Conceptual Green Infrastructure Design for Washington Street, City of Sanford

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About 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. These neighborhood or site-scale green infrastructure approaches are often referred to as *low impact development*.

The U.S. Environmental Protection Agency (EPA) encourages using green infrastructure to help manage stormwater runoff. In April 2011 EPA renewed its commitment to green infrastructure with the release of the *Strategic Agenda to Protect Waters and Build More Livable Communities through Green Infrastructure*. The agenda identifies technical assistance as a key activity that EPA will pursue to accelerate the implementation of green infrastructure. In October 2013 EPA released a new Strategic Agenda renewing the Agency's support for green infrastructure and outlining the actions the Agency intends to take to promote its effective implementation. The agenda is the product of a cross-EPA effort and builds upon both the 2011 Strategic Agenda and the 2008 Action Strategy.

In February 2012, EPA announced the availability of $950,000 in technical assistance to communities working to overcome common barriers to green infrastructure. EPA received letters of interest from over 150 communities across the country, and selected 17 of these communities to receive technical assistance. Selected communities received assistance with a range of projects aimed at addressing common barriers to green infrastructure, including code review, green infrastructure design, and cost-benefit assessments. The City of Sanford was selected to receive assistance identifying green infrastructure opportunities and a conceptual design for Washington Street's storm drain system between Main Street and Pioneer/Riverside Avenue.

For more information, visit http://water.epa.gov/infrastructure/greeninfrastructure/gi_support.cfm.

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Introduction

The Mousam River corridor has historically served as the economic and social heart of the City of Sanford, Maine. The central feature of the waterfront is the Sanford Mill Yard, an early 20th century textile mill complex located along the river. The Mill Yard was long a primary employment provider for the City. Beginning in the mid-20th century, with the closure of the mill the waterfront area has had reduced importance to the City. As an aging brownfield, the Mill Yard contains areas of potential and identified contamination from previous industrial uses. The Mousam River is listed by Maine's Department of Environmental Protection's (DEP) 2012 303(d) list as impaired due to nutrients, metals, BOD and E. Coli (MEDEP, 2012). Maine DEP had identified the Mousam as one of eight coastal rivers that are a priority for cleanup from non-point source pollution impairment.

In recent years the City of Sanford worked to restore the importance and function of the Mousam waterfront to serve economic, social and recreational needs of the community. The City secured a number of grants to clean up contaminated industrial sites, rebuild housing, and rebuild infrastructure. Other activities within the waterfront area include ongoing historic rehabilitation of two mill buildings, waterfront infrastructure improvements, and partnerships with non-profit organizations to improve water quality.

In 2010 the Sanford Mill Yard complex initiated an extensive community planning process as part of an EPA Brownfields Area-Wide Planning Pilot Project (EPA, 2014). This process provided the City with a strategy to attract sustained private investment in the Mill Yard through the integration of green infrastructure and healthy living opportunities. The City now seeks to implement this strategy in part through the development of a suite of green infrastructure practices for the 32-acre Mill Yard Site. Through the EPA Green Infrastructure Technical Assistance Program, EPA worked with the City of Sanford to identify opportunities for Green Infrastructure implementation at the Mill Yard site, quantify green infrastructure benefits, and develop a conceptual design for two areas along Washington Street. Due to their proximity to the visually striking Mousam River spillway, the project sites selected for conceptual design development have been identified by the City of Sanford as a focal point for the Sanford Mill Yard redevelopment efforts. The following report reflects the results of this technical assistance effort.

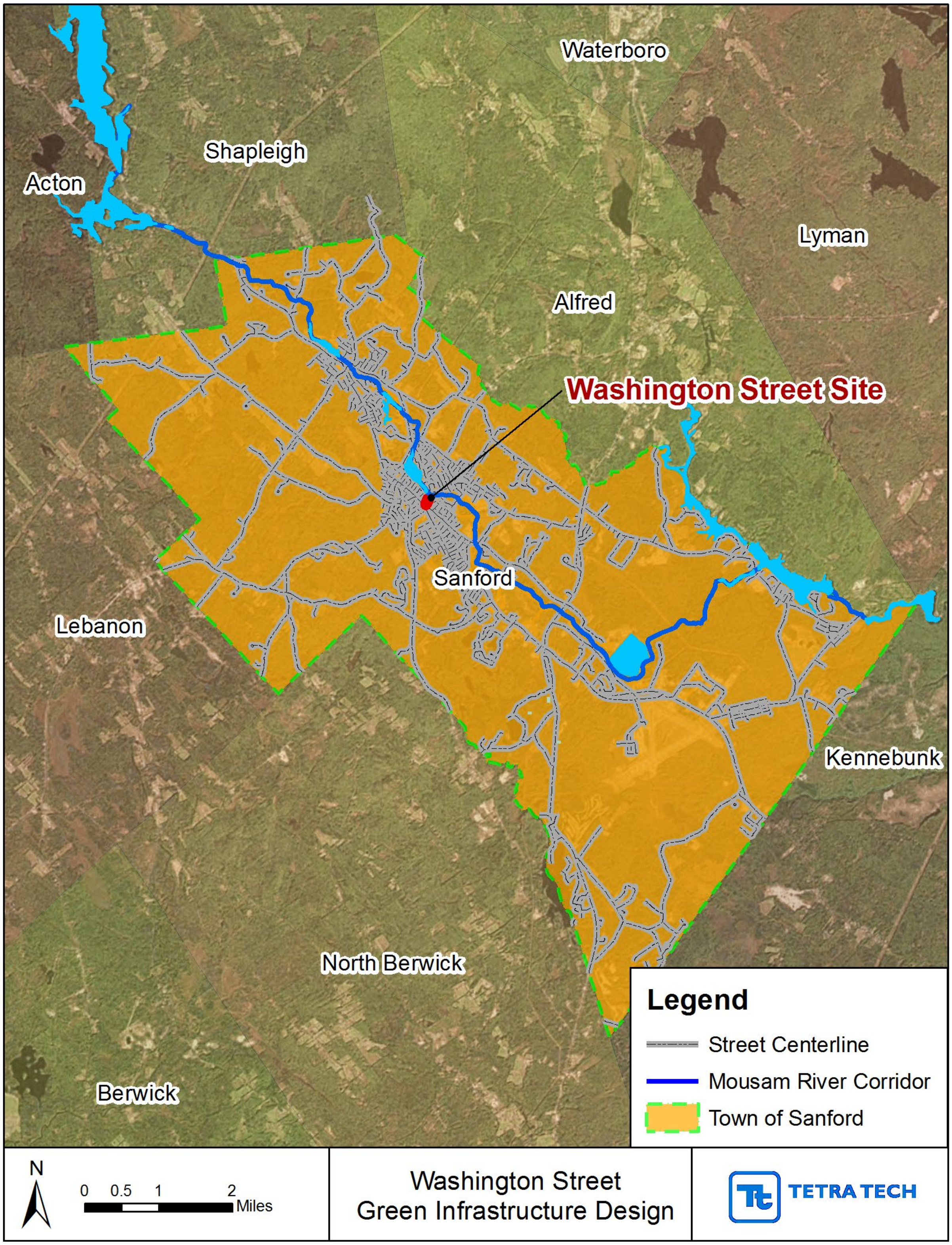

Figure 1. Location Map of Washington St. Project

Report Purpose

The purpose of this report is to identify opportunities for green infrastructure implementation in the City of Sanford waterfront district. The report outlines ways to utilize green infrastructure to support the wider urban renewal effort occurring along the Mousam River waterfront, and more particularly the brownfield redevelopment project at the Sanford Mill Yard complex. Washington Street Corridor and Gateway Park were both identified during preliminary site visits as potential green infrastructure project areas that could enhance existing brownfield restoration by improving aesthetics, drainage and road infrastructure, as well as improvements to water quality. These sites were chosen by the project team due to their potential to integrate green infrastructure into planned redevelopment or potential drainage improvement projects which can result in more cost effective green infrastructure applications. These sites were also selected so that they could demonstrate to local residents and other stakeholders how green infrastructure could be adopted into the waterfront setting and foster additional green infrastructure implementation elsewhere in the Mill Yard.

After discussing general community benefits associated with green infrastructure practices, this report explores site-specific opportunities to implement green infrastructure practices in the Washington Street corridor and Gateway Park area, respectively. A conceptual stormwater management design and cost estimate for each of the two proposed project areas is included in this report. These designs include specifications for green infrastructure practices, as much as practicable, to meet state and local stormwater design criteria.

Note: Final stormwater management designs should be completed by a stormwater management professional in conjunction with final design of the street and park redevelopment. Stormwater management professionals charged with design for the site should use the proposed selection, layout, and sizing of stormwater control measures (SCMs) presented in this report as an initial conceptual design. Final design will need to take into account actual site/building layout, soil infiltration rates, and detailed survey information, which will dictate the final layout, sizing, and outlet control of green and gray infrastructure practices.

Benefits of Green Infrastructure

The Sanford Mill Yard Complex presents an opportunity to include green infrastructure practices in a land redevelopment initiative with relative ease while providing multiple benefits to the surrounding community. The environmental, social, and economic benefits that green infrastructure can provide include, but are not limited to:

Increased enjoyment of surroundings, walkability: Residents living in apartment buildings surrounded by vegetated areas or features reported significantly more use of the area just outside their building than did residents living in buildings with less vegetation (Hastie 2003; Kuo 2003). Research has found that people in greener neighborhoods judge distances to be shorter and make more walking trips (Wolf 2008). Implementing green infrastructure practices that enhance vegetation within the neighborhood will help to create a more pedestrian-friendly environment that encourages walking and physical activity.

