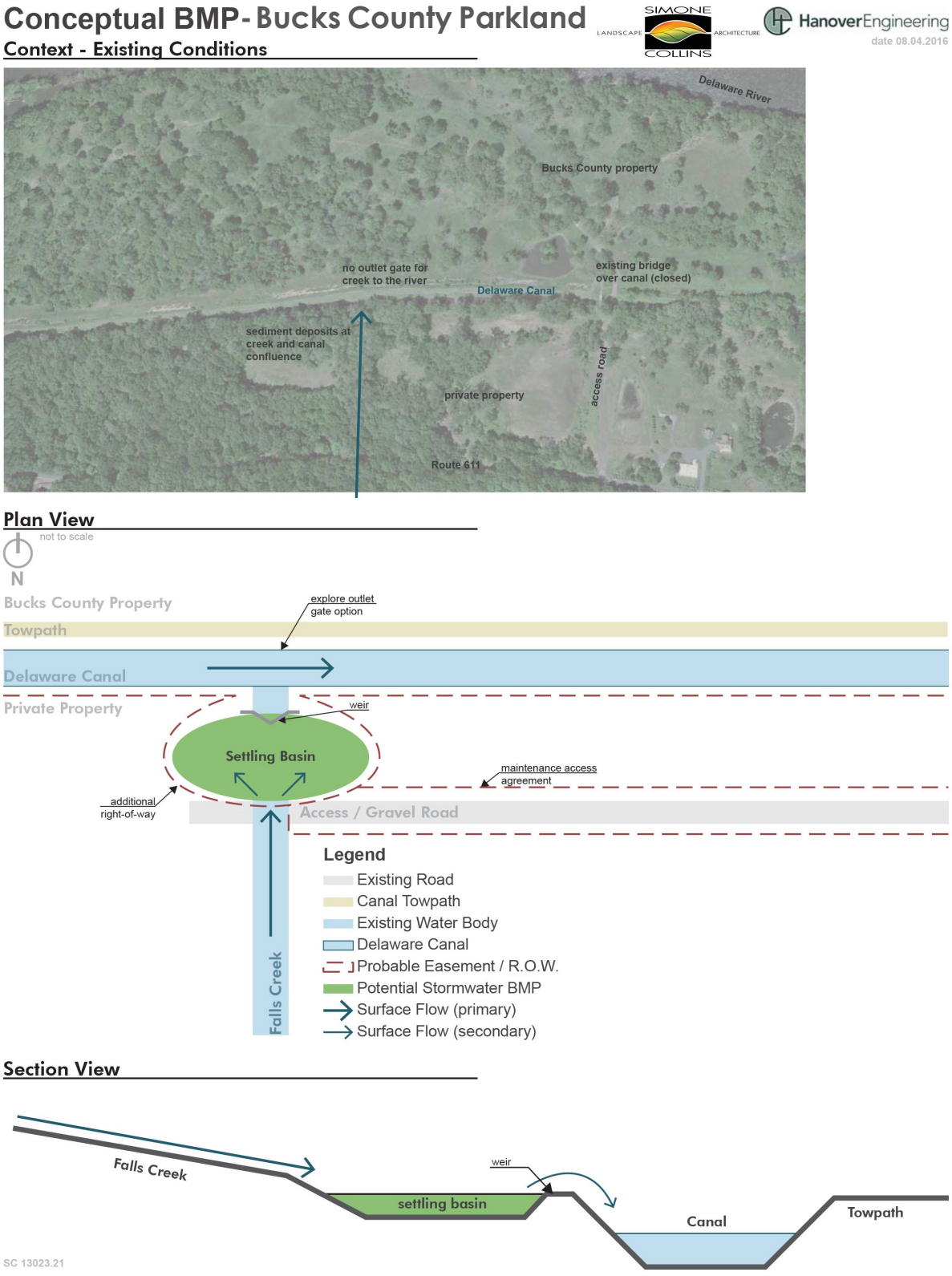
The recommended collection system for sediment deposits is a settling basin on the upstream side of Falls Creek from the confluence. This basin would be controlled by a weir designed at the confluence of the creek and canal. The weir would slow water prior to entering the canal and allow sediments to deposit in the basin. Water would spill through the weir and enter into the canal.

For the settling basin to properly function, maintenance access is key. DCNR will need to acquire additional right-of-way or easements for the creation of the settling basin. Maintenance access easements will have to be established that allow DCNR to periodically remove sediments from the basin.

In addition to the recommended BMP, an outlet gate on the opposite side of the canal from the confluence is lacking and could be considered. This would provide flood mitigation benefits. If this structure is implemented a channel would need to be designed to direct flow to the Delaware River. Given that this property is owned by Bucks County, the implementation of a new stream channel would not involve private landowners, but is a significant engineering project. This new outlet is not detailed in the conceptual BMP. The current design presents an opportunity to implement a low-cost BMP. If funding and agreements are in place for an outlet structure, an outlet could be considered.

Partners:

- DCNR - Right-of-way or easement acquisition. Maintenance agreement and access will need to be established
- Bucks County - Improvements on or near county parkland
- Private Landowners - Improvements on properties with long-term maintenance agreements



Bucks County Parkland as a Model BMP: The concept of catching sediments and allowing for regular maintenance / cleanout of these settling basins might be considered where watercourse confluences with the Delaware Canal exist as a strategy to preempt sediment deposits into the canal flow and enable proactive maintenance directly up-watershed from the canal.

3.4. Erwinna Agricultural Operations

Options Considered:

- Develop and implement Soil Conservation Plan for agricultural operations
- Better on-site retention to serve fields in dry weather
- Slope drain
- Critical areas planting
- Silt curtain
- Stream bank stabilization
- Rehab existing dry pond; install additional ponds downgrade
- Better soil management practices
- Vegetated buffers
- Rain gardens to capture runoff along entire driveway slope

Recommendation: A concept plan for the site was not developed given the private ownership of the agricultural property. Rather this plan recommends options that could both benefit the Delaware Canal and the agricultural operation.

Erosion and Sediment control for agricultural practices is not as strictly regulated under law as other uses. Overall it is recommended that a soil conservation plan be implemented for this operation that reduces soil loss from the crop fields. Additional settling basins would help collect sediments. These sediments could then be reclaimed and redeposited on crop fields where soil loss has occurred. Vegetated ground covers between crop rows would help to limit soil loss. Vegetated bioswales along roads and crop fields could collect, store, and decrease discharge volume to the canal.

