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Technical Memorandum

DRAFT

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SUBJECT: East Rock Green Infrastructure Demonstration Area
Concept, Analysis, and Monitoring Plan
H&S Project 90121-001

Introduction

Within an urban area like New Haven, effective management of stormwater runoff is important in order to reduce combined sewer overflows (CSOs) and improve the quality of receiving waters. Conventional grey infrastructure approaches to CSO control, such as sewer separation and increased in-line or off-line storage, can be effective at reducing CSOs, but also present an array of challenges and offer few benefits beyond CSO control. Due to the evident challenges of managing stormwater runoff and reducing CSOs in an urban environment like New Haven, it is imperative to have access to the full suite of stormwater management tools in order to optimize the effectiveness and efficiency of stormwater management efforts. One stormwater management strategy that is gaining increasing national prominence is the use of green infrastructure. Green infrastructure utilizes predominantly natural processes, like infiltration and evapotranspiration, to manage stormwater runoff. These controls reduce the rate and volume of stormwater runoff entering the combined sewer system, and are often widely distributed in the vicinity of the runoff source. Beyond stormwater management, green infrastructure can provide an array of additional benefits including improved aesthetics, cooling effects, urban greening, and increased property values.

There are many opportunities for green infrastructure implementation with the City of New Haven, as illustrated in the April 2012 "Green Infrastructure Feasibility Scan for Bridgeport and New Haven, CT." While green infrastructure can provide an array of benefits, there are many aspects of implementation efforts that are influenced by local conditions. As such, a green infrastructure demonstration program can provide valuable information on the challenges and benefits of green infrastructure within the City of New Haven, better informing and guiding future implementation efforts. A preliminary evaluation of opportunities for a green infrastructure demonstration program within New Haven was conducted and is discussed within this memorandum. Due to the nature of these assessments, they are not expected to serve as a definitive evaluation of green infrastructure concepts and anticipated benefits, but rather general indications to substantiate the merit of a demonstration program and further associated analyses.

Green Infrastructure Demonstration Area

While green infrastructure demonstration efforts anywhere within the City can provide valuable information, these efforts are particularly informative when implementation can occur within a concentrated neighborhood area. Within the East Rock region of New Haven, there is a combined sewer area largely surrounded by streets where the sewer has been separated through projects dating back to the early 1980s. This area is generally bound by Willow Street, Mechanic Street, Hines Place, and Nash Street (Figure 1). Due to the somewhat isolated combined sewer region in this area, there are no plans in the near future for separating these sewers. This area does contribute to CSOs, with the closest downstream CSO outfall discharging into Mill River in the general vicinity of Interstate 91. GIS and limited on-site evaluations suggest that the nature of this localized combined sewer area makes it a good candidate for a green infrastructure demonstration project. This suitability is further supported by the fact that major sewer separation efforts are planned in the general vicinity of this demonstration area, possibly reducing construction costs by consolidating activities with nearby efforts.

There are a variety of impervious surfaces within this demonstration area, including rooftops, driveways, sidewalks, and streets, which combined cover approximately 55% of the demonstration area. Sidewalks and streets are of particular interest for green infrastructure implementation as they are located within the publicly owned right-of-way, facilitating construction and maintenance logistics, and cover more than 25% of the demonstration area. Furthermore, the directly connected nature and configuration of runoff flow paths along the gutter makes these surfaces amenable to runoff management with green infrastructure retrofits.

The northern portion of the demonstration area, labeled as on-site demo boundary in Figure 1, consists primarily of rooftops and parking lots associated with the East Rock Global Studies Magnet School. There may be opportunities for on-site green infrastructure implementation at this location, utilizing controls such as blue roofs, green roofs, and permeable pavement. In total, GIS analyses indicate that the street-side demonstration area covers approximately 24 acres, with an additional 9 acres associated with the on-site demonstration area. Due to the implementation logistics and opportunities for lessons learned to be readily applied throughout the City, it is anticipated that green infrastructure efforts will initially focus on implementation within the street-side demonstration area, with considerations for further implementation throughout the on-site area. As such, this memorandum is predominantly focused upon green infrastructure within the street-side demonstration area.