Increased pedestrian safety, traffic calming and reduced crime: Researchers examined the relationship between vegetation and crime for 98 apartment buildings in an inner city neighborhood. The study found the greener a building's surroundings are, the fewer total crimes (including violent crimes and property crimes), and that levels of nearby vegetation explained 7 to 8 percent of the variance in crimes reported by building (Kuo 2001a). Studies also show that the traffic-calming effects of trees are also likely to reduce road rage and improve the attention of drivers. Green streets can also increase safety. Generally, if properly designed, narrower green streets decrease vehicle speeds and make neighborhoods safer for pedestrians (Wolf 1998; Kuo 2001a).

Increased property values: Many aspects of green infrastructure can potentially increase property values by improving aesthetics, drainage, and recreation opportunities. These in turn can help restore, revitalize, and encourage growth in the economically distressed areas around Pittsburgh. Table 1 summarizes the recent studies that have estimated the effect that green infrastructure or related practices have on property values. The majority of these studies addressed urban areas, although some suburban studies are also included. The studies used statistical methods for estimating property value trends from observed data.

Table 1. Studies Estimating Percent Increase in Property Value from Green Infrastructure

Source	Percent increase in Property Value	Notes
Ward et al. (2008)	3.5 to 5%	Estimated effect of green infrastructure on adjacent properties relative to those farther away in King County (Seattle), WA.
Shultz and Schmitz (2008)	0.7 to 2.7%	Referred to effect of clustered open spaces, greenways and similar practices in Omaha, NE.
Wachter and Wong (2006)	2%	Estimated the effect of tree plantings on property values for select neighborhoods in Philadelphia.
Anderson and Cordell (1988)	3.5 to 4.5%	Estimated value of trees on residential property (differences between houses with five or more front yard trees and those that have fewer), Athens-Clarke County (GA).
Voicu and Been (2008)	9.4%	Refers to property within 1,000 feet of a park or garden and within 5 years of park opening; effect increases over time
Espey and Owasu-Edusei (2001)	11%	Refers to small, attractive parks with playgrounds within 600 feet of houses
Pincetl et al. (2003)	1.5%	Refers to the effect of an 11% increase in the amount of greenery (equivalent to a one-third acre garden or park) within a radius of 200 to 500 feet from the house
Hobden, Laughton and Morgan (2004)	6.9%	Refers to greenway adjacent to property
New Yorkers for Parks and Ernst & Young (2003)	8 to 30%	Refers to homes within a general proximity to parks

Washington Street Site

Existing Site Conditions

The Washington Street drainage area consists of Approximately 7.6 acres of roadway and adjacent commercial properties which are served by a storm drain system between Main Street and Pioneer/Riverside Avenue. Of this drainage area, approximately 6.6 acres are considered impervious (88%) with an average slope of 3.1%. The land use is predominantly roadway and mixed commercial, although several medium-high density residential lots are located in the eastern side of the drainage area. Figure 2 shows a watershed map including the sub-drainage area delineations and the existing storm drainage system. Note that the study area for the green infrastructure design is the drainage system between the upper catch basin (CB-1) on Washington Street and the blind junction (J-4) located near the intersection with Riverside/Pioneer Ave. Figure 2 also shows a stormwater drainage area on Main Street (MAIN-1) that currently contributes to a combined sewer system in this area. This is one of the few remaining areas within the city served by a combined sewer and the city is currently considering undertaking a sewer separation project. Sewer separation would require diverting the stormwater runoff from this area into an existing drainage network with sufficient capacity or, if sufficient capacity is not available replacing or upgrading an existing culvert system.

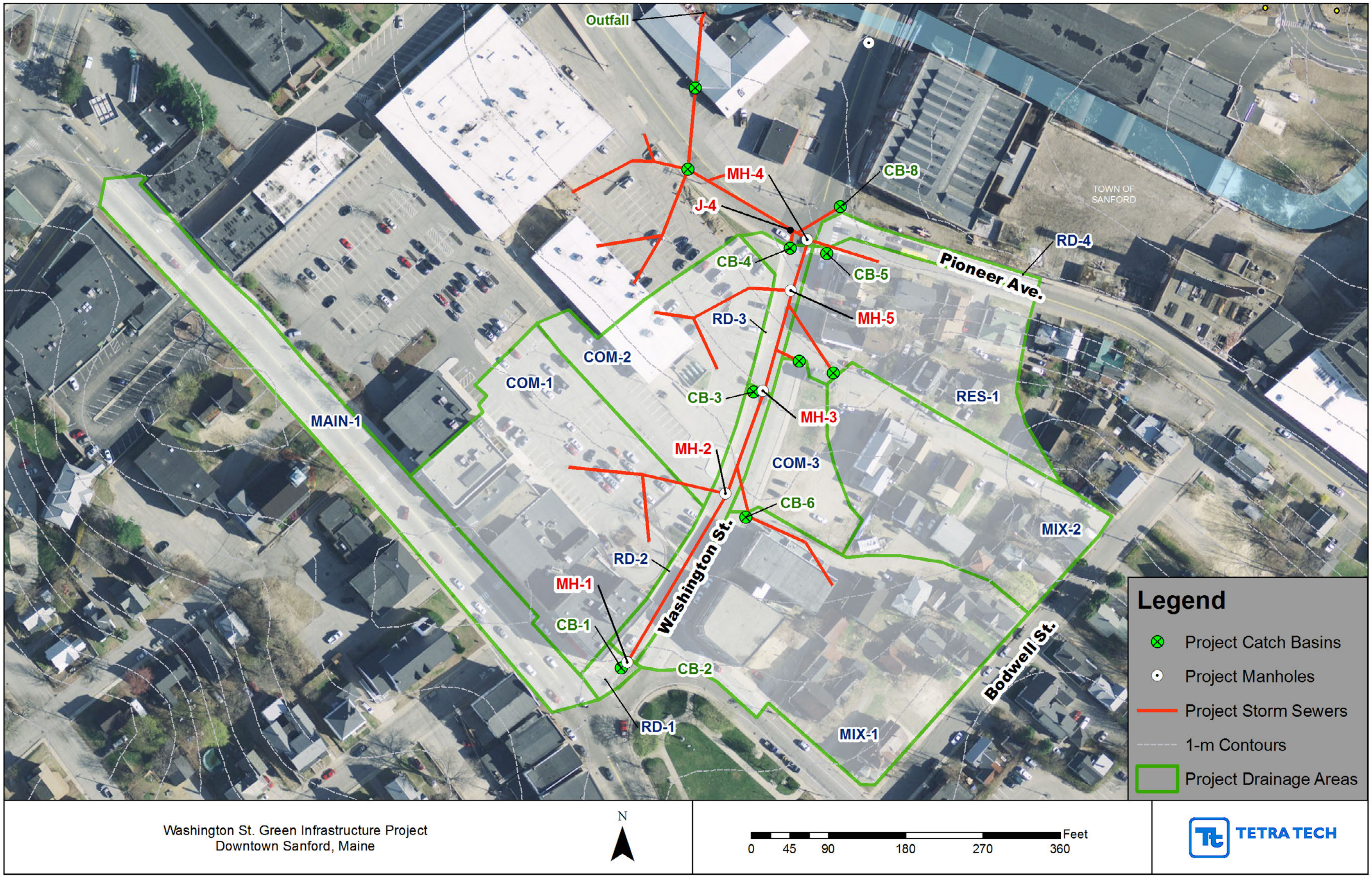

Figure 2. Site Conditions for Washington Street

NRCS soil data classifies the majority of the watershed as 'Urban,' although a portion of the residential drainage area (MIX-1 and MIX-2) are considered 'Adams-urban land complex' with a Hydrologic Soil Group (HSG) classification of 'A.'

Gateway Park Site

Existing Site Conditions

The Gateway Park site sits at the intersection of Washington St. and Riverside Avenue directly bordering the south bank of the Mousam River (Figure 3). The site consists of two commercial properties currently occupied by an unutilized fuel station and restaurant facility. The site has been identified by the City of Sanford for a future municipal park although a park plan or specific park amenities have not been identified. The drainage area for the site includes half of the adjacent roadways (Riverside Ave. and Washington St.), and all of the existing project area. The site is intersected by the downstream section of the Washington St. drainage network that discharges to the river to the north. One catch basin (CB-510) connected to the main drainage network is located within the park boundary. Based on site observations, it is suspected that overflow from the Washington St. drainage network drains via surface flow to the site before eventually discharging to the river.