The agricultural site currently includes a significant area of impervious paving for driveways and parking. Excess parking could be reclaimed as vegetation. Other impervious areas that are necessary for business operations, might be converted to pervious paving, if infiltration rates are favorable. Along the entrance road, roadside swales could collect run-off from the road and provide an aesthetic entrance feature to the site.

Where water is currently directed along manmade berms, interconnected bioretention basins could be installed that step down the slope. If properly maintained and vegetated, stormwater might infiltrate and evaporate. Water velocity would also be slowed by terraced swales to help prevent further erosion and sedimentation downslope.

Current stormwater is directed across the surface of the entrance road and down a slope to a discharge point into the canal. This over the road drainage has serious safety concerns involving road flooding and freezing. A drop inlet on the high side of the road and a pipe under the road would eliminate this issue, but not solve the discharge down the slope below.

Erwinna Agricultural Operations

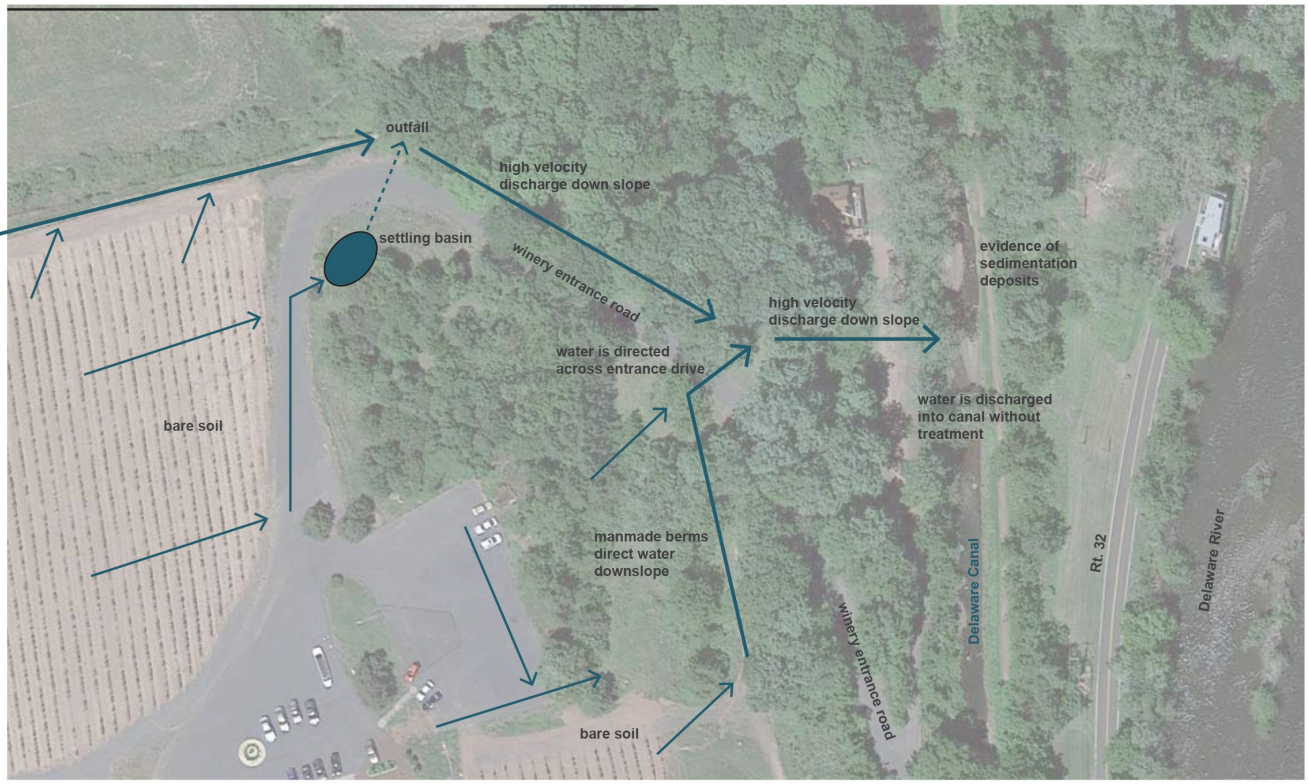
Context - Existing Conditions

SIMONE LANDSCAPE ARCHITECTURE COLLINS

HanoverEngineering

date 08.04.2016

Context - Existing Conditions



SC 13023.21

Erwinna Agricultural Operations, continued

The discharge channel leading to the canal is highly eroded and void of vegetation. Streambank stabilization measures along this channel could introduce vegetation that would stabilize the channel and slow the water moving down the slope. Additional vegetated buffers at the toe of the discharge slope adjacent to the canal are important for collecting any final sediments and slowing the water prior to entering the canal.

Partners:

- DCNR - Work will be done in canal right-of-way. Maintenance agreement will need to be established.
- Private landowners – BMP work will be done on and near property. Establish a soil conservation plan. Maintenance agreement will need to be established.
- Bucks County Conservation District - Oversee and review soil conservation plans. Assist in designing BMPs.

Erwinna Agricultural Operations as a Model BMP: Agricultural activities are periodically found along the Delaware Canal. Establishing a soil conservation plan with many of these recommendations will benefit agricultural operations as well as the functionality and aesthetics of the Delaware Canal.

3.5. Paunacussing Creek and Aqueduct

Options Considered:

- In-stream storage/detention between bridge and canal
- Upstream landowner cooperation to reduce runoff flow and volume via site storage or bio-retention
- Reduce lawn areas and increase brush/undergrowth
- Enlarge riparian areas and protect/enforce
- In stream energy dissipaters
- Channel modifications at the aqueduct
- Treatment wetlands

Recommendation: The goal of the Paunacussing Creek concept is to flush out sediments that build up near and under the Delaware Canal aqueduct. The aqueduct is in poor condition, with visible damage from age and flooding and will need to be replaced in the near future. The opportunity to rebuild the canal aqueduct should be used to explore interagency cooperation with the Army Corp of Engineers to also install streambed modifications below the aqueduct that will facilitate the natural flows to flush eroded materials from under the structure.

To assist in flushing out sediments under the canal, a **hydraulic device** that is sloped to concentrate flows under the aqueduct is envisioned to keep water moving downstream and limit sediment deposits. Such a **hydraulic device** could also be designed to also be more easily maintained and cleaned out by DCNR, without dredging the natural streambed. To provide maintenance to the BMP, an access easement will need to be negotiated with private landowners. An adjacent landowner agreement may already be in place given current maintenance done under the aqueduct.

