



Willow Street Green Infrastructure Design

Reducing Combined Sewer Overflows with Green Infrastructure

About the Green Infrastructure Technical Assistance Program

Stormwater runoff is a major cause of water pollution in urban areas. When rain falls in undeveloped areas, soil and plants absorb and filter the water. When rain falls on our roofs, streets, and parking lots, however, the water cannot soak into the ground. In most urban areas, stormwater is drained through engineered collection systems and discharged into nearby water bodies. The stormwater carries trash, bacteria, heavy metals, and other pollutants from the urban landscape, polluting the receiving waters. Higher flows also can cause erosion and flooding in urban streams, damaging habitat, property, and infrastructure.

Green infrastructure uses vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, *green infrastructure* refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water. Green infrastructure can be a cost-effective approach for improving water quality and helping communities stretch their infrastructure investments further by providing multiple environmental, economic, and community benefits. This multi-benefit approach creates sustainable and resilient water infrastructure that supports and revitalizes urban communities.

The U.S. Environmental Protection Agency (EPA) encourages communities to use green infrastructure to help manage stormwater runoff, reduce sewer overflows, and improve water quality. EPA recognizes the value of working collaboratively with communities to support broader adoption of green infrastructure approaches. Technical assistance is a key component to accelerating the implementation of green infrastructure across the nation and aligns with EPA's commitment to provide community focused outreach and support in the President's *Priority Agenda Enhancing the Climate Resilience of America's Natural Resources*. Creating more resilient systems will become increasingly important in the face of climate change. As more intense weather events or dwindling water supplies stress the performance of the nation's water infrastructure, green infrastructure offers an approach to increase resiliency and adaptability.

For more information, visit <http://www.epa.gov/greeninfrastructure>.

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Cover Photo: Tetra Tech, Inc.

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I Executive Summary

Like many older cities along the northern Atlantic coast, the city of Bath, Maine relies on an aging combined sewer drainage system which exhibits areas subject to combined sewer overflows (CSOs) as a result of insufficient system capacity. Although the city has taken steps to alleviate this condition through the implementation of separate storm drainage systems and combined sewer improvements, some areas of the city are not suitable for these solutions due to existing infrastructure conflicts, space limitations, and inadequate topographic relief. One such area of the city is the Willow Street catchment area, a historical residential neighborhood dating to the 18th century and transected by a rail line. Although the City has upgraded the sewer system downstream of this area to improve overall system capacity, frequent nuisance flooding and CSOs continue to occur. As a result, this technical assistance project evaluated a range of design solutions focused on stormwater management and conveyance – including both green and conventional “gray” infrastructure practices – to mitigate the frequency and magnitude of CSO discharges and localized flooding.

To help evaluate the cost-effectiveness of the various infrastructure design scenarios, a Stormwater Management Model (SWMM) was developed for the Willow Street neighborhood. The design scenarios were developed from field investigations, input from city staff, and available information for the existing combined sewer infrastructure network (including GIS coverages and engineering plans). The primary design scenarios evaluated with SWMM included:

1. Centralized conventional infrastructure (both a surface and subsurface infiltration basin) at two locations in the neighborhood
2. Diversion of stormwater runoff from the combined sewer network via new storm drains
3. Distributed green infrastructure throughout the neighborhood using bioretention planter boxes within existing parking lanes

Based on a long-term simulation, the SWMM model results indicated that no single infrastructure scenario would eliminate CSO occurrences within the neighborhood. Although green infrastructure solutions can provide notable reductions in stormwater volume and CSO events within the Willow Street subcatchment, a combination of practices incorporating both green and conventional infrastructure are ultimately needed to reduce overflows to an acceptable frequency of occurrences. This project demonstrated how hybrid green-gray approaches to stormwater management can solve extreme flooding issues while providing a variety of ancillary benefits associated with green infrastructure.

2 Introduction

Bath, Maine is located near the central coast of Maine on the Kennebec River, approximately 12 miles north of where the river empties into the Atlantic Ocean. The city's culture has centered around maritime activity for hundreds of years, as it is known as the "City of Ships" and is home to one of the best known shipyards in the world (City of Bath 2014). Bath is currently home to approximately 8,500 residents (US Census 2010).

The City of Bath (City) has periodic problems with stormwater, specifically localized flooding and combined sewer overflows (CSO) from its municipal sewer system. The City hopes to alleviate the ongoing problems of flooding and CSOs by controlling the volume of stormwater flows with green infrastructure. Specifically, the City will develop a plan to incorporate water storage and treatment features, such as rain gardens, throughout the community. In addition to accomplishing these water quality goals, the City also hopes to improve the quality of life in the adjoining neighborhoods by adding natural, vegetative features and encouraging a garden-like appearance.

2.1 Water Quality Issues/Goals

The Kennebec River is listed as impaired for fecal coliform from CSOs and the Maine Department of Environmental Protection (DEP) has established a statewide total maximum daily load (TMDL) for bacteria.

The City of Bath has been under a consent decree with DEP since 1992 to address CSO discharges. The City has made significant progress but is struggling to eliminate the remaining four CSO outfalls. One outfall is located in a low-lying area near Willow Street where constrained infrastructure conditions in the upper portions of the drainage network preclude sewer separation. As a result, stormwater runoff is managed by a combined sanitary sewer system. During larger storm events, this leads to the system being overwhelmed, resulting in water backing up through sanitary manholes and creating flood conditions in the neighborhood (Figure 2-1).



Photo credit: Tetra Tech, Inc.

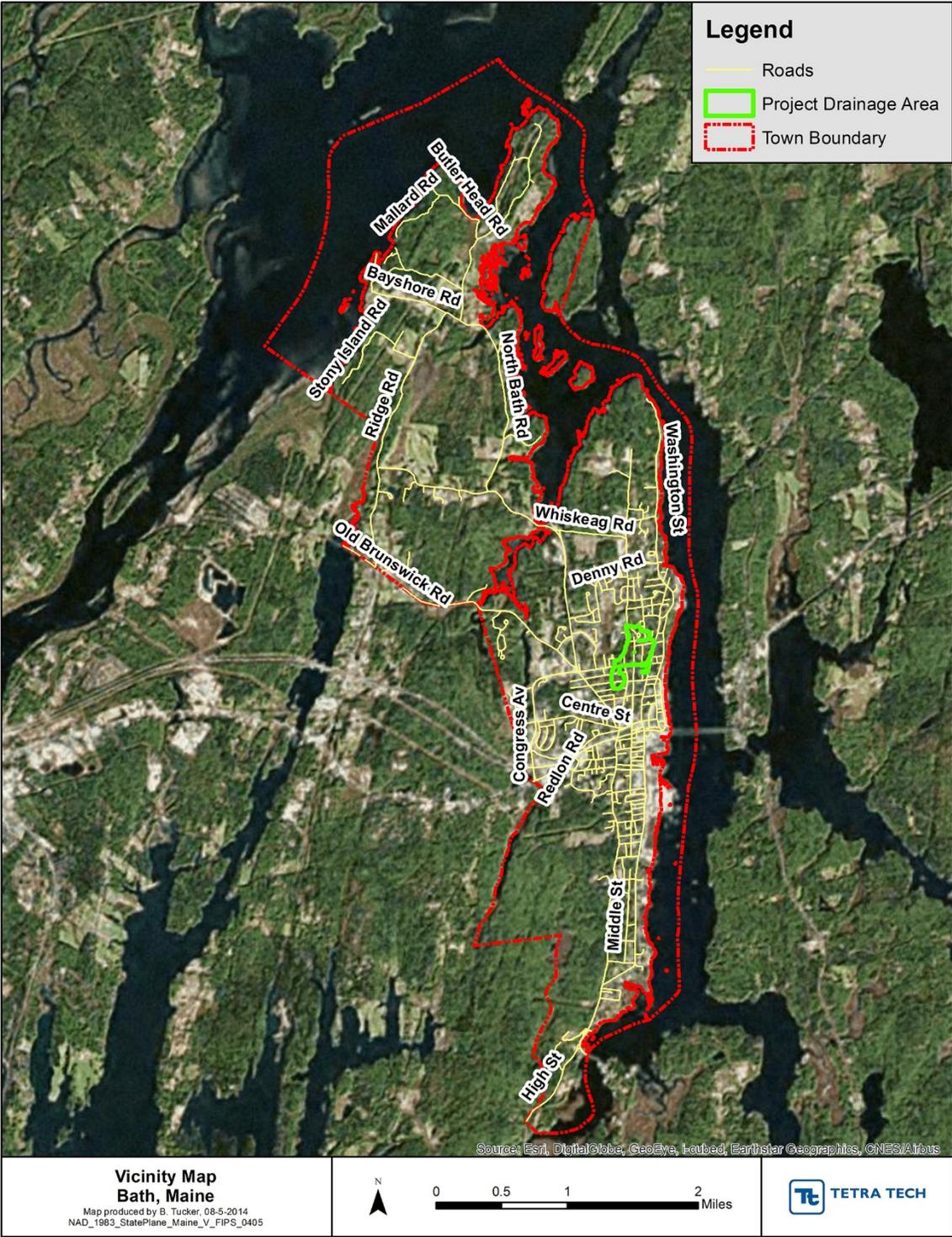
Figure 2-1. Low-lying areas experience frequent ponding of stormwater from upslope areas and occasional sanitary sewer overflows

2.2 Project Overview and Goals

Like many older cities, Bath is constrained by aging or inadequate infrastructure, as well as logistical conflicts, in attempting to identify potential solutions for issues such as CSOs. This combination of challenges is well-represented in the selected project.