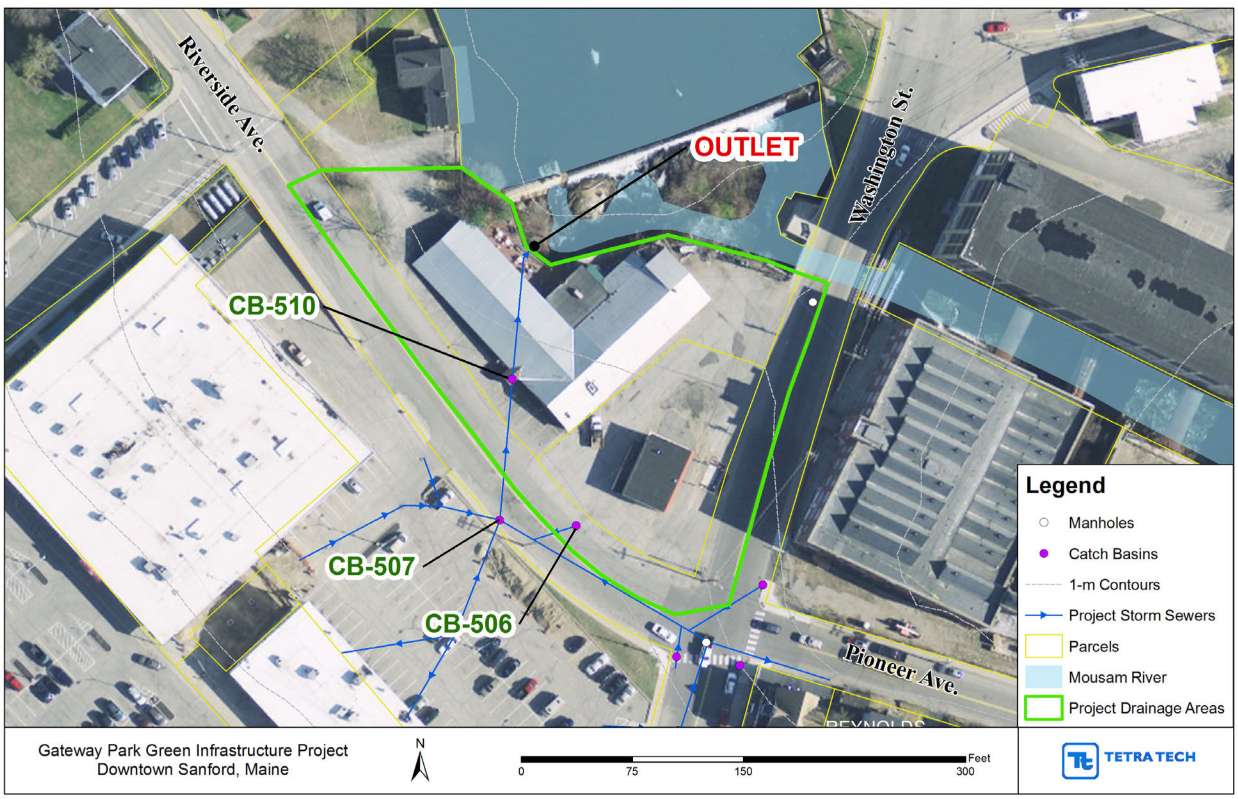

Figure 3. Site Conditions for Future Gateway Park Site

NRCS soil data classifies the entire park drainage area as 'Urban'. The existing imperviousness of the site is almost 100%, although the future park renovation will likely convert most of the impervious area in the parcel boundary to grass or landscaped areas. Photographs of the project area are included in Figure 4 and Figure 5.

Figure 4. Washington St., facing north

Figure 5. Future park site, facing south

Storm Drainage System

An important tool for evaluating and optimizing infrastructure solutions for storm flooding and water quality challenges involves continuous hydro-simulation models. The project team selected the Stormwater Management Model (SWMM; Rossman 2010) for the purposes of assessing both flooding and water quality impacts, and evaluating stormwater infrastructure solutions that help achieve the project goals. 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. 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. 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. Additional information on the SWMM analysis for the Washington Street storm drainage system is provided in Appendix A.

The Washington Street storm drainage system consists primarily of a reinforced concrete pipe (RCP) trunk-line that starts at the intersection of Washington and Main. There are multiple culverts that intersect the trunk-line along the Washington Street study area, consisting of PVC, RCP, or vitrified clay (VC) pipes. Most of the junctions were visible manholes (labeled with an "MH" prefix), although several were blind junctions (labeled with a "J" prefix). Inverts for the blind junctions were interpolated based on the two adjacent manholes with surveyed inverts.

An estimated profile of the main trunk-line system is shown below in Figure 6. The node labels represent manholes, catch basins, or blind junctions along the trunk-line that were included in the SWMM model. There is approximately 240 feet of 12" RCP between the upstream catch basin (CB-1) and MH-2. Between MH-2 and MH-4, the trunk-line changes to a 15" RCP that is approximately 312 feet in total length. At the junction labeled as MH-4, the trunk-line becomes a relic 17" RCP sanitary sewer. Connectivity beyond MH-4 remains uncertain. Field investigations by City of Sanford staff revealed deviation between on-site drainage conditions and GIS data. For the modeling purposes of this project, uncertainty in downstream connectivity in the drainage system does not affect the hydrologic and hydraulic results and the conceptual design configuration.

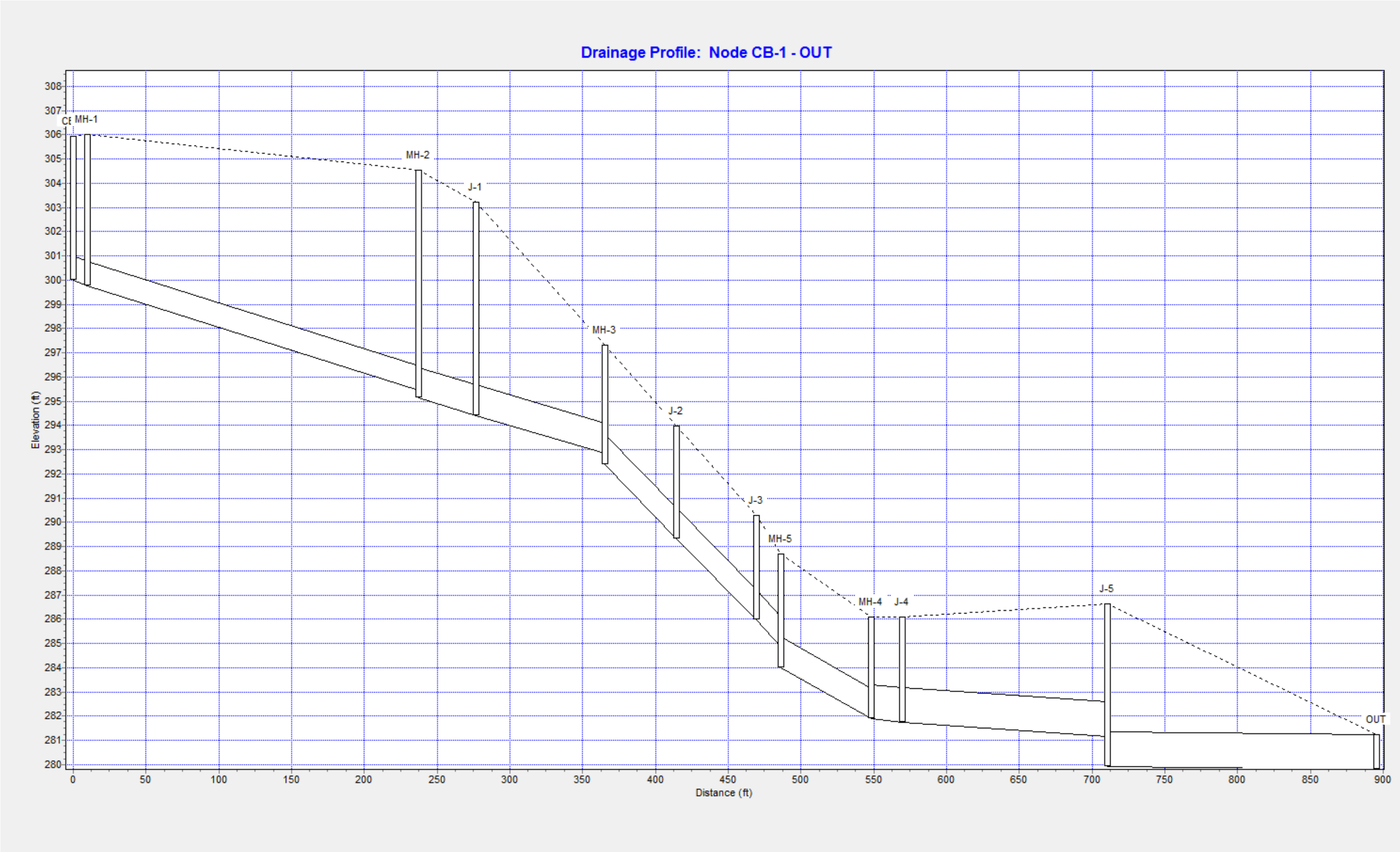

Figure 6. Hydraulic Profile of Main Trunk-Line

Green Infrastructure Conceptual Design

Design Goals

Specific design goals for this project include quantifying the hydrologic benefits of the proposed green infrastructure practices (linear bioretention and permeable pavement) in reducing peak flow rates within the Washington Street drainage network. The project further assesses the impact of these peak reductions on the feasibility of routing stormwater contributions from the Main Street combined sewer system into the Washington Street drainage system. For the Washington Street drainage area, proposed linear bioretention cells were designed to maximize water quality volume treatment and hydraulic function. At Gateway Park, the design objective was to use the green infrastructure practices to treat the entire water quality volume from the park's drainage area (which includes offsite roadway runoff), and utilize a detention feature to mitigate the 2-year, 24-hour flood volume from the Washington Street drainage area. To the extent practicable all of the green infrastructure practices were designed according to specifications in the Maine Stormwater Manual (MEDEP, 2014).

Stormwater Management Toolbox

The green infrastructure practices identified as appropriate for the Washington Street and Gateway Park project areas as well as throughout the mill yard complex include bioretention facilities, planter boxes, and permeable pavement. To assist planners and designers in going forward with these conceptual designs, the following discussion addresses constraints and opportunities associated with each applicable green infrastructure practice.

Bioretention Facilities

Bioretention facilities are shallow, depressed areas with a fill soil and vegetation that infiltrates runoff and removes pollutants through a variety of physical, biological, and chemical treatment processes. The depressed area is planted with small to medium sized vegetation including trees, shrubs, grasses, and perennials, and may incorporate a vegetated groundcover or mulch that can withstand urban environments and tolerate periodic inundation and dry periods. Bioretention may be configured differently depending on site context and design goals. This section summarizes general design considerations for bioretention facilities, and then describes two configurations designed for dense urban areas: planter boxes and tree boxes. Note that use of these practices within the public right-of-way will need prior approval from the City.