The implementation of a hydraulic device could be done in conjunction with the construction of a new aqueduct. A partnership between DCNR, for the construction of the aqueduct, and the Army Corp, for the installation of the hydraulic device, provides funding opportunities and interagency cooperation. The possibility of a new aqueduct without a central pier should be strongly considered. This would improve flow under the aqueduct and limit damage to the structure.

Partners:

- DCNR - Construct new aqueduct. Maintenance agreement will need to be revised or established
- Army Corp - Design and engineering of BMPs. Potential funding partner
- Private Landowners - Work on or near properties. Maintenance agreement will need to be established
- Land trusts - conservation easements

Conceptual BMP - Paunacussing Creek

SIMONE COLLINS LANDSCAPE ARCHITECTURE HanoverEngineering

date 08.04.2016

Context - Existing Conditions

Plan View

not to scale

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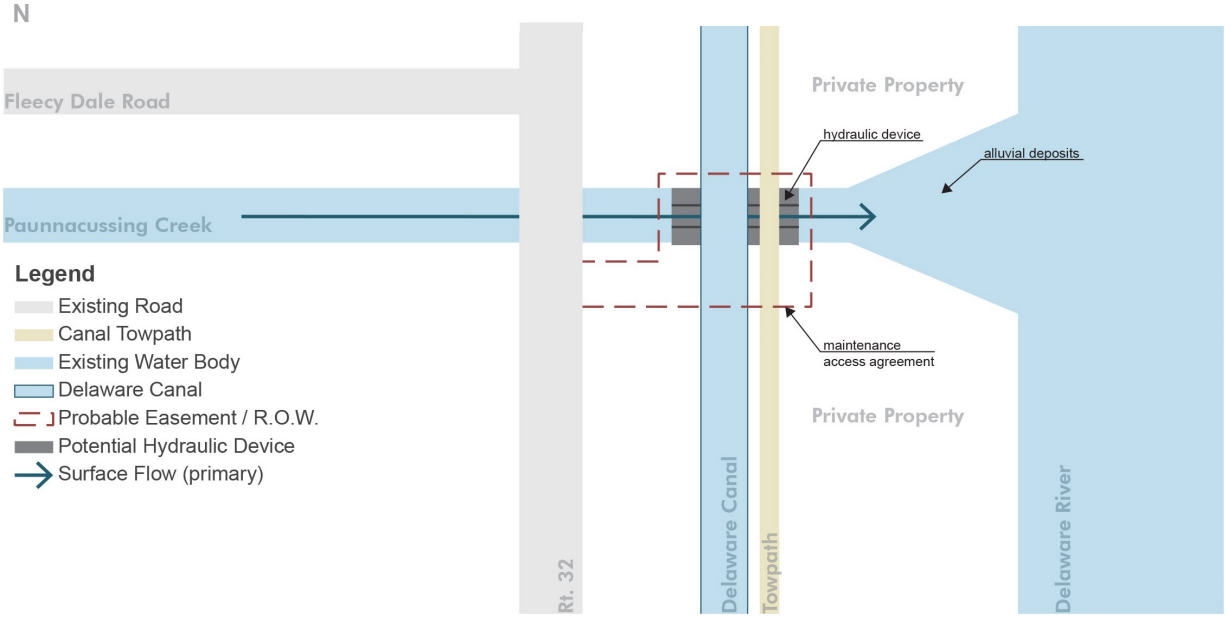
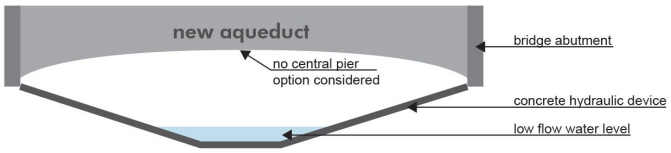


Section View



device intended to concentrate flows and flush out sediment

SC 13023.21

Paunacussing Creek and Aqueduct as a Model BMP: Paunacussing Creek has an extreme case of sediment deposits near and under a Delaware Canal aqueduct. The addition of a hydraulic device may not be appropriate in other locations.

3.6. Conrail Obstruction

The Conrail Obstruction was added to the list of recommended BMPs as a result of findings during the course of the *Delaware Canal Vision Study* (2017). The site includes an elevated railroad spur embankment that was built by filling in the canal and installing an undersized culvert to move water under the railroad.

Extreme flooding occurred three times in Morrisville Borough during 2004, 2005 and 2006. Water overflowed into Williamson Park, causing damage to public facilities, including the catastrophic and permanent loss of the Morrisville public swimming pool.

At the time of this study, DCNR had completed a design on a new trail-only culvert that would eliminate the obstruction to the towpath trail. DCNR has begun the process of a partnership study to determine the causes and solutions to Delaware Canal flooding in Morrisville.

Recommendation: The analysis and schematic design project that is planned in partnership with DCNR and partners will determine the causes of past flooding and propose a preferred solution to help prevent future flooding of the Delaware Canal in this area. Additional information can be found in the *Delaware Canal Vision Study* (2017).

Partners

- DCNR
- Morrisville Borough, D&L Heritage Corridor, DC21
- Army Corp - Design and engineering of BMPs. Potential funding partner
- Conrail
- Amtrak
- Private Landowners - Work on or near properties. Maintenance agreement will need to be established.
- Land trusts - conservation easements

Conrail Obstruction as a Model BMP: Other canal obstructions occur downstream of this location. The concept discussed above and in the *Delaware Canal Vision Study* can be used as a model for improved canal flow and towpath circulation.