The Willow Street neighborhood is primarily comprised of a small number of residential homes and lies adjacent to an operational railroad line and a Federally-recognized historic district. (See Figure 2-2 for an aerial view of Bath.) City officials note that there are an unusually high number of foreclosures in this neighborhood, adding economic distress. They also note that several homes on Willow Street have been abandoned, likely due to the flooding issues. Unfortunately, Willow Street is a topographic low point with no viable location for a gravity-fed discharge; the railroad line and topography limit the City’s ability to develop a separate storm sewer system. As a result, stormwater is routed into the sanitary sewer.

The City has upgraded the sewer system in the area downstream of North Street to reduce sanitary sewer overflow issues, but the upgrades could not fully resolve the issues associated with the addition of stormwater to the system in the headwaters of the drainage system. As a result, Willow Street remains a troublesome location during storm events.



Source: Tetra Tech, Inc.

Figure 2-2. Aerial view of Bath, including the Willow Street project area

The City envisions using green infrastructure as a way to mitigate these effects and reduce the volume of stormwater that reaches the sanitary system, as opposed to the use of conventional “gray” infrastructure (e.g., pipes and pump stations). City staff hope that green infrastructure can preclude the need for what they expect would be very costly conventional infrastructure solutions.

The project involves a number of steps to identify appropriate solutions, including:

- Review watershed conditions
- Identify drainage characteristics, pathways, and peak flows
- Develop a model of existing hydraulic conditions in the catchment
- Identify green and conventional infrastructure practices and locations

The project will also document these steps, develop a conceptual design for selected practices, and provide an estimated cost for construction.

The City also hopes to examine the potential of combining green infrastructure practices with conventional practices. The City recognizes that the project location has an unusual number of design constraints and it may therefore not be possible to resolve the flooding issues via green infrastructure alone. As a result, the project will also describe several conventional infrastructure practices.

2.3 Project Benefits

As noted above, the primary benefit of the Willow Street project will be a reduction in the number and frequency of CSO discharges and reduction of localized flooding. The City also envisions that green infrastructure will improve groundwater recharge, as well as add natural, vegetative spaces to the community. The project could also stabilize an economically troubled neighborhood by reducing private property losses. Additionally, this project could serve as a model for resolving similar issues across the New England region. City officials also anticipate incorporating the design principles into future redevelopment efforts in the City, such as transportation projects.

2.4 Local Challenges

The project location has substantial constraints, which may limit the options for green infrastructure practices. Certain practices may not be appropriate, or site conditions may limit the effectiveness of otherwise appropriate practices. Although green infrastructure can reduce the frequency of flooding and mitigate flood damage, green infrastructure practices are not solely intended to address severe flooding, suggesting that some conventional infrastructure may also be needed. The City also needs to develop a convincing approach in order to win over residents, the general public, and other city or local government staff.

3 Green Infrastructure Opportunity Analysis

On August 14, 2014, Tetra Tech met with the local community team and conducted a site visit of the Willow Street catchment area. The purpose of the meeting and site visit was to discuss local site conditions and identify potential opportunities for green and conventional infrastructure solutions to address the combined sewer overflows.

3.1 General Observations

The Willow Street catchment area refers to a 45.3 acre drainage sub-basin originating near Crescent Street and generally bounded by Washington Street to the east, High Street to the west, and North Street to the south. The catchment area is primarily residential, served by a network of residential streets exhibiting asphalt or granite raised curbs and asphalt sidewalks typically only on one side of the street. The catchment area is highly developed with minimal open space areas except for residential lawns. A railroad track transects the catchment area in the north-south direction (see Figure 3-1) and mostly parallels the main trunk of the combined sewer system in the lowest elevation portions of the catchment area. Previous research of historical documents by City staff revealed that the railroad was constructed after much of the catchment area was already developed and likely placed in the only undeveloped area available at the time, along the drainage corridor. At one time there was a small stream originating in the area most subject to frequent flooding to the north of North Street.

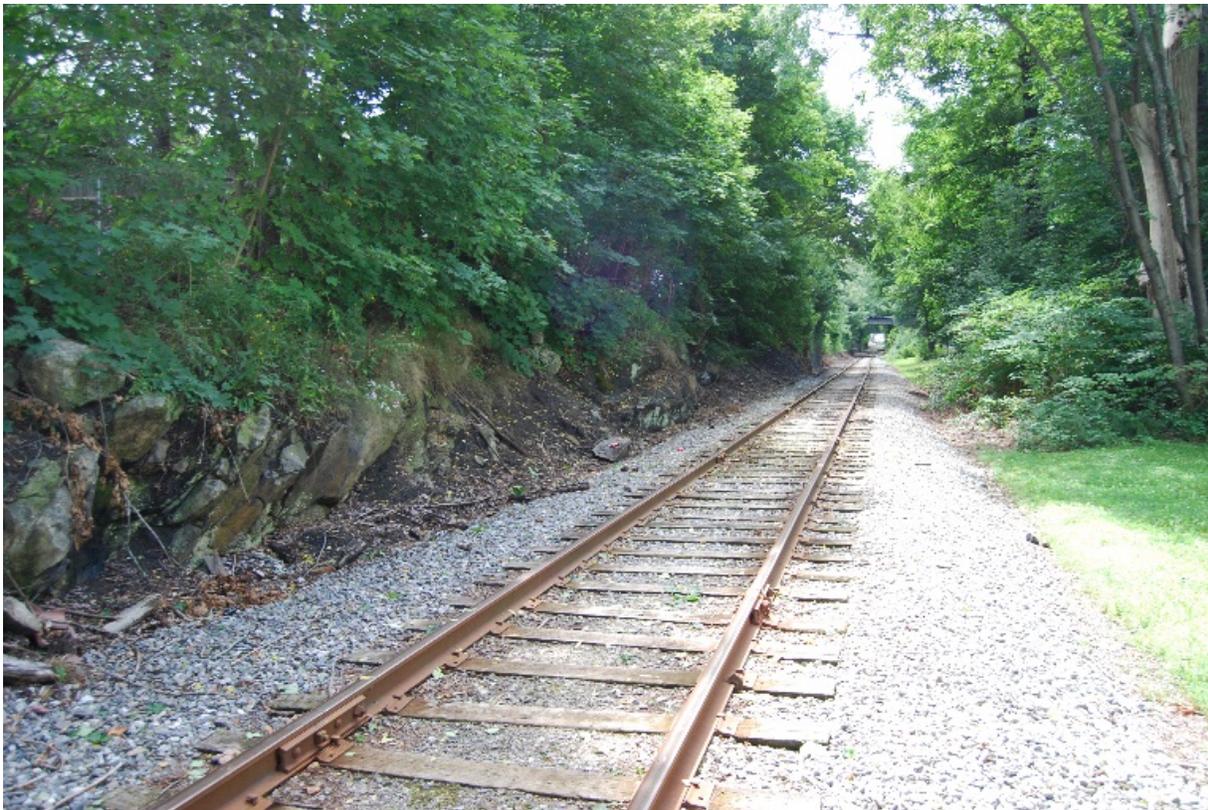


Photo credit: Tetra Tech, Inc.

Figure 3-1. Constrained conditions limit options for sewer separation in the project area

3.2 Opportunities for Conventional Infrastructure

As described above, an important element of this project is to examine the capabilities of green infrastructure as compared to conventional practices. This section of the report describes potential conventional infrastructure practices. In Section 4 below, these practices are further analyzed using the hydraulic model.

3.2.1 Infiltration

While available space for centralized stormwater infrastructure is limited within the project area, City staff identified two areas within the drainage area as potential sites for conventional infrastructure.