Bioretention is well-suited for removing stormwater pollutants from runoff, particularly for smaller (water quality) storm events, and can be used to partially or completely meet stormwater management requirements on smaller sites. Bioretention areas can be incorporated into a development site to capture roof runoff and parking lot runoff and within rights-of-way to capture sidewalk and street runoff (Figure 7 and Figure 8).

- For unlined systems, maintain a minimum of 5 feet between the facility and a building and at least 10 feet with a basement.
- A surface dewatering time of no greater than 12 hours, either through infiltration with soils of sufficient percolation capacity or with an underdrain system and outlet to a drainage system. Use of an underdrain system is very effective in areas with low infiltration capacity soils.
- Planted with native and noninvasive plant species that have tolerance for urban environments, frequent inundation, road salt application, and Maine's cold winter climate.

- Inclusion of an overflow structure with a non-erosive overflow channel to safely pass flows that exceed the capacity of the facility or design the facility as an off-line system.
- Inclusion of a pretreatment mechanism such as a grass filter strip, sediment forebay, or grass swale upstream of the practice to enhance the treatment capacity of the unit.

Figure 7. Bioretention Incorporated into a Right-of-Way.

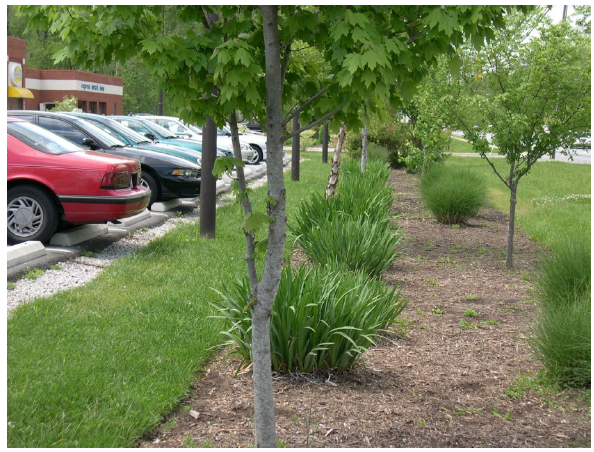

Figure 8. Bioretention Incorporated into Traditional Parking Lot Design.

Planter Box: Planter boxes are bioretention facilities contained within a concrete box, allowing them to be incorporated into tighter areas with limited open space. Runoff from a street or parking lot typically enters a planter box through a curb cut, while runoff from a roof drain typically enters through a downspout. Planter boxes are often categorized either as flow-through planter boxes or infiltrating planter boxes. Infiltrating planter boxes have an open bottom to allow infiltration into the underlying soils. In brownfield settings such as the Mousam Mill Yard area, an evaluation of subsurface conditions should be conducted to determine the potential for existing contamination of subsoil or groundwater. Flow-through planter boxes are completely lined and have an underdrain system to convey flow that is not taken up by plants to areas that are appropriate for drainage away from building foundations. Planter boxes are well-suited to narrow areas adjacent to streets and buildings (Figure 9 and Figure 10).

Figure 9. Planter Box within Street Right-of-Way.

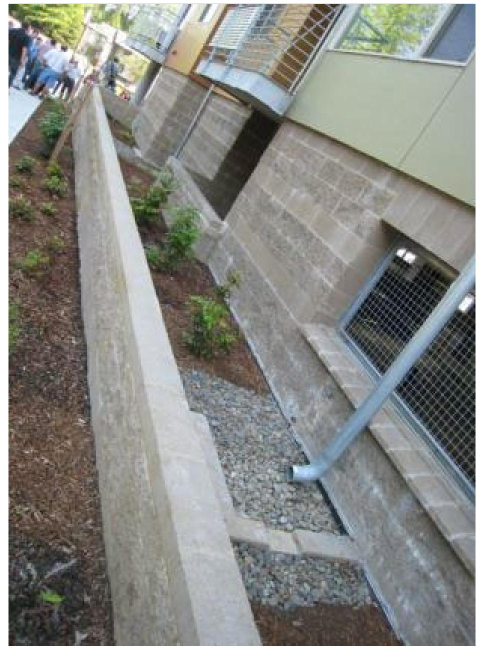

Figure 10. Flow-through Planter Box Attached to Building.

Tree Box: Tree boxes are bioretention facilities configured for dense urban areas that use the water-uptake benefits of trees. They are generally installed along street corridors with curb inlets (Figure 11). Tree boxes can be incorporated immediately adjacent to streets and sidewalks with the use of a structural soil, modular suspended pavement, or underground retaining wall to keep uncompacted soil in its place. Tree boxes typically contain a highly engineered soil media to enhance pollutant removal while retaining high infiltration rates. The uncompacted media allows urban trees to thrive, providing shade and an extensive root system for water uptake. For low to moderate flows, stormwater enters through the tree box inlet and filters through the soil. For high flows, stormwater will bypass the tree box if it is full and flow directly to the downstream curb inlet.

Figure 11. Tree Box at Roberts St. Sanford, Maine.

Permeable Pavement

Conventional pavement results in increased surface runoff rates and volumes. Permeable pavements, in contrast, allow streets, parking lots, sidewalks, and other impervious surfaces to retain the underlying soil's natural infiltration capacity while maintaining the structural and functional features of the materials they replace. Permeable pavements contain small voids that allow water to drain through the pavement to an aggregate reservoir and then infiltrate into the soil. If the native soils below the permeable pavements do not have enough percolation capacity, underdrains can be included to direct the stormwater to other downstream stormwater control systems. Permeable pavement can be developed using modular paving systems (e.g., concrete pavers, grass-pave, or gravel-pave) or poured-in-place solutions (e.g., pervious concrete or permeable asphalt).

Permeable pavement reduces the volume of stormwater runoff by converting an impervious area to a treatment unit. The aggregate sub-base can provide water quality improvements through filtering, and enhance additional chemical and biological processes. The volume reduction and water treatment capabilities of permeable pavements are effective at reducing stormwater pollutant loads (Collins et. al., 2010).

Permeable pavement can be used to replace traditional impervious pavement for most pedestrian and vehicular applications. Composite designs that use conventional asphalt or concrete in high-traffic areas adjacent to permeable pavements along shoulders or in parking areas can be implemented to meet both transportation and stormwater management needs. Permeable pavements are most often used in constructing pedestrian walkways, sidewalks, driveways, low-volume roadways, and parking areas of office buildings, recreational facilities, and shopping centers (Figure 12 and Figure 13).

General guidelines for applying permeable pavement are as follows:

- Permeable pavements can be substituted for conventional pavements in parking areas, low-volume/low-speed roadways, pedestrian areas, and driveways if the grades, native soils, drainage characteristics, and groundwater conditions of the paved areas are suitable.
- Permeable pavement is not appropriate for stormwater hotspots where hazardous materials are loaded, unloaded, or stored unless the sub-base layers are completely enclosed by an impermeable liner.
- The granular capping and sub-base layers should provide adequate construction platform and base for the overlying pavement layers.
- If permeable pavement is installed over low-permeability soils or temporary surface flooding is a concern, an underdrain should be installed to ensure water removal from the sub-base reservoir and pavement.
- The infiltration rate of the soils or an installed underdrain should drain the sub-base in 24 to 48 hours.
- An impermeable liner can be installed between the sub-base and the native soil to prevent water infiltration when clay soils have a high shrink-swell potential or if a high water table or bedrock layer exists.
- Measures should be taken to protect permeable pavements from high sediment loads, particularly fine sediment, to reduce maintenance. Typical maintenance includes removing sediment with a vacuum truck.

Figure 12. Pervious Concrete Parking Stalls.

Figure 13. Permeable Paver Installation in Sanford.

Conceptual Layout

As with most green infrastructure retrofit projects, available space for SCMs is often limited. To address this constraint, many green infrastructure retrofits are designed to optimize small footprints and narrow right-of-ways through the use of vertical retaining walls (rather than gradual side slopes), such as along sidewalks and traffic/parking lanes. Another strategy is to modify road patterns, travel lane configurations, and street widths to provide space for green street SCMs and reduce impervious surface area. Furthermore, coordinating green infrastructure implementation with larger redevelopment or roadway improvement projects can significantly reduce implementation costs relative to projects where green infrastructure is the only element.

The following sections summarize the factors influencing the conceptual designs for the Mill Yard project sites and describe in detail the conceptual design configurations. The proposed layouts are based on overall project goals and site specific priorities that were conveyed by City of Sanford staff as discussed earlier. Detailed design information is also included below to assist with final design of the SCMs.

Washington Street

The proposed green infrastructure approach for Washington Street involves reducing the existing three-lane road configuration to two-lanes. The western lane will convert to a combination of bioretention cells and new parking stalls, while most of the existing parking stalls along the eastern side of the street will be converted to bioretention cells. Both the installation of the vegetated bioretention system and removal of the middle turning lane would most likely slow traffic through the study area, which would increase walkability and improve pedestrian/traffic safety. This impact will need to be further evaluated and discussed among stakeholders prior to final design.

The proposed conceptual plan was designed to maximize water quality volume treatment (per the Maine DEP sizing requirements) and hydraulic function along the Washington Street drainage area. However, during the final design process stakeholder input may justify design modifications that focus on other aspects of green infrastructure implementation, including aesthetics, public parking, safety concerns, constructability, construction cost, etc. For example, if additional hydrologic and water quality impacts are desired, additional media depth can be incorporated into the bioretention cells with the overflow discharging to an underground detention/retention facility beneath the BMP system. Engineered planter boxes and tree boxes can be installed in small footprints (e.g., curbsides and store-fronts) to provide further treatment and improved aesthetics along Washington Street. If additional on-street parking is desired, installation of permeable pavement can be incorporated in place of one or more bioretention areas.