Conrail Obstruction

Context - Existing Conditions

SIMONE LANDSCAPE ARCHITECTURE COLLINS

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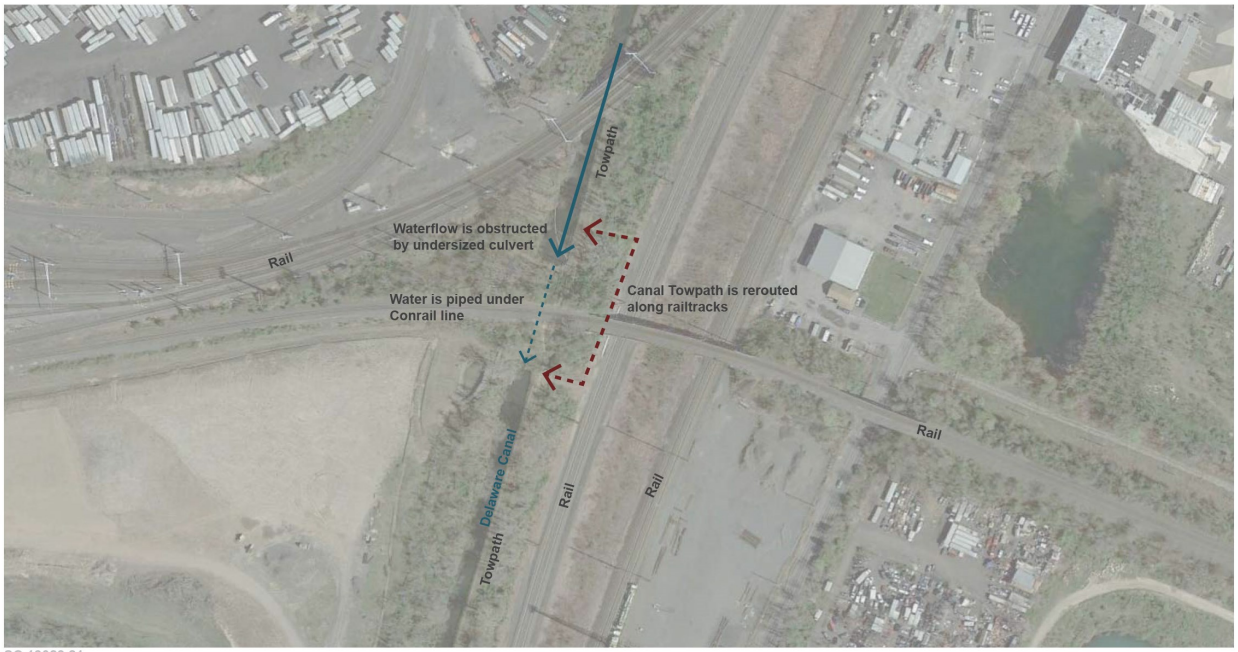
date 08.04.2016



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3.7. Adams Hollow

Options Considered:

- Regular maintenance procedures
- Porous parking areas
- Additional vegetative (non-lawn) contact with runoff
- Riser pipes installed on the upslope and downslope ends of the culvert
- Installation of additional culvert

Recommendation: A potential remediation effort at the Adams Hollow site is limited by the existing perennial forest wetland that is located between the downstream terminus of the culvert and the railroad. Installation of riser pipes are recommended on the upstream and downstream ends of the existing culvert to prevent sediment from entering and clogging the pipes. Another option, or combination of options, is to bore an additional culvert below the canal to assist with stormwater conveyance. However, a new culvert would lie at relatively the same invert elevation as the exiting culvert, and thus not solve the sedimentation issue.

The installation of the riser pipes will have little to no impact on the surrounding wetland. Sediment laden runoff will be allowed to filter to the bottom of the ground surface on the upstream end of the culvert, while the top of the water surface will be skimmed and conveyed through the pipe and discharge at the top of the downstream riser. By this modification to the existing culvert, the upstream side will result in the area having similar properties to a sediment "forebay," since water will be required to pond in the location. This will also likely result in the establishment of wetlands upstream of the canal.

An existing parking lot located off PA Route 13, north of the culvert location, appears to no longer be utilized. The parking lot could be reclaimed and converted back to a vegetative state to serve as a stormwater BMP. By reclaiming this parking lot, it could increase the stormwater treatment area and serve as a stormwater detention area during high flow events.

Partners:

- Private landowners – easements and maintenance agreements will need to be prepared for the proposed improvements; authorization to remove existing parking lot
- Bucks County Conservation District – Review of proposed culvert modification.
- Bucks County Redevelopment Authority
- Bristol Borough