At the first location, the design could include installing a series of linear infiltration basins in the open space area between Crescent Avenue and the railroad track (Figure 3-2). The basins would be designed to receive both direct runoff from Crescent Avenue, as well as diverted runoff from the catch basins located on the south side of Crescent Avenue near York Street. The area is located within the Crescent Street right of way and is currently vegetated with small to medium trees. It appears that the area is not actively managed in any way. Construction of the infiltration basins would require removal of the vegetation and minor grading to provide storage within the basins. Ground cover within the basins can include either rip-rap/gravel, managed turf grass, or a native grass/meadow mix, as depicted by the photo examples in Figure 3-3 and Figure 3-4.



Photo credit: Tetra Tech, Inc.

Figure 3-2. Open space between Crescent Street and railroad (right) provides an opportunity for a surface infiltration bed



Photo credit: Chesapeake Stormwater Network

Figure 3-3. Riprap infiltration basin system



Photo credit: Tetra Tech, Inc.

Figure 3-4. Vegetated infiltration basin

At the second location, a possible design could include installing a subsurface infiltration gallery in two low elevation lots on the west side of Willow Street between the street and the railroad tracks (at approximately 22 Willow Street and 24 Willow Street; see Figure 3-5). Construction of a subsurface gallery would require acquisition of the parcels and demolition of any existing structures, but would preserve the area for potential green space amenities such as a public park. Overflow from the infiltration gallery would discharge to the combined sewer system.



Photo credit: Tetra Tech, Inc.

Figure 3-5. Two low elevation lots on Willow Street provide an opportunity for retrofit of an infiltration gallery

3.2.2 Stormwater Diversion

Previously, the City completed stormwater diversion projects for significant portions of the Willow Street catchment area downstream of North Street. This project involved the installation of a dedicated stormwater drainage system serving nearly all of the Willow Street drainage area downstream of North Street. During the site visit, City staff identified two additional areas with suitable conditions for diversion of stormwater to the new stormwater sewer system. These two areas consist of portions of Bedford and North Streets between High Street and Lincoln Street. Implementation of the stormwater diversion scenario would involve construction of a new stormwater drainage line under North Street from High Street to Willow Street and a new stormwater drainage line under Bedford Street originating at approximately 32 Bedford Street and terminating at High Street. Stormwater diversion would directly reduce hydrologic loading to the Willow Street combined sewer system.

3.2.3 Overview of Conventional Infrastructure

Figure 3-6 shows the location of both the potential infiltration areas (in yellow) and stormwater diversions (in blue), as well as the drainage areas associated with these designs.

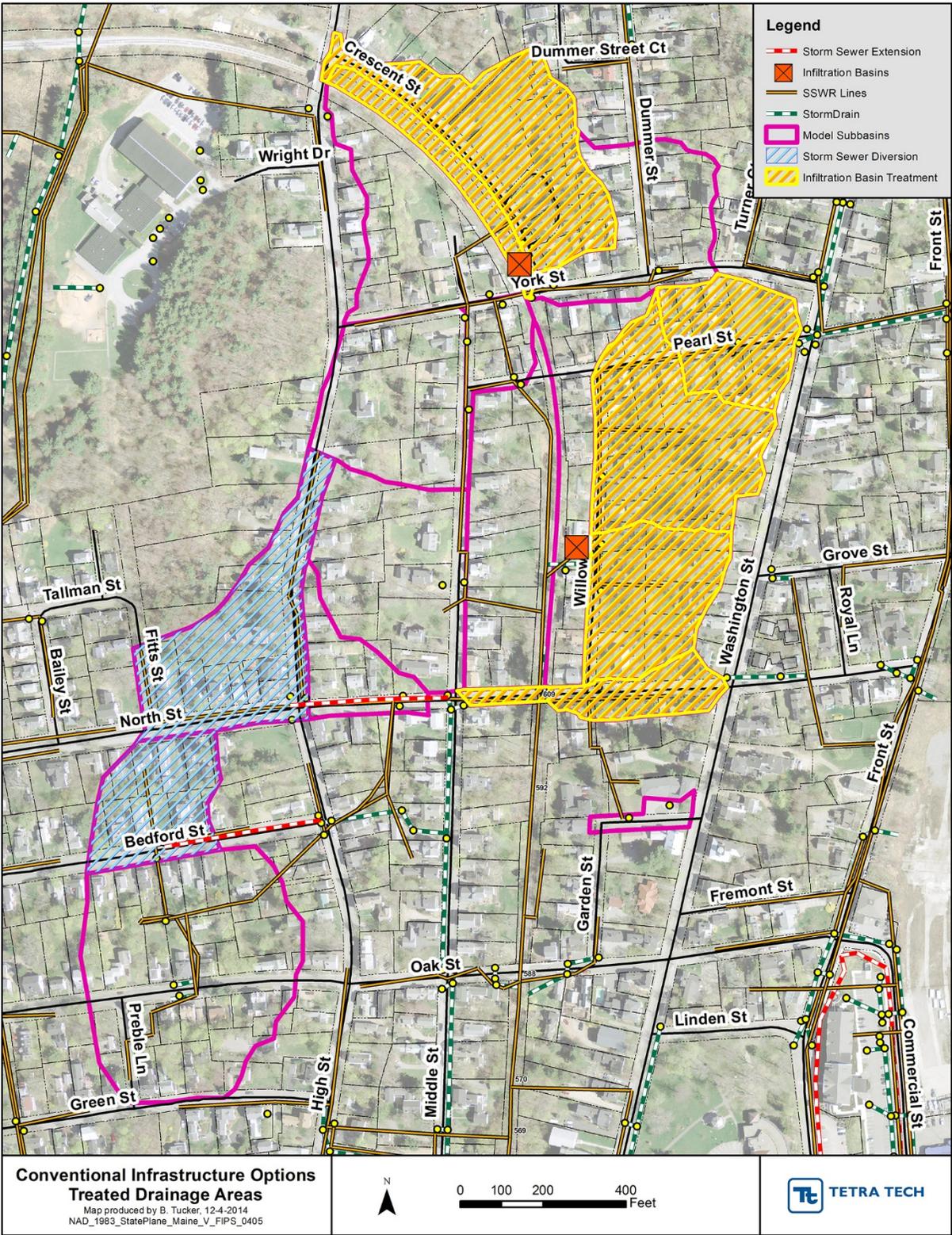


Photo credit: Tetra Tech, Inc.

Figure 3-6. Conventional infrastructure solutions identified within the Willow Street catchment area

3.3 Opportunities for Green Infrastructure

This section of the report describes potential green infrastructure practices.