Gateway Park

Since the City of Sanford plans to redevelop this site into a “focal point” for the Sanford Mill Yard brownfield project, as well as to potentially serve as a public congregating/recreation area, the stormwater improvements at the site were designed for aesthetics, multifunction, and adaptability. The City has yet to develop a design for Gateway Park, so the stormwater plan leaves most of the internal park area open for subsequent park planning efforts.

Linear bioretention is proposed in the park along both Riverside Ave. and Washington St. to treat the water quality volume from the adjacent roadway and park area. The bioretention cells were designed with 6’-wide media beds and an underdrain layer that connects to the existing storm drainage system. The cells were also segregated to provide multiple pedestrian access points to the park. Planting plans for the bioretention areas can be later adopted to meet the specific needs of the park (e.g., visibility goals, maintenance needs, site aesthetics, etc.).

Permeable walkways are also proposed for the entire perimeter of the park site to provide pedestrian access along the waterfront and roadway, and to reduce the required area for the bioretention cells. The permeable walkways can be designed with porous asphalt, porous concrete, or a paver system. Currently, the permeable walkways are design without an underdrain to encourage infiltration (although this feature can be incorporated later if required by soil and site conditions).

The park’s stormwater plan also includes two grassed detention areas within the park. Although both basins include visible outlet structures, the grassed basins will be unobtrusive in the landscape while simultaneously providing a grassed surface for public use and recreation during dry weather. The shallow side slopes were designed for mower access and easy maintenance. Figure 14 and Figure 15 shows the proposed placement and relative sizing of the green infrastructure SCMs along Washington Street and within Gateway Park, respectively.

Figure 14 Conceptual Layout for Washington Street Green Infrastructure SCMs

Figure 15. Conceptual Layout for Gateway Park Green Infrastructure SCMs

Green Infrastructure Sizing

The primary green infrastructure practice proposed as part of the conceptual designs is bioretention filter cells. According to Chapter 7.2.3 of the Maine BMP Technical Design Manual, bioretention cells must be sized to capture a treatment volume that is equal to 1.0 inch times the impervious area within the catchment, plus 0.4 inches times the catchment's landscaped area. In addition, the surface area of the bioretention filter must be no less than the sum of 7% of the impervious area and 3% of the landscaped area within the catchment. After using this method to size each bioretention cell according to its respective catchment area, SWMM was used to simulate hydrologic performance for the 2- and 10-year, 24-hour storm events for the overall drainage network along Washington St. and Gateway Park.

Washington Street

Based on the locations of existing catch basins and road entrances, six separate linear bioretention cells are proposed for the Washington Street study area. Each cell was sited just up-gradient of an existing catch basin to easily connect underdrains and bypass overflows into the existing storm sewer network. Table 2 shows the surface area dimensions of each SCM, designed according to the Design Manual sizing criteria. The cells have either a 10-foot or 8-foot width and range in length between 80 feet and 130 feet. Each cell will contain 18 inches of bioretention media and a 14" gravel layer with 4" slotted PVC underdrain that connects to the existing manholes and catch basins along Washington Street. Due to site constraints, bioretention cell 04 is undersized according to the design guidance and is only 64% of the recommended surface area.

Table 2. SCM Sizing for Bioretention Cells

SCM ID	Drainage Area (Ac)[1]	% Impervious	Width (Ft)	Length (Ft)	Surface Area (Sq ft)	Ponded Storage Volume (Cu ft)
01	0.14	100	10	102	1016	508
02	0.11	100	10	80	800	400
03	0.12	100	10	90	900	450
04	0.23	100	8	130	1040	520
05	0.09	100	8	85	680	340
06	0.12	100	8	100	800	400

[1] Includes BMP footprint

Table 3 shows the hydrologic and hydraulic impacts at each of the trunk-line nodes as a result of adding the proposed bioretention cells along Washington Street. To better illustrate the impacts, Table 4 shows the percent change due to the proposed infrastructure.

Table 3. Conceptual Design Hydrology/Hydraulics at Truck-Line Junctions

Junction Node	2-year, 24-hour			10-year, 24-hour		
	Q (cfs)	Hours Surcharged	Hours Flooded	Q (cfs)	Hours Surcharged	Hours Flooded
CB-1	0.13	0	0	1.4	0.22	0.01
MH-1	0.21	0	0	1.3	0.23	0
MH-2	4.16	0.17	0	6.84	0.37	0.14
J-1	8.15	0.36	0	12.32	0.67	0
MH-3	8.16	0.16	0	12.32	0.37	0.26
J-2	8.7	0.37	0	9.06	0.65	0
J-3	11.35	0.56	0	12.82	0.81	0
MH-5	13.65	0.4	0.29	16.39	0.7	0.55
MH-4	9.71	0.7	0.01	9.71	0.94	0.17
J-4	9.88	0.57	0	10.12	0.82	0

Table 4. Percent Change in Hydrology/Hydraulics from Green Infrastructure

Junction Node	2-year, 24-hour			10-year, 24-hour		
	Q (cfs)	Hours Surcharged	Hours Flooded	Q (cfs)	Hours Surcharged	Hours Flooded
CB-1	0%	N/A[1]	N/A[1]	10%	5%	N/A[1]
MH-1	-34%	N/A[1]	N/A[1]	7%	5%	N/A[1]
MH-2	0%	-11%	N/A[1]	8%	0%	40%
J-1	0%	0%	N/A[1]	0%	2%	N/A[1]
MH-3	-2%	-20%	N/A[1]	0%	-3%	0%
J-2	-4%	-10%	N/A[1]	0%	-4%	N/A[1]
J-3	-2%	-7%	N/A[1]	0%	-5%	N/A[1]
MH-5	-2%	-9%	-6%	0%	-1%	-4%
MH-4	0%	-5%	-50%	0%	-3%	-11%
J-4	-1%	-7%	N/A[1]	0%	-5%	N/A[1]

[1] No flooding/surcharge calculated for both existing and proposed conditions

Table 5 and Table 6 show the performance summary for the six bioretention areas as estimated by SWMM. Surface overflow represents the volume of runoff that bypasses the bioretention area and is not treated. Drain outflow represents the volume of runoff that infiltrates through the bioretention media and discharges through the underdrain, while the final storage is the runoff volume remaining in the bioretention area at the end of the simulation period, which will eventually be treated.

Table 5. Bioretention Performance Summary: 2-yr, 24-hr Storm

Bioretention Cell	Total Inflow (in)	Surface Overflow (in)	Drain Outflow (in)	Final Storage (in)	Percent Treated
01	17.8	1.9	12.5	3.5	89.5%
02	17.3	1.6	12.3	3.4	90.7%
03	17.5	1.7	12.4	3.4	90.2%
04	27.9	8.2	15.8	4.0	70.7%
05	17.4	1.7	12.3	3.4	90.4%
06	19.9	3.1	13.3	3.6	84.5%

Table 6. Bioretention Performance Summary: 10-yr, 24-hr Storm

Bioretention Cell	Total Inflow (in)	Surface Overflow (in)	Drain Outflow (in)	Final Storage (in)	Percent Treated
01	27.4	7.7	15.8	3.9	71.8%
02	26.7	7.2	15.6	3.9	72.9%
03	27.0	7.5	15.7	3.9	72.4%
04	43.0	19.2	19.2	4.6	55.3%
05	26.8	7.4	15.6	3.9	72.6%
06	30.7	10.0	16.7	4.0	67.4%

As expected, the total percentage of runoff volume treated by the bioretention cells is significant. For the 2- and 10-yr storm events, the treatment percentages range from 71 to 91%, and 55 to 73%, respectively. However, the impacts from green infrastructure on hydraulic performance and peak flow reduction within the Washington St. drainage network were less evident. Although SWMM results predict a 34% peak flow reduction at one of the upstream manholes (MH-1) during the 2-year event, peak reductions at the remaining storm structure locations only ranged between 0 and 4%. In addition, the 10-year storm simulation predicts a noticeable increase in peak flow events at the three upstream storm structures (CB-1, MH-1, MH-2) of up to 10%. One possible cause for this observation relates to the "area-conversion" method that SWMM uses to model LID practices like bioretention, which may limit the accuracy for hydraulic routing and peak flow estimation at an event scale (versus annual hydrology). Also, the implementation of bioretention cells along Washington Street might influence the curb/bypass flooding that occurs during existing conditions, and allow for additional ponding and driving head at some of the higher elevation nodes that would increase simulated flow rates through the structure. In other words, the locations of the existing flood occurrences was re-distributed (not reduced) throughout the Washington St. drainage network as a result of the bioretention cells.

Gateway Park

Since hydraulic capacity analyses were not required for the Gateway Park green infrastructure, SWMM was not used to design the proposed BMP system. Chapter 7.2 in Volume III of Maine's BMPs Technical Design Manual was used to size the bioretention cells in Gateway Park.

Approximately 0.5 acres of catchment area directly drain to the proposed bioretention cells sited along the park's roadside perimeter. The majority of the catchment area, which is approximately 70% impervious, includes off-site roadway from Riverside Ave. and Washington Street. Most of the pervious area in the catchment includes the proposed permeable pavement within the park and adjacent landscaped areas. For the purposes of required treatment volume calculations, the BMP surface area was treated as pervious landscaped area for the Gateway Park design. Based on the ME DEP sizing guidelines, the required treatment volume for the bioretention cells is 1,480 ft^3. With a 6" ponding depth, the recommended bioretention area is approximately 3,000 ft^2.