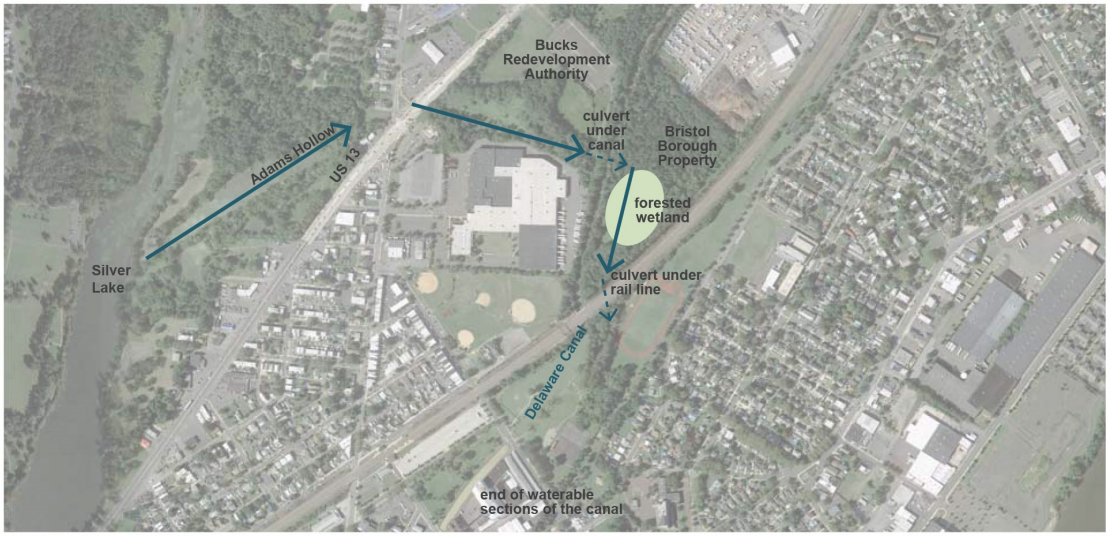
Conceptual BMP - Adams Hollow

Context - Existing Conditions

SIMONE LANDSCAPE ARCHITECTURE COLLINS

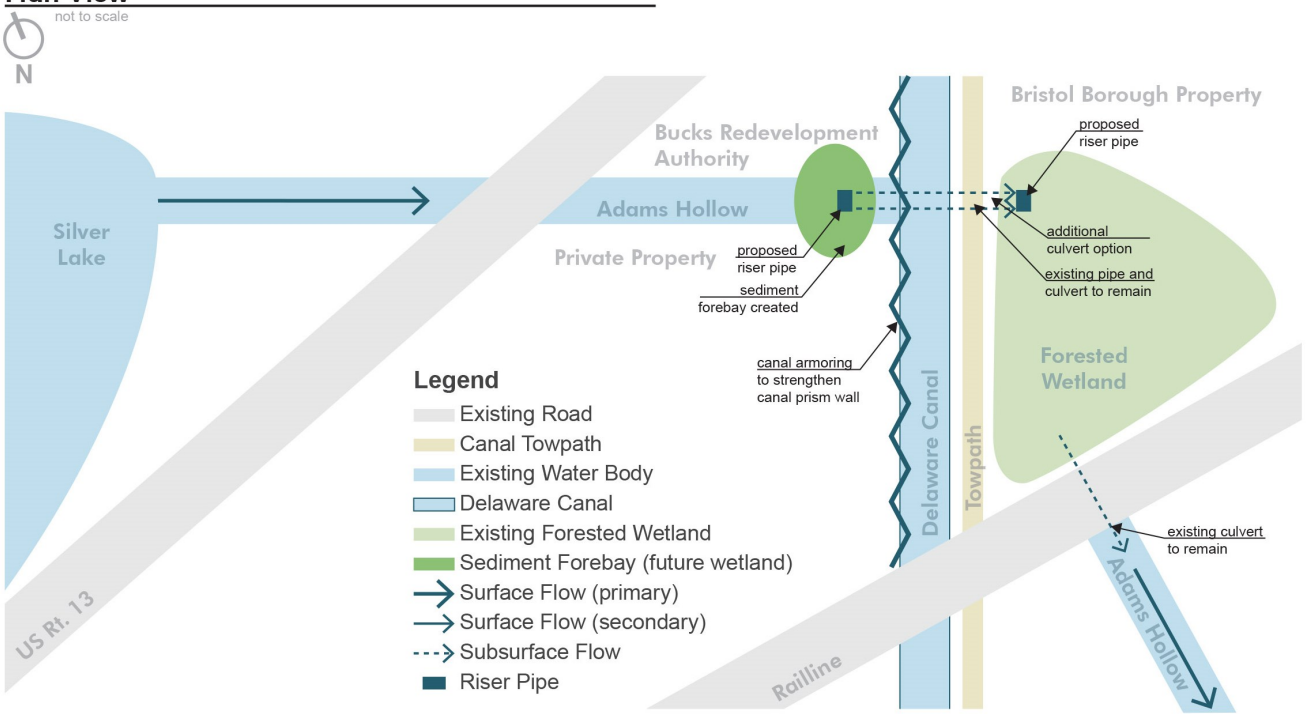
HanoverEngineering

date 08.04.2016

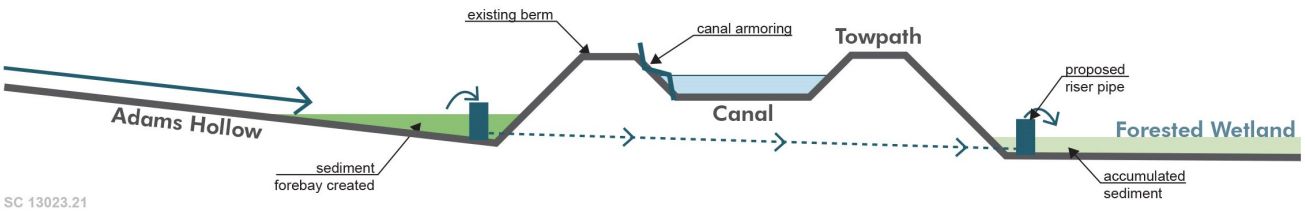


Plan View

not to scale



Section View



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Adams Hollow, continued

Adams Hollow as a Model BMP: The Adams Hollow concept acts as a model storm-water BMP by essentially constructing a sediment forebay, or settling basin. This concept can be applied to similar situations where culverts installed below the canal are prone to frequent sediment clogging due to shallow conditions and daylighting issues.

4. Recommendation Opportunities

BMPs recommended in this study begin to introduce innovative designs that can be duplicated as model concepts throughout the Delaware Canal corridor. Some of these opportunities have been discussed as part of the recommended conceptual BMPs. Others are general and apply to the canal as a whole.

Upper Watershed Management - Management in upper watershed areas is an imperative practice that has a trickle-down effect to the rest of the watershed. This management practice generally involves participation of private landowners in the implementation of conservation practices.

Interagency Cooperation - Much of the canal directly abuts PennDOT roads and right-of ways. Cooperation between DCNR and PennDOT has been limited in the past. Introducing stormwater BMPs presents opportunities to establish working agreements between agencies to solve stormwater problems. These solutions should have cost benefits to operations and maintenance procedures for both agencies.

Maintenance Agreements - The implementation of stormwater BMPs must come with maintenance agreements to guarantee the continued function of these systems. Maintenance agreements should be negotiated prior to constructing the BMPs.

DCNR Maintenance Plan - Currently DCNR lacks a formal maintenance plan that establishes a schedule and informs priorities. Such a maintenance plan would help ensure the effectiveness of newly implemented BMPs and influence staffing and budgeting.

Land Survey - The Delaware Canal lacks an official engineering survey that accurately locates structures and elevations. Much of the PennDOT roads that abut the canal also lack a survey. This presents an opportunity for an interagency cooperation between DCNR and PennDOT to complete a joint survey. This would establish a level of consistency between the two surveys that facilitate work on and near the canal.

Short and Long-Term Projects and Priorities - Many of the recommended BMPs of this study include short and long-term projects. Projects should be implemented on a timeline consistent with DCNR priorities, the availability of funding, and the beneficial impacts to the canal.

Combination of BMP Projects with other Enhancements - By combining Stormwater BMPs with public enhancement projects (i.e. public access and trails), alternative funding sources may be pursued. These projects may also appeal more to the general public and local municipalities.

5. Agency Outreach

5.1 Pennsylvania Department of Transportation (PennDOT)

The SC and HEA Team organized and met with PennDOT District 5 and District 6 officials. The meetings were intended to initiate conversations about the study, discuss BMP concepts, learn about current PennDOT projects and priorities, and determine possibilities for future involvement of the agency. A summary of the key points is discussed below:

- Little to no stormwater plans exist along PA Route 611 and PA Route 32.
- Maintenance is a serious concern. There are some options for interagency cooperation and agreements.
- PennDOT is more involved in multi-modal transportation projects, such as sidewalks and trail connections.
- BMP concepts could be added to the 2018 Transportation Improvements Plan (TIP) at the earliest.
- There is currently a Cultural Resources Study underway that includes both Districts 5 and 6
- District 6 owns and maintains stormwater infrastructure under PennDOT roads.
- District 5 does not own stormwater infrastructure under PennDOT roads.