3.3.1 Distributed Bioretention Planter Boxes

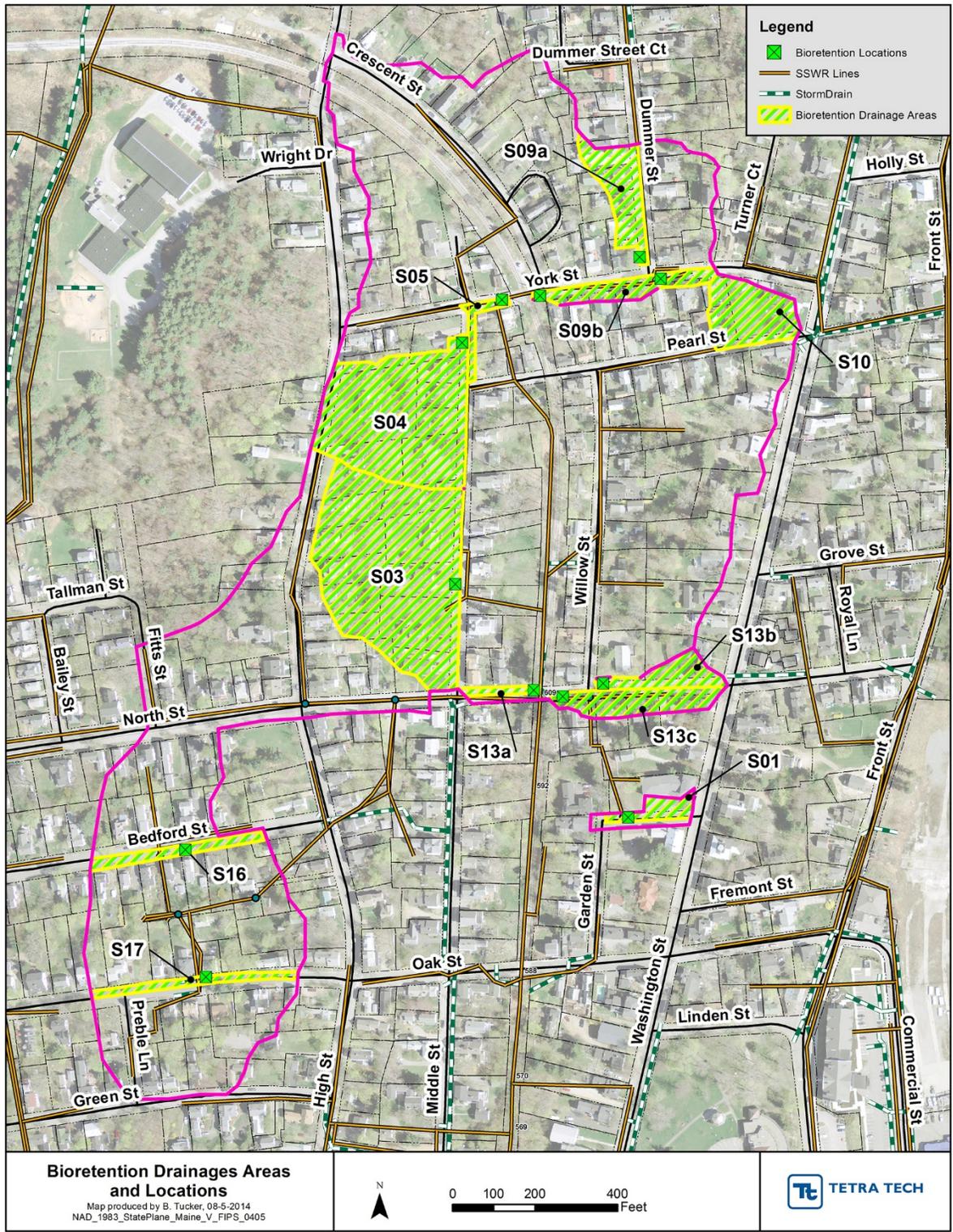
During the site visit, potential locations for retrofit bioretention planter boxes were identified within the project drainage area subcatchment for installation along the existing roadway curb edge. Installation of the planter boxes, sometimes referred to as bump-outs, would encroach into the roadway, reducing width. Feasible locations were determined by factors such as: roadway slope, proximity to existing manholes or catch basins, and avoidance of adjacent obstacles like telephone poles and driveway entrances (Figure 3-7).



Photo credit: Tetra Tech, Inc.

Figure 3-7. Retrofit opportunity for bioretention planter box

In many locations, both sides of the street were determined to be suitable for bioretention installations. However, roadway widths in this area are not sufficiently wide to allow encroachment on both sides of the roadway without impact to vehicular access. In such cases, the side of the street exhibiting the best characteristics for bioretention planter box implementation was selected. Twelve priority locations were identified as suitable locations for bioretention planter boxes within the Willow Street catchment area. These locations and their associated contributing drainage areas are provided in Figure 3-8.



Source: Tetra Tech, Inc.

Figure 3-8. Recommended bioretention planter box retrofit locations and their associated contributing areas

4 Design Approach

An important tool for evaluating and optimizing green infrastructure solutions for storm flooding and water quality challenges involves continuous hydro-simulation simulation models. Given the complexity of the combined sewer network within the Bath project area, the project team selected the Stormwater Management Model (SWMM; Rossman 2010) as the optimal tool for helping achieve the project goals.

4.1 Overview of SWMM

SWMM is a dynamic precipitation-runoff simulation model designed for discrete event or continuous representation of hydraulics, hydrology, and water quality. It is optimized and designed for storm event flow management in urban area drainage systems. First developed in 1971, SWMM has undergone numerous updates and enhancements. SWMM is currently maintained by USEPA and generically referred to as SWMM 5 (distinguishing it from SWMM 4 which is still in use, though not updated). The project used version 5.0.022 (released April 2011), which was the most current version available at the time.

Modeling was performed using PCSWMM, a commercial product developed by Computational Hydraulics International (<http://www.chiwater.com/>). PCSWMM implements the public-domain SWMM 5 computational engine, but provides an advanced user interface and tool set for building models and analyzing simulation results.

Precipitation and other meteorological input data are used to drive the hydrologic response in the simulation. SWMM 5 represents land areas as a series of subcatchments, with properties that define retention and runoff of precipitation, infiltration, and (optionally) percolation to a shallow aquifer and discharge from the aquifer. Subcatchments are connected to the drainage network, which may include natural watercourses, open channels, culverts and storm drainage pipes, storage and treatment units, outlets, diversions, and many other elements of an urban drainage system. Nodes and links are used in SWMM 5 to define the connectivity and control within the drainage network.

4.2 Existing Conditions Model

The existing conditions model (also referred to as a baseline model) represents current conditions within the study area, and includes the recent Willow Street/Railroad Track sewer and storm drain modifications as represented in the as-built drawings. Although PCSWMM is fully capable of modeling a highly articulated drainage network (including all surface and subsurface stormwater infrastructure within the subcatchment), a more simplified representation of the combined sewer and drainage network was utilized in the model, particularly within the headwater subcatchments located further from the sewer trunk main. This simplification was based on the lack of invert elevation data for the headwater combined sewer network, the inherent uncertainty of long-term simulation modeling, and strategy to focus modeling efforts on creating a higher-resolution simulation near the flooded areas of interest.

Simulation of hydrology in PCSWMM is largely driven by meteorological data, including rainfall and evapotranspiration (ET). The ability of a model to predict hydrologic response and pollutant generation, fate, and transport is strongly influenced by the accuracy and appropriate representation of

meteorological data. Meteorology data was developed from Phase 2 of the North American Land Data Assimilation System (NLDAS-2).¹

The meteorological data were obtained for the 1/8th degree grid cell corresponding to the location of the study area. A daily climate file was produced with minimum and maximum air temperature, potential daily evapotranspiration, and average daily wind speed. An hourly precipitation file was also produced. Both files spanned twenty years from July 1994 through June 2014. One adjustment was performed on the precipitation file; to more accurately represent the calibration storm event occurring on June 13, 2014, observed precipitation data were obtained from a monitoring station at Wiscasset Airport (WBAN 94623) located a few miles from the study area. The precipitation data were in a raw format with a variable time-step and numerous accumulated values, and could not be used directly for representing long term hourly precipitation. However, it was possible to interpret the file and obtain hourly precipitation values specifically for the June 13 event. Those values were inserted into the twenty-year SWMM 5 precipitation input file to better represent the calibration storm event.

The key model parameters for hydrology and hydraulics include subcatchments and drainage infrastructure (e.g., pipes, manholes, and catch basins). Each is described below.

4.2.1 Subcatchments

The analysis of subcatchments within SWMM 5 utilized the following assumptions and resources:

- Subcatchment area was calculated using geospatial datasets provided by the City (e.g., 2 ft topographic contours, combined sewer/storm drainage networks), field verification, and subcatchment delineations performed by a previous consultant.
- The majority of impervious surface area in the watershed is comprised of: secondary roadways, residential rooftops, and driveway/parking areas. Impervious area was calculated for each subcatchment using two geospatial datasets provided by the City -- a digitized building footprint layer and roadway centerlines. Since the buildings coverage did not include extraneous impervious areas like driveways, sidewalks, patios, outbuildings, etc., the modelers applied an adjustment factor based on an average of actual impervious measurements from several parcels.
- Roadway/sidewalk areas were calculated by creating a 15 ft buffer on both sides of the road centerline. Based on areal measurements, a 30 ft impervious right-of-way was observed as typical within the subcatchment.
- The Percent Routed parameter (a measure of impervious disconnection) was represented as the percentage of impervious area that discharges to pervious area. This parameter was based on the assumption that all impervious roadway runoff is routed directly to sewer drainage systems, and only a fraction of on-lot impervious area is routed to pervious area. Note that the final calibrated model, which used the 'percent routed' input value as a calibration parameter, assumed that only 20% of the on-lot impervious area within each subcatchment drains directly to pervious area. This is not unreasonable, since during large storm events, the infiltration capacity of pervious land may be quickly overwhelmed, and the impervious areas becomes effectively connected.