The grassed storage areas within the park's open space area were sized to retain the 2-year, 24-hour flooding volumes from Washington Street. Based on SWMM output, the internal outflow from Washington Street with the proposed green infrastructure improvements (without Main St. drainage) is 0.097 ac-ft, or 4,225 ft^3. Assuming a 1-ft maximum ponding depth in the storage areas, the required footprint area is 4,225 ft^2. As currently proposed, the storage area footprint is 4,840 ft^2 to account for volume reductions associated with the shallow side slopes.

Stormwater Control Measure Technical Specifications

The purpose of this section is to provide guidance for designing the SCMs during final design. Design criteria for the bioretention cells are based on Chapter 7.2 of Maine Stormwater Manual. Additional design guidance for bioretention and permeable pavements is presented in Table 7 and Table 8 at the end of this section along with accompanying figures showing cross-sections of typical roadside bioretention and permeable pavement details.

Common Elements

Soil Media

Soil media is typically specified to meet the growth requirements of the selected vegetation while still meeting the hydraulic requirements of the system. The system must be designed to drain the surface storage volume in no less than 24 hours and no more than 48 hours. The expected infiltration rate should range from 2.4 to 4 in/hr after compaction to 90-92% standard proctor (ASTM D6998).

The engineered soil mixture shall be a blend of a silty-sand soil or soil mixture that is 20-25 percent (by volume) moderately fine aged bark fines or wood fiber mulch. Organic matter is considered an additive to help vegetation establish and contributes to sorption of pollutants. Organic material should not consist of manure or animal compost. Newspaper mulch has been shown to be an acceptable additive.

Gradation analyses of the blended material, including hydrometer testing for clay content and permeability testing of the soil filter material, should be performed by a qualified soil testing laboratory and submitted to the project engineer for review. Particle gradation tests should conform to ASTM C117/C136 (AASHTO T11/T27) and the blended material should have no less than 8% passing the 200 sieve and shall have a clay content of less than 2%. Other soil media design criteria include:

- pH should be between 6–8, cation exchange capacity (CEC) should be greater than 5 milliequivalent (meq)/100 g soil.
- High levels of phosphorus in the media have been identified as the main cause of bioretention areas exporting nutrients. All bioretention media should be analyzed for background levels of nutrients. Total phosphorus should not exceed 15 ppm.

- Geotextile fabric of Mirafi 170n or equivalent may be placed between the sides of the filter layer and adjacent soil to prevent surrounding soil from migrating into the filter and clogging the outlet. Overlap seams must be a minimum of 12 inches.

Underdrain

An underdrain is required in areas where existing soils have an infiltration rate less than 0.5 in/hr and should meet the following criteria:

- The underdrain piping should be 4” of 6” slotted, rigid Schedule 40 PVC or SDR35. The total opening area exceeds the expected flow capacity of the underdrain and does not limit infiltration through the soil media. The perforations can be placed closest to the invert of the pipe to achieve maximum potential for draining the facility. Structure joints shall be sealed so they are watertight.
- At least one line of underdrain should be placed for every 8 feet of filter area’s width (i.e., placed no further than 8 feet apart)
- Underdrain pipes must be bedded in 12 to 14 inches of clean, well-graded coarse gravel that meets the MEDOT specification 703.22 Underdrain Type B for Underdrain Backfill.
- A choking layer composed of 2” of washed sand and 2” of #8 stone should be placed above the gravel layer to prevent the underdrain from clogging from migrating media particles.
- The underdrain must drain freely and discharge to the existing stormwater infrastructure.

Plant Selection

For the SCM to function properly as stormwater treatment and blend into the landscape, vegetation selection is crucial. Appropriate vegetation will have the following characteristics:

1. Plant materials must be tolerant of drought, ponding fluctuations, and saturated soil conditions for 10 to 48 hours.
2. It is recommended that a minimum of three tree, three shrubs, and/or three herbaceous groundcover species be incorporated to protect against facility failure from disease and insect infestations of a single species.
3. Native plant species or hardy cultivars that are not invasive and do not require chemical inputs are recommended to be used to the maximum extent practicable.
4. Refer to Appendix B, Volume 1 of the Maine Stormwater Manual for a list of appropriate bioretention plant species for the City of Sanford.
5. After planting, the filter area should be mulched with 2-3 inches of triple-shredded hardwood mulch. Do not fertilize after planting.

Geotechnical Investigation

A full geotechnical investigation is necessary to characterize the soils prior to final design. Pertinent information includes permeability at each bioretention site, hydrologic soil group type, depth to water table, and the presence of expansive soils. If expansive soils are present, bioretention design should include an impermeable barrier since the proposed bioretention cell locations are adjacent to infrastructure such as roads and buildings.

As a result of the historic industrial use of the gateway park parcel and areas adjacent to Washington Street an investigation of potential soil and groundwater contaminants should be conducted in these areas before the implementation of any infiltration based treatment practices. In the event that subsurface investigations reveal the presence of contaminants, infiltration limiting elements such as impermeable synthetic or clay liners may be incorporated into any green infrastructure practices. While the use of liners will certainly alter the runoff volume reducing properties of these practices, pollutant and flow rate reduction benefits will be partly retained.

Maximizing Infiltration

SCMs implemented over soils with low permeability can be hydrologically connected to SCMs implemented over high permeability soils through the underdrain systems. Hydrologically connecting the SCMs where infiltration will be limited to locations where infiltration will be higher will maximize the treatment capacity of the site providing a greater overall infiltration capacity. Note that when infiltration is concentrated via a subsurface fluid distribution system, it may be considered a Class V well and will need a permit.

Table 7. Traditional Bioretention Specifications

1. Siting Setbacks	
Pavement	No requirement
Building	No requirement with lined bottom; otherwise, Basement: ≥ 10 feet No Basement: ≥ 5 feet
Property lines/ROW	≥ 2 feet / ≥ 0 feet
2. Volume	
Bottom slope	Flat
Side slopes	Bioretention: 2H:1V or flatter Planter Box: Vertical retaining wall
Freeboard	6 to 12 inches
3. Vertical Component	
Surface Storage	6 to 12 inches
Growing Layer	≥ 12 inches soil media; 3 inches of mulch, max
Filter Layer	2 to 4 inches of clean medium sand (ASTM c-33) over 2 to 3 inches of #8 or #78 washed stone when drainage layer is used
Drainage Layer	Recommended 12 to 30 in. of clean coarse aggregate AASHTO #4, #5, or equivalent
Native Material	Test infiltration; ≥ 1/2 in/hr if designing with infiltration
4. Drainage	
Inlet	Curb inlet; sheet flow through grass filter strip; downspout w/ energy dissipation
Underdrain	4-inch perforated PVC placed to meet dewatering requirement if needed; cleanout at terminal ends and every 250-300 feet
Outlet	Required to meet release rates
Overflow	Downstream inlet or catch basin set 6 to 12 inches above soil surface and connected to storm drainage network

4. Drainage (cont.)	
Infiltration	Meet water quality volume requirement
Dewatering	Surface: ≤ 24 hours Sub-surface: ≤ 72 hours
5. Composition	
Surface Treatment	Vegetation and mulch
Soil Media	With or without an underdrain, meets dewatering requirement; supports plant growth
Side Slopes	Grass or mulch
Mulch	Triple-shredded hardwood
6. Pollutant	
Pretreatment	Required. May include grass filter strip, stone trench, forebay, sump inlets
7. Maintenance	
Access	Able to be accessed by a vehicle
Requirements	Designed and maintained to improve water quality; Maintenance plan should be in place

Table 8. Permeable Pavement Specifications

1. Siting Setbacks	
Pavement	No requirement
Building	No requirement with lined bottom; otherwise, Basement: ≥ 10 feet No Basement: ≥ 5 feet
Property lines/ROW	≥ 2 feet / ≥ 0 feet
2. Volume	
slope	Less than 0.5 percent
Side slopes	Not applicable
Freeboard	Not applicable
3. Vertical Component	
Surface Layer	Interlocking Concrete Pavers; Concrete Grid Pavers; Plastic Grid Pavers; Concrete; Asphalt
Growing Layer	Not applicable
Bedding	1) Perm. Interlocking Conc. Pavers: 1.5 to 3 inches of #8 or #78 washed stone 2) Concrete and Plastic Grid Pavers: 1 to 1.5 inches of bedding sand 3) Permeable Concrete and Asphalt: None
Base Layer	12 to 30 in. of clean aggregate AASHTO #56 or equivalent; thickness depends on strength/storage needed; install 30 mil geotextile liner where aggregate meets soil
Native Material	Compacted as sub-base

4. Drainage	
Inlet	Pavement surface
Outlet	Required to meet release rates
Overflow	Downstream inlet
Infiltration	Meet water quality volume requirement
Dewatering	≤ 72 hours
5. Composition	
Surface Treatment	For interlocking or grid-type pavers use fine aggregate, coarse sand, or top soil & grass in openings
6. Pollutant	
Pretreatment	Divert runoff from sediment sources away from pavement
7. Installation and Maintenance	
Installation	Per manufacturer's recommendation
Load Bearing	Designed for projected traffic loads using AASHTO methods
Requirements	Designed and maintained to improve water quality; Maintenance plan should be in place

Notes: A reinforced concrete transition width (12-18 inches) is required where permeable pavement meets adjacent non-concrete pavement or soil.