5.2 Bucks and Northampton County Conservation Districts

The SC and HEA Team organized a joint meeting between the Bucks County Conservation District (BCCD) and the Northampton County Conservation District (NCCD). The meeting was intended to initiate the conservation about the study, discuss and receive feedback on the BMP concepts, and determine additional involvement from the Conservation Districts moving forward. A summary of the key points is discussed below:

- Plans for sediment control of agricultural activities is protected by law.
- Upper watershed management of erosion in creeks is difficult to address. It is better to address the problem downstream at the problem area.
- Forested wetlands are generally off limits. Other options should be examined.

5.3 Pennsylvania Department of Conservation and Natural Resources

A 2015 Delaware Canal Plan was prepared by DCNR to establish department project priorities for the state park. These projects have been identified separately from this stormwater study. Two of the seven concept BMPs discussed in this stormwater study report are mentioned in the 2015 DCNR Plan.

Dredging under the Paunacussing Creek aqueduct and dredging the Adams Hollow culvert are both ongoing maintenance operations conducted regularly by DCNR. Other projects mentioned in the 2015 DCNR Plan that relate to stormwater involve the repair of culverts and a reclamation project for a portion of the canal that has since been filled in.

Separate from the 2015 DCNR Plan, DCNR has assembled a list of 40 sites that have stormwater concerns. These sites were discussed earlier in this report and have been narrowed down to six of the seven pilot sites described in this report.

5.4 Bucks County and Lehigh Valley Act 167 Plan Review

For the purpose of this study, the Delaware River North and Delaware River South and Fry's Creek Act 167 Stormwater Management Plans were utilized since the sites are located within these watersheds. The Act 167 Plans were developed by the Lehigh Valley Planning Commission (LVPC) and Bucks County Planning Commission (BCPC) to control stormwater runoff on a watershed basis. Implementation and enforcement of the plans regarding future developments will prevent new drainage problems from occurring. Proper stormwater management reduces the potential for flooding, soil and stream bank erosion, and sedimentation. It will also improve the overall health of the receiving streams, and thus the canal. The Act 167 stormwater management were referred to as a basis for the individual site analysis and stormwater computations.

6. Delaware Canal as a Stormwater Management Facility

6.1 The Canal as a Stormwater BMP

The Pilot Project BMPs discussed in this report seek to mitigate stormwater impacts that affect the Delaware Canal. None of these concepts explore the potential of using the canal itself as a stormwater management facility. Given the storage capacity and linear length of the canal, this option needs to be explored.

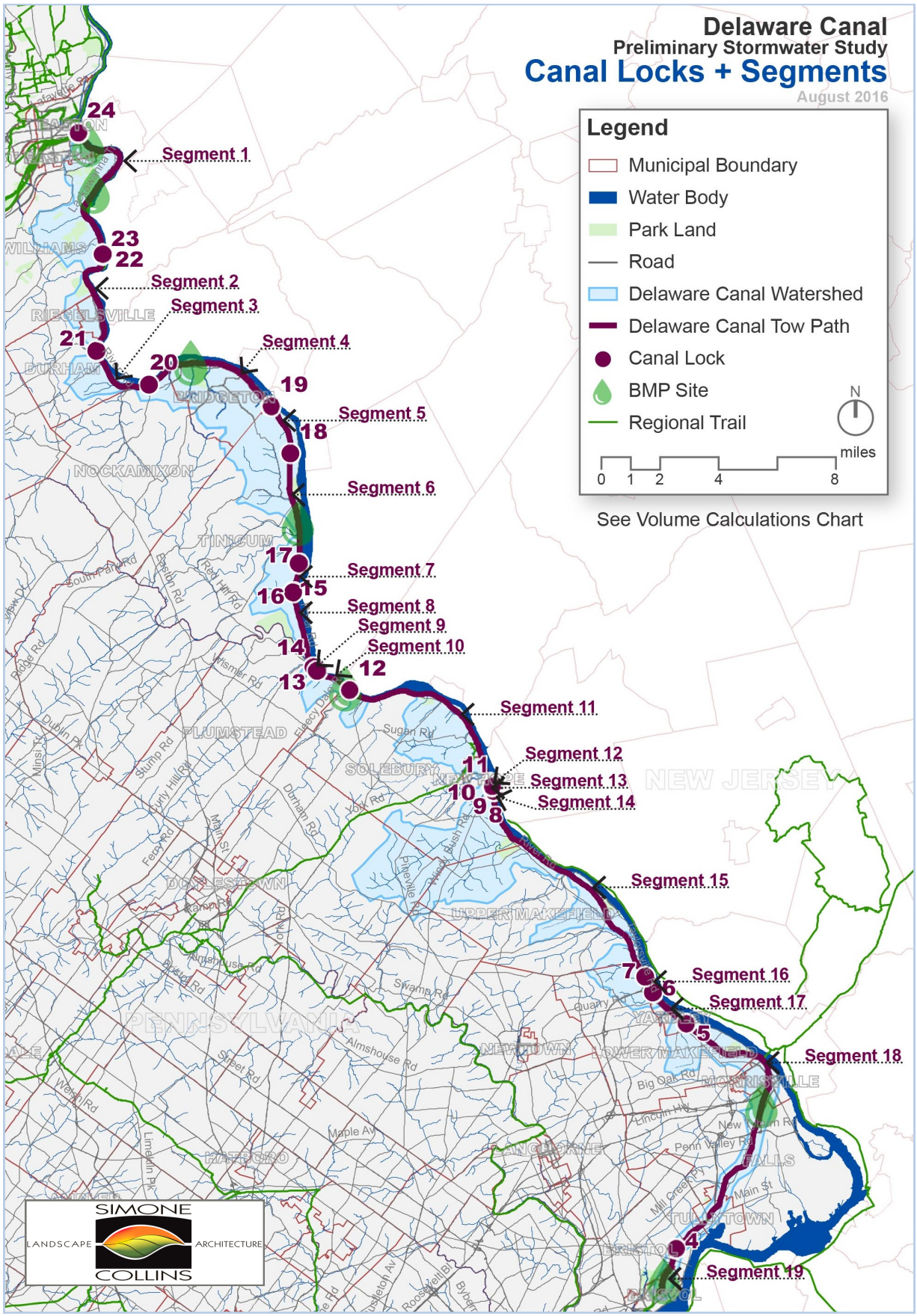
Theoretically, the canal prism might function as a flood mitigation in the form of a detention facility. Preliminary calculations using historic dimensions and measurements from DCNR were calculated as a baseline for further assessing the canal as a stormwater management facility (see below). These estimates are gross calculations based on average canal dimensions. Further study is required, based on the need for additional topographic survey and information to accurately access the canal's storage capacity. The canal was not designed and is not operated as a flood control device. Any additional capacity calculation should be based on the difference between normal pool level and flood stage levels.