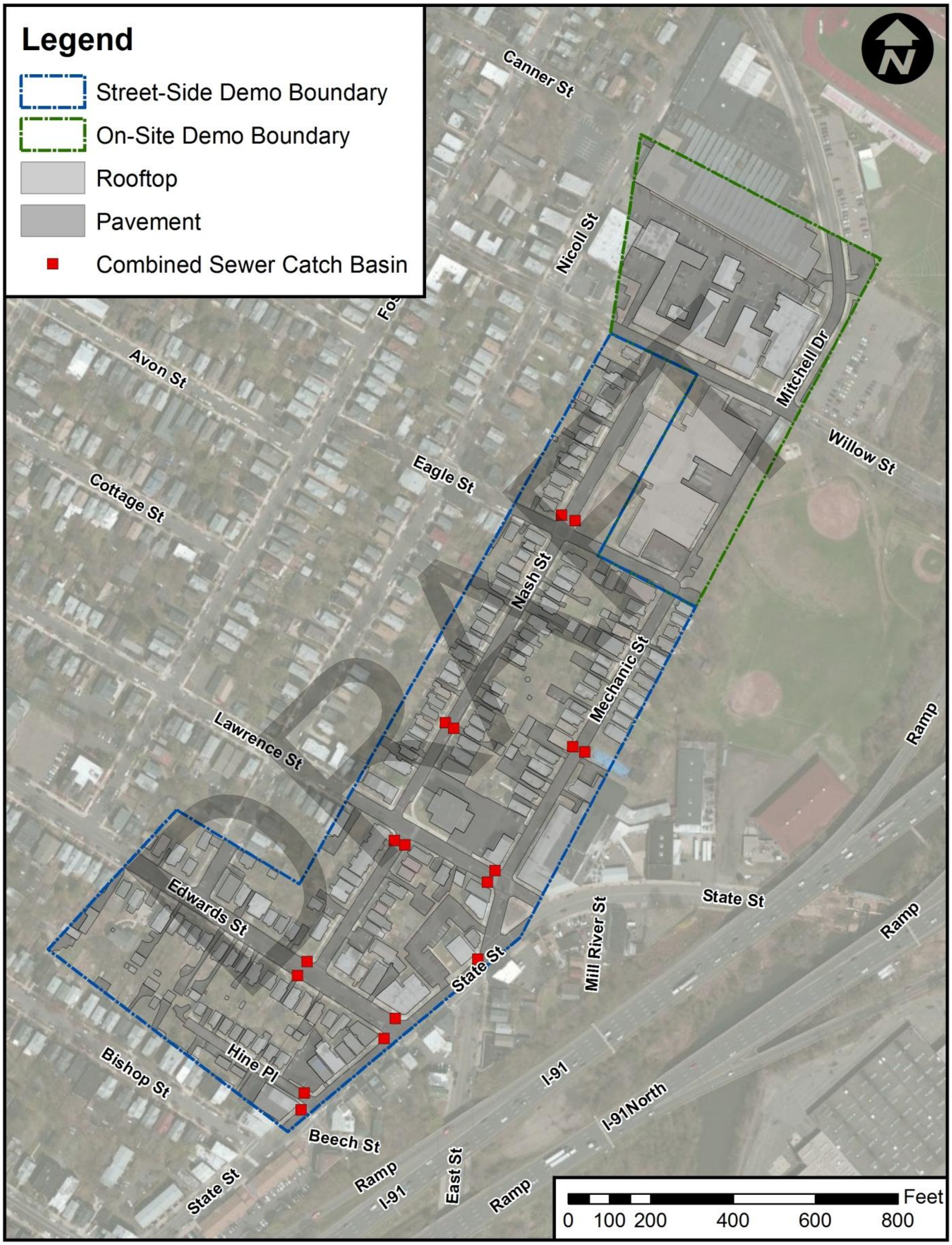

Figure 1: General boundary of green infrastructure demonstration area

Conceptual Design

With a green infrastructure neighborhood demonstration area identified, planning level reviews of GIS data, aerial and street-side photography, and cursory site walkthroughs were performed to develop concepts for green infrastructure controls within this area. Street-side bioswales are expected to be the predominant green infrastructure control utilized within the demonstration area (Figure 2). These controls share similarities in appearance with typical tree pits, but contain a number of elements designed to manage stormwater runoff. Along the street, curb cuts divert runoff from the roadway into the bioswale. Within the bioswale, a shallow surface depression provides temporary storage for runoff, allowing it to infiltrate into the bioswale soil. The bioswale soil consists of an engineered sandy mix, designed to support plant growth at the surface while also rapidly infiltrating stormwater runoff. Underneath the bioswale soil, a layer of crushed stone provides additional storage capacity. Bioswales are generally designed with an open bottom and no underdrain system, allowing water to seep from the bottom of the system into the underlying soils. Typically, bioswales are installed in the sidewalk, upstream of existing catch basins.

Figure 2: Conceptual schematic of a street-side bioswale

As with any urban area, there are unique localized constraints within the demonstration area that influence the feasibility of green infrastructure controls and their overall design. In general, bioswales are sited to avoid surface structures, utilities, driveways, building entrances, and existing trees. Although detailed site analyses have not yet been performed, planning level reviews have indicated the presence of some potential conflicts throughout the demonstration area, as well as alternative green infrastructure configurations to address those challenges. A standard street-side bioswale is generally