¹ <http://ldas.gsfc.nasa.gov/index.php>

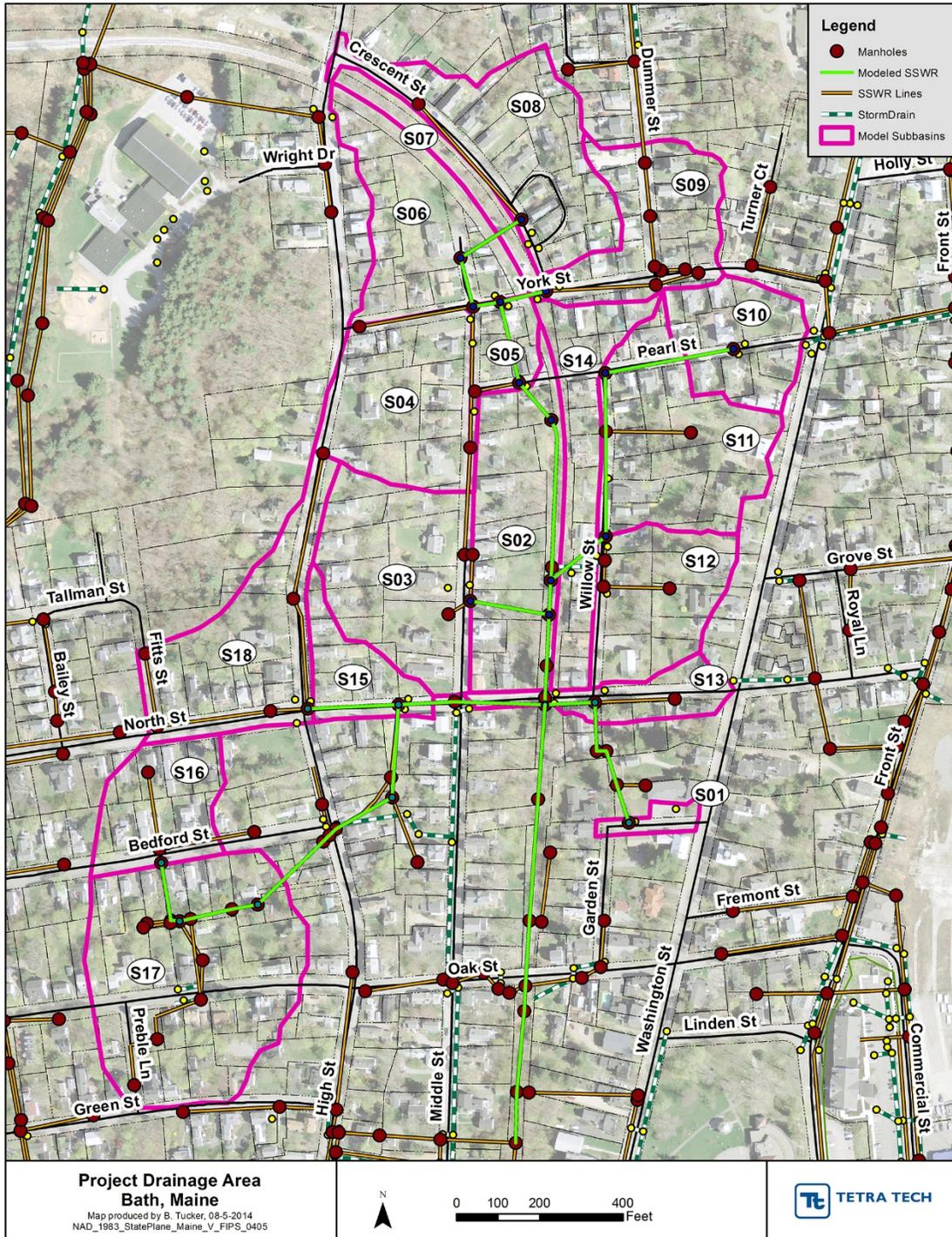
- Default Manning’s N values from EPA SWMM 5 User’s Manual (Rossman 2010) were used for overland flow. Impervious depression storage for all subcatchments was set to 0.05 inches, and the pervious depression storage was set to 0.15 inches.
- The Green-Ampt option was selected for surface infiltration. Parameters were set using guidance from Rossman (2010) and James et al. (2005). Soil properties were based on area-weighted USDA SSURGO data for each subcatchment. According to SSURGO, soils in a subcatchment vary between a silty loam with HSG C, and fine sandy loam with HSG D. Area-weighted values for suction head and initial moisture deficit were applied directly from SSURGO, while Infiltration Conductivity values were adjusted by a factor of 0.06 (final calibration value) since watershed modeling infiltration rates are much lower than those typically published for saturated hydraulic conductivity.
- Aquifer-groundwater modeling was not enabled due to the complexity of the parameterization, which typically requires continuously monitored streamflow for a meaningful calibration. Soil wetting and drying followed default SWMM 5 behavior.

Table 4-1 shows the final calculated (or calibrated) parameters for each subcatchment used in the existing conditions model. The subwatershed delineation for the existing conditions model is shown in Figure 4-1. As depicted, the model boundary condition was extended to just north of Winter Street to account for the tailwater conditions that occur in the sewer main along the railroad tracks.

Table 4-1. Subcatchment inputs to SWMM model

SWS ID	Subcatchment (ac)	% Impervious	% Routed ^a	Slope (%)	Soil Conductivity (in/hr)
S01	0.30	60%	2%	0.65	0.24
S02	3.58	29%	19%	0.6	0.19
S03	3.59	37%	15%	1.98	0.20
S04	3.06	43%	14%	1.48	0.24
S05	0.88	77%	11%	1.12	0.24
S06	3.11	33%	15%	2.3	0.24
S07	0.84	4%	0%	0.71	0.24
S08	3.55	53%	12%	1.69	0.18
S09	2.57	61%	13%	1.49	0.22
S10	1.88	71%	17%	0.52	0.24
S11	3.63	46%	15%	1.27	0.23
S12	2.38	36%	15%	1.41	0.24
S13	1.10	61%	7%	0.89	0.22
S14	2.33	49%	18%	1.18	0.12
S15	1.20	61%	15%	2.25	0.13
S16	1.87	52%	16%	0.85	0.08
S17	6.05	44%	16%	0.94	0.06
S18	3.38	53%	11%	1.38	0.16

^a Percent of impervious area that is directly routed to pervious area; used as the primary calibration parameter.



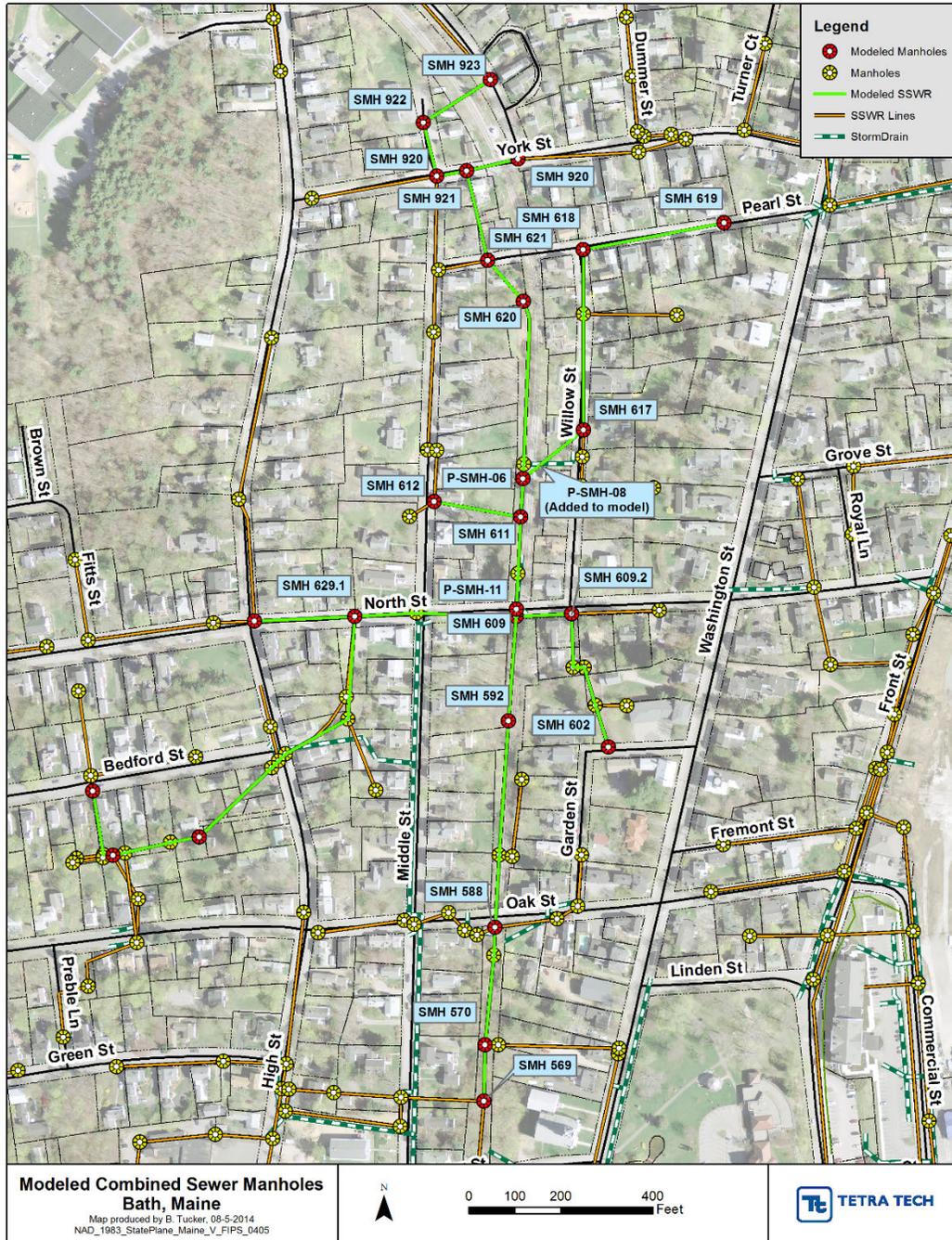
Source: Tetra Tech, Inc.