Delaware Canal Preliminary Stormwater Study

Canal Volume Calculations

Segment*		Length watered		Volume to Full		Volume to Tow Path	
#	Description	Miles	Feet	Cubic Feet	Gallons	Cubic Feet	Gallons
1	Lock 24 to Lock 22, 23	5.79	30,571	6,236,525	46,655,442	9,049,075	67,696,132
2	Lock 22, 23 to Lock 21	3.88	20,486	4,179,226	31,264,787	6,063,974	45,364,592
3	Lock 21 to Lock 20	2.50	13,200	2,692,800	20,144,837	3,907,200	29,229,763
4	Lock 20 to Lock 19	5.00	26,400	5,385,600	40,289,674	7,814,400	58,459,526
5	Lock 19 to Lock 18	1.60	8,448	1,723,392	12,892,696	2,500,608	18,707,048
6	Lock 18 to Lock 17	3.80	20,064	4,093,056	30,620,152	5,938,944	44,429,240
7	Lock 17 to Lock 15, 16	1.00	5,280	1,077,120	8,057,935	1,562,880	11,691,905
8	Lock 15, 16 to Lock 14	2.69	14,203	2,897,453	21,675,844	4,204,147	31,451,225
9	Lock 14 to Lock 13	0.13	686	140,026	1,047,532	203,174	1,519,948
10	Lock 13 to Lock 12	1.36	7,181	1,464,883	10,958,791	2,125,517	15,900,991
11	Lock 12 to lock 11	6.78	35,798	7,302,874	54,632,797	10,596,326	79,271,118
12	Lock 11 to Lock 10	0.10	502	102,326	765,504	148,474	1,110,731
13	Lock 10 to Lock 9	0.10	502	102,326	765,504	148,474	1,110,731
14	Lock 9 to Lock 8	0.10	502	102,326	765,504	148,474	1,110,731
15	Lock 8 to Lock 7	8.62	45,514	9,284,774	69,459,397	13,472,026	100,784,224
16	Lock 7 to Lock 6	0.62	3,274	667,814	4,995,920	968,986	7,248,981
17	Lock 6 to Lock 5	1.57	8,290	1,691,078	12,650,958	2,453,722	18,356,291
18	Lock 5 to Lock 4	10.72	56,602	11,546,726	86,381,060	16,754,074	125,337,225
19	Lock 4 to Washington Street	1.76	9,293	1,895,731	14,181,965	2,750,669	20,577,753
	Totals	58.11	306,794	62,586,058	468,206,297	90,811,142	679,358,156

* Assumption: Segment 1 to Segment 14 determined using DCNR data acquired on 03-31-2016
* Assumption: Segment 15 to 19 determined using GIS information from DCNR


Delaware Canal
Preliminary Stormwater Study
Canal Locks + Segments
August 2016
Legend
Municipal Boundary
Water Body
Park Land
Road
Delaware Canal Watershed
Delaware Canal Tow Path
Canal Lock
BMP Site
Regional Trail
N
miles
0 1 2 4 8
See Volume Calculations Chart
Segment 1
Segment 2
Segment 3
Segment 4
Segment 5
Segment 6
Segment 7
Segment 8
Segment 9
Segment 10
Segment 11
Segment 12
Segment 13
Segment 14
Segment 15
Segment 16
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WILLIAMS
RIEGELSVILLE
BURHAM
NOCKAMIXON
TINICUM
PLUMSTEAD
SOLEBURY
NEW JERSEY
PENNSYLVANIA
NEWTOWN
FALLS
TULLYTOWN
BRISTOL
SIMONE
LANDSCAPE ARCHITECTURE
COLLINS

6.2 Canal Storage Calculations

The canal was assessed by segments that run from lock to lock. Each of these segments was calculated as a chamber with an estimated stormwater volume using historic canal prism dimensions provided by DCNR. Theoretically, the canal might function as a series of separate stormwater basins that step down in elevation from segment to segment to maximize the volume capacity of the canal. Preliminary storage calculations are shown on page 64. However, The canal was not designed and is not operated as a flood control device. Additional capacity calculations beyond this study should be based on the difference between normal pool level and flood stage levels.

6.3 Hydraulic Mechanisms that Controls the Flow

The flows of water in the Delaware Canal are regulated manually by DCNR staff through several types of historic structures, including waste gates, control gates, and previously lock gates / bypasses. Flows into the Delaware Canal are regulated by inlet gates at the City of Easton, Northampton County and New Hope Borough, Bucks County as well as periodic electric pumping from the Delaware River.

6.4 DCNR Protocols for managing Canal water during storm events

DCNR records of operational decisions do not exist for general waterway management or storm event waterway management. In the recent past, DCNR protocols included lowering the water level in the Delaware Canal in anticipation of river flooding. This was not historic protocol, and the lowered canal water level, actually exacerbated erosion of canal structures during the floods of 2004, 2005, and 2006.

Since that time DCNR, has modified its protocols to maintain canal water levels during river flooding events. This practice uses the water in the canal as a "buffer" to the erosive forces of river flooding. The volume of stormwater management capacity in a dry canal is a minimal benefit compared to the volumes of a flooding Delaware River.

6.5 Need for further engineering study

Somewhere, between 100-year river flooding and one-year storms to local watersheds, the Delaware Canal has the potential "freeboard" capacity to accept and detain a certain volume of additional water in each "chamber" between locks. To calculate the effectiveness of this concept, an engineering survey and assessment is needed to determine projected stormwater runoff from each watershed and capacities of each canal chamber to accept additional water volumes. Models will need to be run regarding options for DCNR operation of gates during storm events. This work is the subject of future study.