designed to include a tree, along with other smaller vegetation; however, this configuration could present challenges within certain portions of the demonstration area. Overhead utilities and large existing tree canopies are prevalent within parts of the demonstration area. Planting new trees in these areas creates the potential for future interference. Additionally, there are sections within the demonstration area where potential bioswale locations are located directly in front of existing homes. Planting new trees in these areas could conceal the view of these homes from the street in the future, which may be undesirable to residents. In order to address these issues, an alternative bioswale design will be considered that utilizes the same stormwater management components as a standard bioswale, but relies upon smaller shrubs and other vegetation instead of larger trees. Coordination with other City agencies during detailed planning and design efforts could also support resolution of these conflicts, selecting compatible vegetation, while also siting and designing bioswales in order to minimize any potential impacts to existing trees.

Figure 3: Large mature trees lining Nash Street, potentially interfering with newly planted bioswale trees

An additional consideration for street-side bioswale implementation is for areas where there is limited existing space along the sidewalk. Bioswales are typically installed within the sidewalk adjacent to the street. In areas where existing sidewalks or interim grass strips are narrow, there may not be adequate room to install a bioswale without impeding pedestrian traffic. In these areas, alternative bioswale designs could utilize a narrow width, extend out into street-side parking areas through the use of bump-outs, or rely upon permeable pavement for stormwater management instead of bioswales (Figure 4). Opportunities for further development and consideration of design alternatives to address a range of site constraints will exist during detailed planning and design efforts.