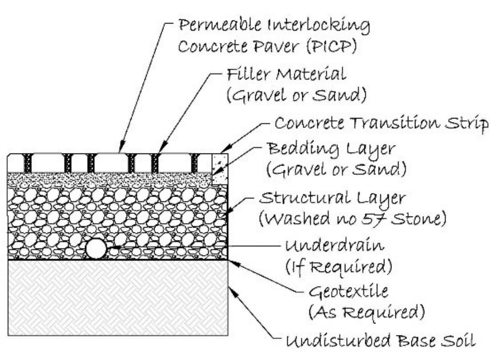

Figure 16. Permeable interlocking concrete

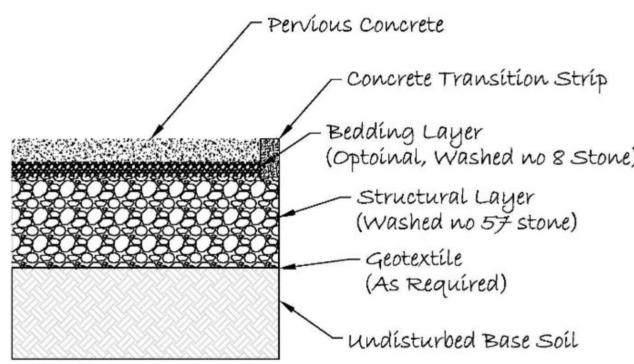

Figure 17. Pervious concrete

Operations and Maintenance

This section provides recommendations for the maintenance of green infrastructure practices applicable to the conceptual design at the Washington Street and Gateway Park sites. Maintenance tasks and the associated frequency of the tasks are included for the practices incorporated into the conceptual designs.

Bioretention

Maintenance activities for bioretention are generally similar to maintenance activities for any public garden or landscaped area. The focus is to remove trash and monitor the health of the plants, replacing or thinning plants as needed. Over time, a natural soil horizon should develop which will assist in plant and root growth. An established plant and soil system will help in improving water quality and keeping the practice drained. Irrigation for the landscaped practices may be needed, especially during plant establishment periods or in periods of extended drought. Irrigation frequency will depend on the season and type of vegetation. Native plants often require less irrigation than non-native plants.

In winter climates experiencing heavy snowfall, such as southern Maine, the plowing of snow on to the bioretention area should be avoided if possible. Over time the snow and ice can compact the bioretention media reducing infiltrative capacity and overall function. In addition sand which is spread on roadways to provide vehicular traction can accumulate on the top of the media bed near inlets and should be removed after each snow season using hand tools.

Table 9. Bioretention Operations and Maintenance Considerations.

Task	Frequency	Maintenance notes
Monitor infiltration and drainage	1 time/year	Visually inspect drainage time (12 hours). Might have to determine infiltration rate (every 2–3 years). Turning over or replacing the media (top 2–3 inches) might be necessary to improve infiltration (at least 0.5 in/hr).
Pruning	1–2 times/year	Nutrients in runoff often cause bioretention vegetation to flourish.
Mowing	2–12 times/year	Frequency depends on the location, plant selection and desired aesthetic appeal.
Mulching	1–2 times/ year	Recommend maintaining 1”–3” uniform mulch layer.
Mulch removal	1 time/2–3 years	Mulch accumulation reduces available water storage volume. Removal of mulch also increases surface infiltration rate of fill soil.
Watering	1 time/2–3 days for first 1–2 months; sporadically after establishment	If drought conditions exist, watering after the initial year might be required.
Fertilization	1 time initially	One-time spot fertilization for first year vegetation.
Remove and replace dead plants	1 time/year	Within the first year, 10% of plants can die. Survival rates increase with time.
Inlet inspection	Once after snow season, then monthly during the remainder of the year.	Check for sediment accumulation to ensure that flow into the bioretention area is as designed. Remove any accumulated sediment.

Task	Frequency	Maintenance notes
Outlet inspection	Once after the snow season then monthly during the remainder of the year	Check for erosion at the outlet and remove any accumulated mulch or sediment.
Underdrain inspection	Once per year	Check for accumulated mulch or sediment. Flush if water is ponded in the bioretention area for more than 12 hours.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, plant health, spot weeding, and removing mulch from the overflow device.

Permeable Pavement

The primary maintenance requirement for permeable pavement consists of regular inspection for clogging and sweeping with a vacuum-powered street sweeper. If interlocking concrete permeable pavers are installed, the small aggregate used to fill the void between pavers must be replaced following vacuum sweeping. However, if use of the proposed permeable walkways in Gateway Park is limited to foot traffic only, actual maintenance requirements will be much less than are typically recommended in Table 10.

Table 10. Permeable Pavement Operations and Maintenance Considerations

Task	Frequency	Maintenance notes
Impervious to Pervious Interface	Quarterly	Check for sediment accumulation to ensure that flow onto the permeable pavement is not restricted. Remove any accumulated sediment. Stabilize any exposed soil.
Vacuum street sweeper	Twice per year as needed	Portions of pavement should be swept with a vacuum street sweeper at least twice per year or as needed to maintain infiltration rates.
Replace fill materials (applies to pervious pavers only)	1-2 times per year (and after any vacuum truck sweeping)	Fill materials will need to be replaced after each sweeping and as needed to keep voids with the paver surface.
Miscellaneous upkeep	4 times per year or as needed for aesthetics	Tasks include trash collection, sweeping, and spot weeding.
Monitor infiltration and drainage	After each rainfall event	Visually inspect pavement surface for signs of surface ponding.

Stormwater Control Measure Cost Estimates

The construction cost estimates for implementing the Green Infrastructure SCMs along Washington Street are found in Table 11. Costs for the project are estimated based on the existing site conditions and account for the potential necessity of underdrains and providing detention for 1" of runoff from impervious surfaces. The construction cost estimate for implementing the Gateway Park Green Infrastructure SCMS is included separately in Table 12. These costs do not include the cost associated with removal of the existing buildings and pavement surfaces. The costs for both project areas include both construction of the SCMs as well as site preparation, mobilization, etc., but do not account for utility removal/rerouting that may be required upon site survey and final design. It is also assumed that all construction is retrofit.

Table 11. Cost Estimate for Washington Street Green Infrastructure SCMs

Item No	Description	Quantity	Unit	Unit Cost	Total
	Preparation				
1	Traffic Control	15	day	$1,000.00	$15,000
	Site Preparation				
2	Curb and Gutter Removal	591	LF	$3.30	$1,951
3	Excavation and Removal	680	CY	$45.00	$30,582
	Traditional Bioretention				
4	Fine Grading	5238	SF	$0.72	$3,771
5	Soil Media	291	CY	$40.00	$11,639
6	Filter Layer (sand and No. 8 stone)	65	CY	$45.00	$2,910
7	Vegetation	5238	SF	$4.00	$20,950
8	Mulch	32	CY	$55.00	$1,778
9	Curb and Gutter	1290	LF	$22.00	$28,389
Construction Subtotal					**$116,970**
10	Planning (20% of subtotal)				$23,394
11	Mobilization (10% of subtotal)				$11,697
12	Construction contingency (20% of subtotal)				$23,394
Construction Total					**$175,454**
13	Design (30% of Construction Total)				$52,636
Total Cost					**$228,091**

Table 12. Cost Estimate for Gateway Park Green Infrastructure SCMs

Item No	Description	Quantity	Unit	Unit Cost	Total
	Preparation				
1	Traffic Control	15	day	$1,000.00	$15,000
	Site Preparation				
2	Excavation and Removal	574	CY	$45.00	$25,817
	Traditional Bioretention				
3	Fine Grading	5969	SF	$0.72	$4,298
4	Soil Media	169	CY	$40.00	$6,756
5	Filter Layer (sand and No. 8 stone)	38	CY	$45.00	$1,689
6	Vegetation	3040	SF	$4.00	$12,160
7	Mulch	19	CY	$55.00	$1,032
8	Curb and Gutter	478	LF	$22.00	$10,516
	Permeable Pavement				
9	Permeable Concrete	4420	SF	$12.00	$53,040
10	Structural Layer (washed no 57 or no 2 stone)	82	CY	$50.00	$4,093
	Grassed Detention				
11	Fine Grading	4840	SF	$0.72	$3,485
12	Concrete Box Riser Structures	2	EA	$3,500.00	$7,000
13	Precast Concrete Junction Box	1	EA	$1,200.00	$1,200
14	18" CMP	105	LF	$31.26	$3,282
Construction Subtotal					**$77,267**
15	Planning (20% of subtotal)				$15,453
16	Mobilization (10% of subtotal)				$7,727
	Bond (5% of subtotal)				$773
17	Construction contingency (10% of subtotal)				$15,453
Construction Total					**$116,673**
18	Design (40% of Construction Total)				$46,669
Total Cost					**$163,343**

Conclusions

Evaluation of the Sanford Mill Yard complex revealed numerous opportunities to integrate green infrastructure primarily within the existing transportation right of ways and on publically owned spaces. Permeable pavement, bioretention, and tree box filters were identified as the most applicable practices within the project area; additionally, grassed detention is suitable for the Gateway Park site. Through hydrologic modeling, the incorporation of these practices was shown to provide significant treatment of the total runoff volume for the 2- and 10-year storm events (between 55% and 91% total volume). In addition, a small amount of peak flow reduction is also provided for the 2-year storm event, particularly at the higher elevation storm structures. Although a majority of design storm flows were treated and discharged through the drainage network, implementation of the green infrastructure retrofits alone did not mitigate the increase in peak flow along Washington St.; with or without the addition of the Main Street drainage diversion.

However, the Washington Street project site is ideal for demonstrating a variety of green infrastructure practices incorporated into a redeveloping brownfield to address water quality concerns. Because of its location along the Mousam Mill Yard and adjacent to the visually stimulating dam for Millpond Number 1 there is potential for much interest from local officials, developers, and residents. Implementation of green infrastructure in the project area will enhance ongoing redevelopment activities in the Mill Yard while reducing the impact of stormwater runoff to the Mousam River. In addition, the green infrastructure practices prescribed for the Mill Yard Complex and the integration of these practices in the project site may serve as examples to other similar communities in the northeastern region or elsewhere in the U.S. where aging brownfields are being converted into residential and commercial uses.