7. District Stormwater Management Opportunities

Across the nation, the number of communities that are managing stormwater using a "district" approach is growing. The City of Philadelphia is the closest example and a national model for municipal stormwater management.

The Philadelphia model treats stormwater as the responsibility of each individual property owner to manage stormwater on their own site – or pay for the City to manage stormwater as a public utility service.

The Delaware Canal traverses 18 municipalities. Creation of a single stormwater district for the entire Delaware Canal watershed would require considerable cooperation between those communities. To achieve such an option for the Delaware Canal would require "carrot and stick" incentives – as well as extensive negotiations. A multi-municipal stormwater district for the Delaware Canal may even require state legislation.

The increasing requirements of the MS4 municipal stormwater plans as mandated by the Clean Water Act, may be an important future catalyst for municipalities to cooperate with DCNR to create a mutually beneficial alliance where the Delaware Canal officially contributes to municipal compliance with stormwater regulations.

This option needs additional research in a subsequent phase of study.

8. Next Steps: Implementation and Further Study

8.1 Implementation of Pilot Project BMPs

Every BMP described in this report will need a local champion to advance each specific project. Perhaps the most significant and immediate opportunities to improve stormwater management for the Delaware Canal is to promote cooperative projects between PennDOT and DCNR.

The current historic resource survey of the Delaware Canal by PennDOT is an example of agency cooperation for inventory, assessment and planning.

Another area of potential cooperation is for the two agencies to jointly undertake an engineering survey of River Road and the Delaware Canal – beginning with the segments where the two corridors run adjacent.

A joint engineering survey could pick up data at potential BMP sites – specifically where raingardens and bioswales are possible in or directly adjacent to the PennDOT rights-of-way. These surveys will be invaluable for multiple uses by both agencies, beyond the value for planning and designing stormwater BMPs.

8.2 Facilitation

It is imperative that the catalyst partners who conceived and managed this preliminary stormwater study continue to negotiate partnerships that will advance its recommended BMPS and more broadly nurture a culture of proactive, integrative stormwater management planning by all agencies and potential Delaware Canal partners.

8.3 Potential Funding

Implementation of plans is always dependent upon available funding. Funding sources constantly change and sponsors continually modify the focus of their funding programs.

Several of the BMP projects identified in this preliminary stormwater study are multi-objective and multi-benefit as compared to single-purpose projects.

Integrated, comprehensive projects such as these have the potential to attract more support from the local public, partner agencies and funding partners. Multi-objective projects are typically of broader appeal to a variety of funders. Multi-objective projects also tend to be more complex, owing to: multiple funding sources, requirements of permitting agencies, etc. However, multi-objective projects have additional benefits as compared to single-purpose projects, generally have higher return on investment, benefits to more public sectors, etc.

Project partners should work together to anticipate and be ready to respond with specific projects when eligible funding may become available. This proactive approach will require advance negotiations with local partners so that the general terms of a project are supported by the partners in preparation for ultimate funding applications. This process will include many terms, with the most long-term preparedness being negotiated frameworks for future private easements.

Some potential funding sources for various stormwater BMP projects might include:

Five Star and Urban Waters Restoration Grant Program. A public-private partnership funded in part by the U.S. Environmental Protection Agency's Wetlands and Urban Waters Programs, the U.S. Forest Service, and the U.S. Fish and Wildlife Service in conjunction with the Urban Waters Federal Partnership. Available for the Greater Philadelphia Area and Delaware River Watershed (Pennsylvania, New Jersey, Delaware). Grant announcement usually in November.

Watershed Restoration and Protection Program (WRPP). Act 13 of 2012 established the Marcellus Legacy Fund and allocated funds to the Commonwealth Financing Authority for watershed restoration and protection projects. The overall goal of the Watershed Restoration and Protection Program is to restore and maintain restored stream reaches impaired by the uncontrolled discharge of nonpoint source polluted runoff, and ultimately to remove these streams from the Department of Environmental Protection's Impaired Waters list. Potential projects may involve the construction, improvement, expansion, repair, maintenance or rehabilitation of new or existing watershed protection BMPs. There is a maximum of $300,000 per project. A 15% match of the total project cost is required. Application deadline is June 30.

National Fish and Wildlife Foundation (NFWF)/ U.S. Environmental Protection Agency Technical Capacity Stormwater Management Grants Program. The National Fish and Wildlife Foundation, in partnership with the U.S. Environmental Protection Agency, is soliciting applications from approved NFWF Technical Assistance Providers to provide technical services on behalf of local governments, nonprofit organizations, and conservation districts for projects that enhance local capacity to more efficiently and effectively restore the habitats and water quality of the Chesapeake Bay and its tributaries. Application Period: August 30—September 29.

Pennsylvania Infrastructure Investment Authority (PENNVEST) provides construction and related funding for BMPs for the following categories:

- Urban Stormwater BMPs
- Agricultural BMPs
- Abandoned Mine Drainage BMPs
- Brownfields BMPs

Funding terms vary depending on the capacity of the applicant to handle debt service. For more information, visit www.pennvest.state.pa.us; call 717-783-6798, or DEP at phwenrich@pa.gov or 717-705-6345.

PA DEP Stormwater BMP Implementation Program Project. The Department of Environmental Protection is offering funding for implementation of urban stormwater BMPs. The maximum funding amount per applicant is $200,000 with no minimum funding amount. All costs must be incurred within two years. A single application may include funding for more than one BMP. Funding is intended for use by counties, cities, boroughs, townships, and municipal authorities. Other parties that wish to promote funding for a project are encouraged to approach the eligible local entity where the project would be located and offer to assist with the project application and project management.

PennDOT – Transportation Alternatives Programs Grants. These periodic grant rounds are for Federal Highway Administration funds that are administered through DVRPC and managed through PennDOT. Eligible activities include construction of transportation-related stormwater management improvements.

8.5 Areas for Further Study

1. Engineering survey of the Delaware Canal and River Road
2. Engineering assessment of the Delaware Canal stormwater management potential.

Its scenes of rural splendor
Are portrayed by artists' touch;
Its winter landscapes immortalized
By the mighty Redfield's brush.
It served mankind a century
But now its days are spent
We must preserve its beauty
And leave nothing to repent.
Oh, old canal, flow serenely on,
And may beauty grace your way,
Throughout the coming centuries,
As she does at the present day!

Catherine Curran Smith, 1931