Figure 4-1. Subcatchment delineations for the existing conditions model

4.2.2 Drainage Infrastructure

Combined sewer and drainage infrastructure configurations were obtained from GIS layers, construction drawings for the recent sewer separation project on Willow Street, and surveyed elevations of manhole

inverts collected by City staff. The primary infrastructure information used in the model included manhole invert elevations, pipe length/material/size, and the new storm sewer diversion configurations. Figure 4-2 shows the manhole labels and combined sewer pipe that was included in the SWMM 5 model. Labels preceded by a "P" indicate new manholes installed as part of the Willow Street project that did not replace an existing manhole.



Source: Tetra Tech, Inc.

Figure 4-2. Combined sewer network modeled in SWMM

4.3 Model Calibration

A detailed, long term calibration of the Bath flood model was not feasible for several reasons. Foremost, flow monitoring data was not available from the City within the project sewer network. Second, recent modifications to the combined sewer network along Willow Street and the adjacent railroad track trunk line would have made any prior monitoring data inconsistent with the hydraulic response to the existing sewer configuration. Instead, the modelers performed a qualitative calibration based on an extreme flooding event from June 13, 2014, using observed locations where manholes were known to have flooded. According to City staff, manhole covers were lifted at three manholes south of North Street (MH's 592, 570, and 588), and three manholes north of North St. (P-SMH-06, P-SMH-07, and P-SMH-08). This level of calibration is considered acceptable given that the primary project goal is to compare the relative flood reduction impacts of various infrastructure options.

As previously indicated, the primary calibration parameters that were adjusted to simulate flood occurrences at the targeted manhole locations included 'percent routed' and 'soil conductivity.' The final parameter values used in the calibrated model are shown in Table 4-1.

Figure 4-3 shows a typical hydraulic profile from the June 13 calibration event. The profile includes the main sewer line between MH-620 (new junction south of Pearl St.) and the boundary condition manhole, MH-569, which was represented as the outfall in the model. Although the profile only includes a selection of the overall modeled network, it shows the flooded area of interest used for model calibration. The manholes in the visible profile that flooded during the calibration simulation are P-07, 588, and 570.

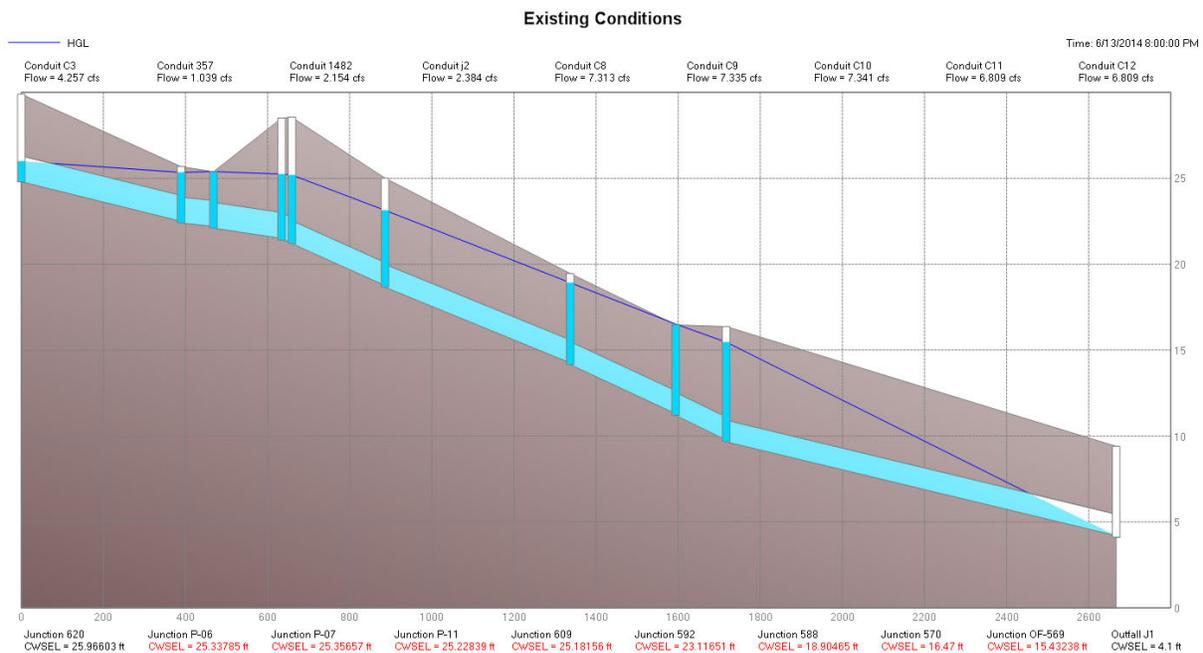


Figure 4-3. Hydraulic profile from June 13, 2014 calibration event between SMH 620 and SMH 569

Table 4-2 compares the full list of manholes that simulated flooding during the calibration event to the manholes with observed flooding (as reported by City staff). As shown, 4 of the 6 observed flooded manholes also simulated flooding, in addition to the next manhole below 570 (569). Two headwater

manholes (612 and 569), which had no reported flooding during the calibration event, also simulated flooding in the calibration (although likely as a result of reduced resolution in the sewer network within the headwater subcatchments).

Table 4-2. Observed and modeled flooded manholes

Manhole ID	Observed	Modeled
592	X	
570	X	X
588	X	X
612		X
6341		X
569		X
P-06	X	
P-07	X	X
P-08	X	X

The limited extent of observed data justified the narrow calibration time period, and these model results do not provide a comprehensive evaluation of drainage system response among the variation in storm timing/intensity/duration patterns that are exhibited across a range of events. However, the event-based simulation was useful for calibrating the system response to the recently observed flooding impacts and lifted manhole cover locations. For the calibration, the June 13 event was preceded by 20 days to more accurately represent antecedent moisture conditions.

4.4 Alternative Scenarios

To evaluate potential solutions for addressing flooding issues within the project area, the green and conventional infrastructure opportunities identified in Section 3 were developed into distinct model scenarios and simulated in SWMM 5. The intent was to evaluate the hydrologic and hydraulic impacts for each scenario separately so that each approach could be evaluated independently. The alternative scenarios evaluated include:²

Scenario 1A: Centralized Conventional Infrastructure

- Surface infiltration basins along Crescent Avenue (treats S07 and S08).
- Subsurface infiltration gallery along Willow Street (S10, S11, S12, and S13)

Scenario 1B: Modified Centralized Conventional Infrastructure Option

- Same as Scenario 1A, but includes:
 - A check valve between Manholes P-SMH-06 and P-SMH-08

² Unfortunately, due to resource constraints, this report was not able to quantitatively analyze combinations of the various scenarios. However, as stated above, it is possible that a hybrid of conventional and green infrastructure could be used at the project site.

Scenario 2: Stormwater Diversion

- New storm drains would divert runoff from S16 and S18 to existing, separate storm sewer on Middle Street

Scenario 3: Distributed Green Infrastructure

- Includes 12 bioretention planter boxes installed throughout the watershed with approximately 4,300 sf of treatment area.

4.4.1 Conventional Infrastructure Scenarios

Scenario 1A (Centralized Conventional Infrastructure)

This scenario incorporates both of the centralized infiltration basins identified as opportunities during field investigations. As a starting basis for design, water quality volumes for the 1 inch rainfall events were calculated (using the Simple Method) for both sites and used to develop reasonable footprint and storage depth targets.

Based on the calculated water quality volume, infiltration basins along Crescent Street with a 12 inch ponding depth would require approximately 7,050 sf of area, which can conservatively fit into the available open space area between the railroad and the street when accounting for side slopes and setback requirements. In the case of the subsurface infiltration gallery at Willow Street, stormwater that currently enters the new storm drain system at SMH 617 from subcatchments S10 through S13 would be diverted to the infiltration gallery, which could statically store almost 230,000 gallons below the outlet invert. Overflow from the infiltration basin would discharge back to existing manhole P-SMH-08. Practice dimensions and SWMM input parameters are provided for these two opportunities in Table 4-3.