As the City of Sanford moves forward with development of the Gateway Park and potential modifications to Washington Street and its associated drainage system, the concept plans contained in this report can serve as a basis for development of final design documents. In order to ensure project success the community should conduct detailed subsurface investigations to verify conditions are suitable for the green infrastructure practices proposed. Furthermore as the city begins planning for these project areas the conceptual design plans should be provided to any stakeholder groups or planning consultants so that they can be incorporated into the planning process.

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Appendix A. SWMM Analysis

Hydrology and Hydraulics

SWMM Background

The EPA's Stormwater Management Model (EPA SWMM v5.0) was utilized to assess the existing conditions of the Washington Street stormwater infrastructure and evaluate green infrastructure opportunities. 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; the current public version of SWMM as of this writing is 5.0.022 (released April 2011).

SWMM represents land areas as a series of *subcatchments*, with properties that define retention and runoff of precipitation, infiltration, 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 to define the connectivity and control within the drainage network. Precipitation and other meteorological input time series are used to drive the hydrologic and water quality response in the simulation. Subcatchment runoff is directed to *junction nodes*, which are connected to the channel network. The channel network is represented with a series of *conduits* (a type of link) and junction nodes, allowing for the specification of variation in channel properties.

Green infrastructure improvements were represented using the LID component recently introduced in SWMM 5. LID is modeled in SWMM using a layered configuration, and it allows a great deal of flexibility in representing various types of practices, including bioretention, swales, infiltration devices, permeable pavement, rain barrels, cisterns, etc. Green-Ampt infiltration parameters can be defined for filtering media, and the model tracks evaporation and soil moisture allowing infiltration rates during runoff events to be dynamic. Table A-1 provides the assumptions used in the configuration for bioretention utilized in the LID control feature of SWMM. The primary design parameters for modeling hydraulic performance of bioretention in SWMM include the surface storage depth, planting soil depth and void space ratio, aggregate reservoir depth and void space ratio, and native soil infiltration rate.

Table A-1. SWMM LID Input Values for Bioretention

Property	Bioretention
Surface ponding (in)	6
Media thickness (in)	36
Porosity (fraction)	0.437
Field Capacity (fraction)	0.105
Wilting Point (fraction)	0.047
Conductivity (in/hr)	1.18
Conductivity slope	7
Suction head (in)	2.4
Storage layer (in)	14
Storage void ratio	0.54
Bottom infiltration rate (in/hr)	0
Underdrain?	Yes
Underdrain offset	0
Underdrain coefficient *	5
Underdrain exponent *	1

* Values used reflect no limitation on underdrain outflow (i.e., outflow rate is limited by media filtration rate)

Existing Hydrology and Hydraulics

To assess the existing capacity of the Washington Street drainage system and to evaluate the feasibility of using green infrastructure SCMs to mitigate the increase in proposed drainage area, multiple hydrologic calculations were required. Rainfall/runoff simulations were calculated for the 2-year, 24-hour and 10-year, 24-hour storm events which were identified by the project team as appropriate design storms to evaluate the performance of piped storm system conveyance. According to Chapter 2, Volume III of Maine's BMPs Technical Design Manual, rainfall depth estimates for Sanford, Maine are 3 inches and 4.6 inches, respectively, for the two design storms. Rainfall distributions for the Type III, 24 hour storm were applied to the rainfall depths to develop an event-based time series for the model with 6 minute time intervals.

SWMM automatically calculates the runoff coefficient (C) based on a subcatchment's percent impervious area. Runoff coefficients are used to estimate initial abstraction from the drainage areas and calculate the fraction of rainfall that becomes runoff. Table A-2 shows the calculated runoff coefficients and the estimated peak runoff rates for the existing drainage network in the study area.

Table A-2. Existing Drainage Area Runoff Rates

Subcatchment	C	Peak Runoff 2-year, 24-hour (cfs)	Peak Runoff 10-year, 24-hour (cfs)
Com-1	0.978	3.96	6.11
Com-2	0.992	2.3	3.57
RD-1	0.92	0.13	0.21
RD-2	0.992	0.63	0.97
RD-3	0.914	0.37	0.58
Mix-1	0.89	4.22	6.71
Mix-2	0.872	2.65	4.26
Com-3	0.657	0.82	1.42
Res-1	0.873	2.39	3.86
Rd-4	0.992	0.34	0.52

Results from the hydraulic routing through the existing drainage system are displayed in Table A-3 for both design storms. Reported parameters include the peak flow through the junction, the amount of time that the node is surcharged (depth of water is above the highest conduit), and the amount of time the node is flooded (depth of water is above rim elevation of the structure). These parameters were most important in mitigating the impact from the additional drainage area using the proposed green infrastructure practices.

Table A-3. Existing Condition Hydrology/Hydraulics at Trunk-Line Junctions

Junction Node	2-year, 24-hour			10-year, 24-hour		
	Q (cfs)	Hours Surcharged	Hours Flooded	Q (cfs)	Hours Surcharged	Hours Flooded
CB-1	0.13	0	0	1.27	0.21	0
MH-1	0.32	0	0	1.21	0.22	0
MH-2	4.14	0.19	0	6.32	0.37	0.1
J-1	8.13	0.36	0	12.32	0.66	0
MH-3	8.34	0.2	0.01	12.32	0.38	0.26
J-2	9.05	0.41	0	9.07	0.68	0
J-3	11.64	0.6	0	12.84	0.85	0
MH-5	13.94	0.44	0.31	16.41	0.71	0.57
MH-4	9.68	0.74	0.02	9.68	0.97	0.19
J-4	9.98	0.61	0	10.11	0.86	0

Total runoff from all of the drainage areas was estimated as 1.66 ac-ft and 2.86 ac-ft, respectively, for the 2- and 10-year storm events. However, not all of this runoff is conveyed through the drainage system and discharged through the outlet. As shown above, some of the junctions experience periodic flooding during the 2-year storm event and greater. Based on SWMM results, approximately 0.3 ac-ft and 0.7 ac-ft of runoff is considered internal outflow for the 2- and 10-year events. Internal outflow is the total volume of runoff that exceeds the capacity of the underground conveyance system and leaves the system via non-outfall nodes (e.g., surface flow). Based on the steep gradient and curb-inlet configurations within the Washington Street study area, the model was configured to assume no ponding and temporary storage at the storm sewer junctions.

Proposed Hydrology and Hydraulics

SWMM was also utilized to evaluate the hydraulic impacts to the drainage system by adding runoff from Main Street as a part of a subsequent combined-sewer separation project. The proposed drainage area on Main Street consists of approximately 1 acre of impervious roadway between the Washington Street and Berwick Road intersections. The drainage area, as detailed in Table A-4, is modeled in SWMM to connect to the Washington Street drainage system at CB-1. This catch basin is approximately 6 feet deep, which is more than sufficient depth to receive drainage from a storm sewer installed down the proposed 415-foot long Main Street drainage area.

Table A-4. Main Street Drainage Area

Property	Main-1
Area (ac)	0.99
Flow path (ft)	415
Slope (%)	0.1%
Imperv. (%)	100
Outlet node	CB-1

Results from the SWMM model (Table A-5) show the impacts to the existing drainage system junctions on Washington Street by adding the Main Street drainage area at CB-1. As shown in Table A-6, Significant increases in peak flow and time of surcharge/flooding are predicted at the upper junctions (e.g., CB-1, MH-1, MH-2) where flooding was not previously occurring for the existing conditions simulation. However, less impact to the drainage system is incurred at the lower junctions since these junctions already experience flooding. Since the model assumes no ponding at these junctions, extra runoff to these locations is added to the internal outflow in the model.

Table A-5. Proposed Condition Hydrology/Hydraulics at Trunk-Line Junctions

Junction Node	2-year, 24-hour			10-year, 24-hour		
	Q (cfs)	Hours Surcharged	Hours Flooded	Q (cfs)	Hours Surcharged	Hours Flooded
CB-1	2.15	0.17	0	3.5	0.4	0.23
MH-1	2.16	0.17	0	2.83	0.39	0
MH-2	6.1	0.31	0	8.25	0.59	0.19
J-1	10.32	0.54	0	12.32	0.8	0
MH-3	10.33	0.29	0.15	12.32	0.53	0.34
J-2	9.14	0.54	0	9.18	0.8	0
J-3	11.64	0.71	0	12.84	0.96	0
MH-5	13.94	0.56	0.4	16.41	0.81	0.67
MH-4	9.67	0.83	0.01	9.67	1.11	0.18
J-4	9.98	0.7	0	10.11	0.94	0

Table A-6. Percent Increase in Hydrology/Hydraulics from Main Street Drainage Area

Junction Node	2-year, 24-hour			10-year, 24-hour		
	Q (cfs)	Hours Surcharged	Hours Flooded	Q (cfs)	Hours Surcharged	Hours Flooded
CB-1	1554%	N/A[1]	0%	176%	90%	N/A[1]
MH-1	575%	N/A[1]	0%	134%	77%	0%
MH-2	47%	63%	0%	31%	59%	90%
J-1	27%	50%	0%	0%	21%	0%
MH-3	24%	45%	1400%	0%	39%	31%
J-2	1%	32%	N/A[1]	1%	18%	0%
J-3	0%	18%	N/A[1]	0%	13%	0%
MH-5	0%	27%	29%	0%	14%	18%
MH-4	0%	12%	-50%	0%	14%	-5%
J-4	0%	15%	N/A[1]	0%	9%	0%

[1] No flooding calculated for existing conditions; divisible-by-zero error