Table 4-3 Infiltration practice input parameters

Infiltration Practice Location	Max. Surface Area (sf)	Storage Depth (ft)	Weir Length (ft)	Weir Height (ft)	Orifice Dia. (in)	Soil Conductivity (in/hr)
Crescent Ave.	7,980	1	12	0.12	N/A	0.12
Willow St.	10,200	3	N/A	N/A	15	0.24

Scenario 1B (Modified Centralized Conventional Infrastructure Option)

This scenario involves the low-cost option of installing a check valve or flap gate in the new Willow Street connection and was simulated to evaluate the impact on hydraulics in the flooded area of interest. The check valve would be installed below P-SMH-08. This scenario would prevent backflow in the main sewer trunk line from flooding the manholes east of P-SMH-6. This scenario was identified during model simulation as an enhancement of the original scenario configuration.

Scenario 2 (Stormwater Diversion)

This is also a conventional infrastructure option that would involve installing new storm sewer to divert runoff from subcatchments S16 and S18 to the existing storm drainage network on Middle Street. For the SWMM 5 simulation, these two subcatchments (and their connecting sanitary sewer network) was removed from the existing conditions (calibration) model and re-simulated.

4.4.2 Green Infrastructure Scenario

Scenario 3 (Distributed Green Infrastructure)

For the purposes of conceptual modeling, all bioretention cells were assumed to have internal widths of 5 feet, ponding depths of 6 inches, and variable lengths based on site constraints. Table 4-4 shows both the conceptual BMP area for each identified bioretention cell, as well as the percentage of water quality volume that can be instantaneously stored from its respective subcatchment. More detailed input parameters used to model bioretention cells within SWMM's LID Controls function are displayed in Table 4-5. As is common with many green street retrofits, existing road/utility configurations and other site constraints prevent roadside linear bioretention cells from being adequately sized to treat the entire water quality volume; this design will also not provide enough capacity for significant mitigation of peak runoff flows which may limit its potential for reducing CSO frequency.

Table 4-4. Bioretention planter box assumptions

BMP ID	Unit Length (ft)	BMP Area (sf)	Subcatchment (ac)	% WQ Treated
S01	85	425	0.20	64%
S03	100	500	3.40	8%
S04	100	500	2.40	11%
S05	80	400	0.12	58%
S09a	50	250	0.56	9%
S09b	80	400	0.41	32%
S10	75	375	0.69	17%
S13a	30	150	0.08	38%
S13b	60	300	0.35	33%
S13c	80	400	0.53	21%
S16	70	350	0.24	21%
S17	45	225	0.21	15%

Table 4-5. SWMM LID Control parameters for bioretention cells

Input Parameter		Value
Surface	Surface storage (in)	6
	Vegetation volume (fraction)	0.2
	Surface roughness (n)	0.25
	Surface slope (%)	2.2
Soil	Soil thickness (in)	18
	Porosity (vol. fraction)	0.437
	Field capacity (vol. fraction)	0.105
	Wilting point (vol. fraction)	0.047
	Conductivity (in/hr)	1.18
	Conductivity slope	7
	Suction head (in)	2.4
Storage	Storage depth (in)	12
	Void ratio (voids/solids)	0.54
	Conductivity (in/hr)	0.2
	Clogging factor	0
Underdrain	Drain coefficient (in/hr)	5
	Drain exponent	1
	Drain offset height (in)	0

4.5 Modeling Results

Table 4-6 shows a summary of the modeling results from the June 13 event simulation. The results indicate that response of the infiltration basin scenario without backflow prevention (Scenario 1A) significantly mitigates flooding duration and volume for the event relative to the other modelled scenarios.

Table 4-6. Surcharging and flooding results for calibration event

Model Scenario	Surcharge		Flooding		
	# MH's	Total Hrs.	# MH's	Total Hrs.	Total Vol. (cf)
Existing Conditions	11	29.4	6	4.7	35,830
Scenario 1A (Conventional)	11	32.7	5	2.2	1,200
Scenario 1B (Modified Conventional)	9	19.9	5	4.2	18,315
Scenario 2 (Diversion)	11	24.2	5	4.1	24,600
Scenario 3 (Green Infrastructure)	11	28.9	5	4.7	35,560

4.5.1 Long-term Simulation

To better evaluate the system's response across a range of storm events, a 20-year simulation period (7/1/1994 – 6/30/2014) was performed for each scenario. Table 4-7 shows the overall flooding duration and overflow volumes and Table 4-8 shows the number of individual flooding events over the 20-year simulation period. The historic rainfall record also predicts significant flood reductions from the centralized infiltration basin scenarios. Collectively, the two infiltration basins were sized to provide over 7000 c.f. of runoff storage. The green infrastructure scenario (Scenario 3), which only provides approximately 2,140 c.f. of surface storage, yields little impact in reducing flood occurrences.

Table 4-7. Surcharging and flooding results for 20-year simulation

Model Scenario	Flooding				
	# MH's	Total Hrs.	(%) Reduction Hrs.	Total Vol. (gal 10 ⁶)	(%) Reduction Vol.
Existing Conditions	12	263	--	11.1	--
Scenario 1A (Conventional)	12	84	68	3.5	69
Scenario 1B (Modified Conventional)	12	138	47	4.8	57
Scenario 2 (Diversion)	11	158	40	6.6	40
Scenario 3 (Green Infrastructure)	12	246	6	10.6	4

To provide a more relevant analysis with regards to regulatory reporting requirements of combined sewer overflow occurrences, the number of discrete flooding events was calculated for two manholes. The two selected manholes – SMH 570 and P-SMH-08 – were the most frequently flooded manholes based on both the calibration simulation and the long-term continuous simulation. According to Table 4-8, which shows the number of discrete flooding events at these two manholes by model scenario, the centralized infiltration basins (Scenario 1A) indicate a significant reduction in flooding frequencies.

Table 4-8. Total number of flooding events

Scenario	Parameter	Modelled Combined Sewer Overflows	
		Total (20-yrs)	Annual Average
Existing	# events	107	5.4
	% reduction	--	--
Scenario 1A	# events	38	1.9
	% reduction	65%	
Scenario 1B	# events	44	2.2
	% reduction	59%	
Scenario 2	# events	60	3.0
	% reduction	44%	
Scenario 3	# events	97	4.9
	% reduction	9%	

Green infrastructure BMPs, especially those implemented under retrofit scenarios, are not typically optimal for peak flood control compared to centralized detention facilities. As a result, the modeling results were also evaluated for the impacts on long-term hydrology within the subcatchment. Table 4-9 shows the total annual external outflow from the modeled sewer network, as predicted for each scenario. As shown, the conventional infrastructure scenarios yield significantly greater annual volume reductions as compared to the other scenarios.

Table 4-9. Long-term annual outflow comparison

Scenario	Total Outflow (ac-ft)	% Reduction (vol)
Existing	1136	n/a
Scenario 1A	806	29%
Scenario 1B	804	29%
Scenario 2	974	14%
Scenario 3	1075	5%

5 Conceptual Design

As described in Section 4, each of the scenarios evaluated as part of the modelling analysis showed a reduction in CSO frequency within the known problem areas. Green infrastructure can provide a marked reduction in stormwater flows, flooding and CSO events. This section describes a conceptual design for these measures.

To help visualize the potential green infrastructure scenario for community consideration, a conceptual design was developed for the implementation of the twelve distributed bioretention areas throughout the Willow Street catchment area. The conceptual design includes a rendering of a potential bioretention installation on Bedford Street, as seen in Figure 5-1. A complete conceptual design is provided in Appendix A.



Source: Tetra Tech, Inc.

Figure 5-1. View of Willow Street (top) and an artist's rendering of the greenstreet design (bottom)

5.1 Stormwater Management Calculations

In order to develop a properly sized conceptual design, calculations (or detailed assumptions) are required. For this project, the hydraulic modeling effort described in Section 4 of this report provided all of the necessary input values for designing the conventional and green infrastructure practices that were analyzed. As a result, these calculations will not be described again here.

5.2 Cost Estimates

In order to provide a basis for cost-effectiveness of the various solutions identified for the Willow Street catchment area, planning level implementation cost estimates were developed for each of the modelled scenarios. For the centralized infiltration and distributed bioretention practices contained in scenario's 1A, 1B, and 3, costs were derived using unit cost values reported by King and Hagen (2011) who estimate cost on a per acre treated basis. Costs for Scenario 2 (stormwater diversion) were estimated using bid summary results provided by City staff from similar work recently completed in the City.

Since the 12 distributed bioretention systems were all undersized relative their typical design criteria, their reported contributing areas are not appropriate for use in determining unit costs. To address this issue, the actual contributing area for each bioretention practice were adjusted relative to the percent of the 1 inch runoff volume each practice captured and treated. This adjustment normalized the drainage area to a more appropriate unit cost basis. A drainage area adjustment was not necessary for the infiltration practices, as they were sized generally according to standard sizing criteria.

A summary of implementation costs for these Scenarios is provided in Table 5-1 and detailed planning level costs for each scenario are provided in Appendix B.

Table 5-1. Summary of planning level implementation costs

Scenario	Implementation Costs
Scenario 1A Centralized Infiltration w/o check valve	\$145,531
Scenario 1B Centralized Infiltration with check valve	\$149,531
Scenario 2 Stormwater Separation	\$164,032
Scenario 3 Distributed Bioretention	\$138,110

6 Conclusion

The project team sought to explore the use of green infrastructure as a way to reduce stormwater flows causing nuisance flooding and frequent combined sewer overflows in the historic Willow Street Catchment area. The project team identified roadside bioretention areas as the most suitable green infrastructure practice for the neighborhood and identified numerous locations throughout the catchment area where these practices could be integrated into the community with minimal impact on existing infrastructure and other community needs. However, older established neighborhoods such as Willow Street often exhibit limited opportunities to retrofit green infrastructure practices.

To supplement the proposed bioretention measures, the project team identified potential options for conventional stormwater diversion and centralized hybrid green-gray approaches to stormwater management, including underground infiltration and surface infiltration swales. Long-term simulation using a hydraulic stormwater model of the catchment area revealed that each of the identified solutions, both green and grey, would individually reduce the frequency but not eliminate CSOs. To optimize a reduction in flooding and CSOs in the Willow Street catchment area, the city of Bath may consider a combination of practices which incorporate both green and conventional infrastructure.

7 References

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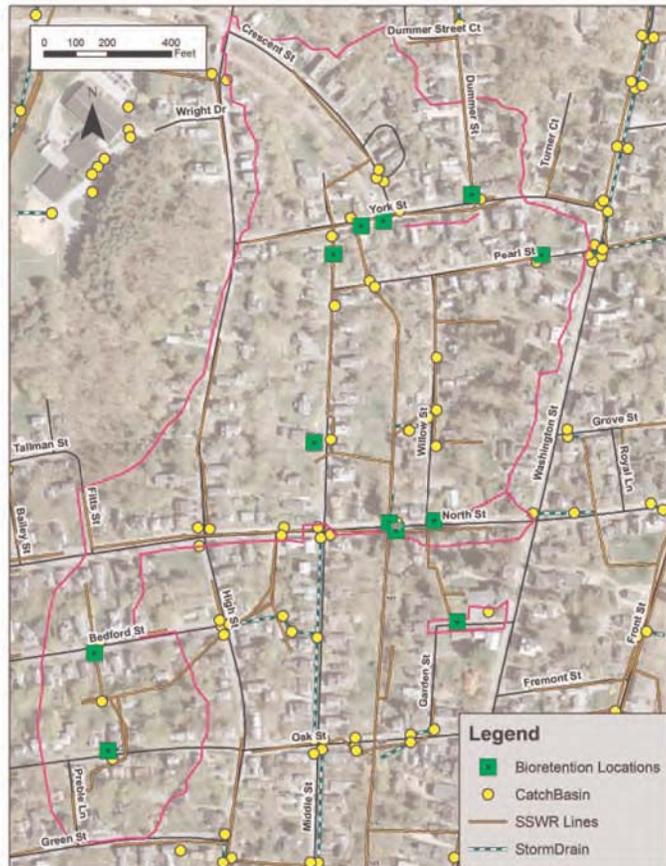
Appendix A: Willow Street Greenstreet Concept Design

Site Location				Drainage Area Characteristics		Proposed Characteristics*	
Date of Field Visit	8/14/2014	Latitude	43° 55' 12" N	Drainage Area, acres	45.3	Proposed BMPs	BR
Field Visit Personnel	J. Smith	Longitude	69° 48' 57" W	Hydrologic Soil Group	D, Urban	Treated drainage area, acres	9.0
Major Watershed	Kennebec River	Landowner	Multiple private and City owned ROW	Total Impervious, %	32	Bioretention Area, ft ²	4,276
Catchment Area	Willow Street Catchment Area			Design Storm Event, in	1.0	Estimated Cost	\$138,110

Existing Site Description: The proposed project site includes the Willow Street catchment area. The area is a residential neighborhood dating to the early 1800's with a conventional street network served by a combined sewer drainage system. Roadway drainage is routed via curb and gutter into a slotted drain catch basins located at various locations throughout the watershed.

Proposed Green Infrastructure Description: Twelve locations were identified for the implementation of bioretention planter boxes within the existing roadway. Retrofit locations were identified based on existence of curb edge catch basins, local topography and relative absence of conflicts such as utilities, trees, and adjacent structural elements.

BR = Bioretention.
 *Green Infrastructure characteristics are based on field observations and GIS data resources available at the time of conceptual design analysis. Note that final design characteristics will be dependent on a detailed site survey and could vary slightly from conceptual design characteristics.



Proposed Bioretention Locations



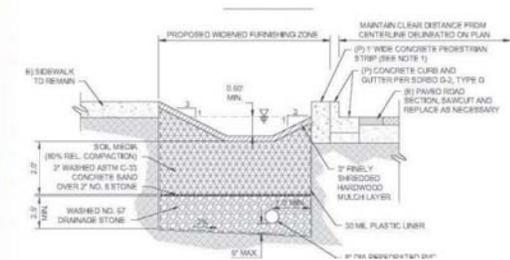
Current Street View



Conceptual Bioretention Rendering



Bioretention Planter Schematic



Typical Cross-section



Appendix B: Willow Street Greenstreet Concept Cost Estimates

The following tables contain the detailed cost estimates for the information presented in Section 5.

Table 1. Cost estimate for Scenario 1 (Centralized Infiltration Systems)

Item No.	Description	Reference	Quantity	Unit	Unit Cost	Total
Pre-construction						
1	Survey, design, permitting, etc. ^a	King and Hagen, 2011	1.9	ac	\$16,700.00	\$31,985
Construction						
2	Capital, labor, materials, overhead ^a	King and Hagen, 2011	1.9	ac	\$41,750.00	\$79,962
Construction Subtotal						\$111,947
3	Construction contingency (30% of subtotal)					\$33,584
Total Cost Scenario 1A						\$145,531
Total Cost Scenario 1Bb						\$149,531

a. Categorized as "Infiltration Practices w/o Sand, Veg"

b. \$4,000 added to construction subtotal to account for additional check valve

Table 2. Cost Estimate for Scenario 2 (Storm Sewer Diversion)

Item No.	Description	Reference	Quantity	Unit	Unit Cost	Total
Preparation						
1	Traffic Control	Bid Tab	8	day	\$1,000.00	\$7,500
Storm Sewer Installation						
2	Furnish and Install 12" Storm Drain	Bid Tab 12898A	775	LF	\$85.00	\$65,875
3	Furnish and Install Catch Basin	Bid Tab 12898A	2	EA	\$3,000.00	\$6,000
4	Furnish and install aggregate base	Bid Tab 12898A	24	CY	\$65.00	\$1,555
5	Furnish and install aggregate sub-base	Bid Tab 12898A	47	CY	\$55.00	\$2,605
6	Furnish and install HMA 12.5 mm	Bid Tab 12898A	93	TN	\$110.00	\$10,198
Construction Subtotal						\$93,733
7	Estimating Contingency (30% of subtotal)					\$28,120
8	Planning (20% of subtotal)					\$18,747
9	Mobilization (10% of subtotal)					\$9,373
10	Construction contingency (15% of subtotal)					\$14,060
Total Cost						\$164,032

Table 3. Cost Estimate for Scenario 3 (Distributed Bioretention)

Item No.	Description	Reference	Quantity	Unit	Unit Cost	Total
Pre-construction						
1	Survey, design, permitting, etc. ^a	King and Hagen, 2011	0.6	ac	\$52,500.00	\$30,354
Construction						
2	Capital, labor, materials, overhead ^a	King and Hagen, 2011	0.6	ac	\$131,250.00	\$75,884
Construction Subtotal						\$106,238
3	Construction contingency (30% of subtotal)					\$31,871
Total Cost						\$138,109

a. Categorized as "Bioretention (Retrofit-Highly Urban)"