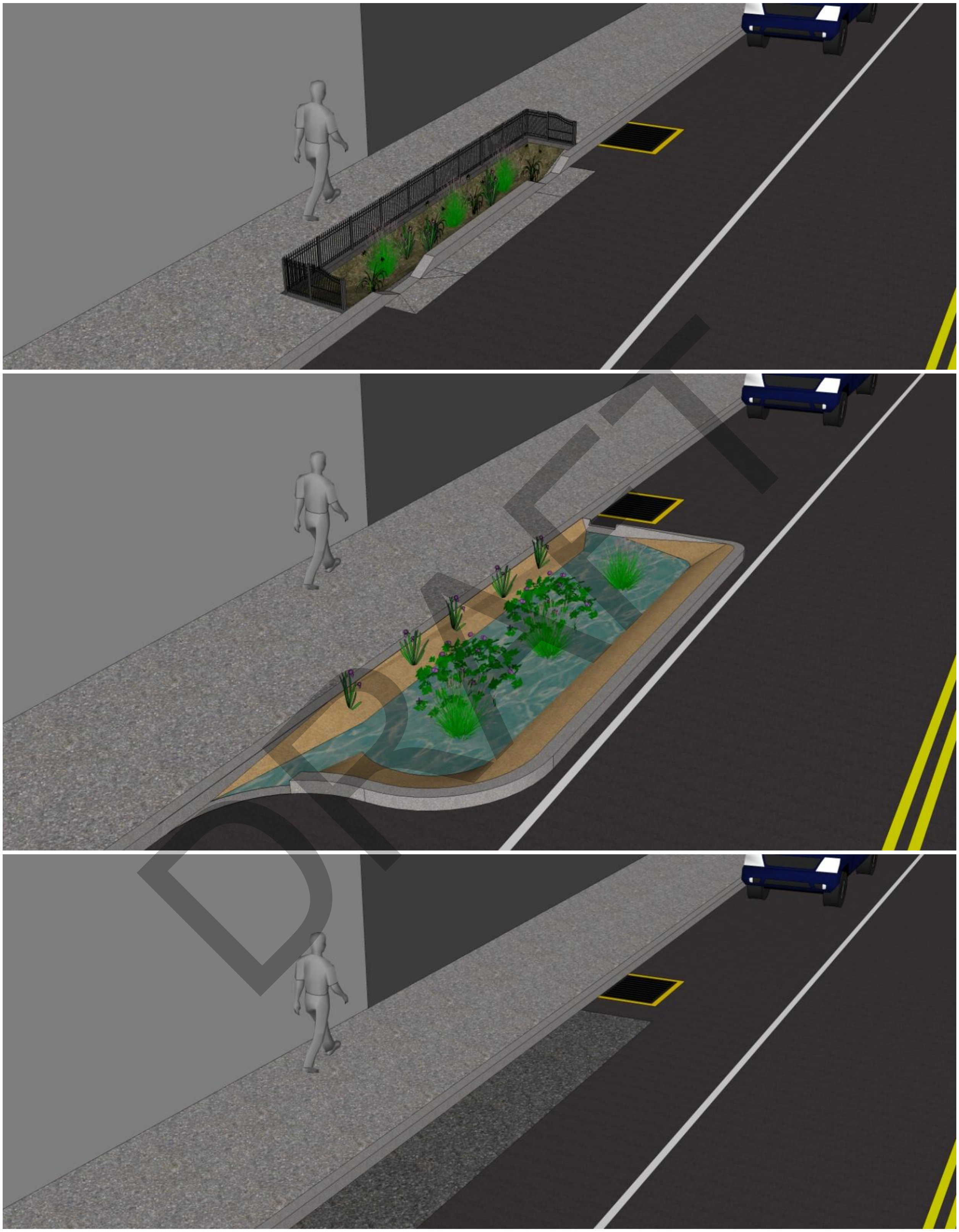

Figure 4: Conceptual illustration of narrow bioswale (top), bump-out bioswale (middle), and street-side permeable pavement (bottom) to address narrow sidewalk constraints

There are a variety of additional constraints to be considered during detailed design efforts, including the location of subsurface utilities, soil properties, water table elevations, detailed street and sidewalk geometry and topography, and evaluation of overall drainage patterns. Although these detailed evaluations have not yet been conducted, preliminary reconnaissance efforts, relying upon GIS data, aerial and street-side photography, and cursory site walkthroughs, have identified possible areas for bioswale implementation throughout the demonstration area (Figure 5). These preliminary evaluations suggest that more than 10% of total impervious coverage within the demonstration area could be managed with green infrastructure. This 10% managed area is in line with goals established for other urban areas utilizing green infrastructure, and equates to approximately 1.3 acres of managed impervious area for this demonstration project. Initial estimates indicate that it may cost approximately $500,000 to construct bioswales to provide this level of stormwater management. A preliminary estimate of the impact managing this area with green infrastructure will have on the sewer system and CSOs based on sewer system modeling is presented later in this memo, although the ultimate effect of green infrastructure could be established through monitoring efforts, also discussed later in this memo.

Figure 5: Preliminary bioswale locations within the demonstration area

CSO Reduction Approximations

The effect of green infrastructure on CSO frequency and volume can be difficult to predict. Combined sewer systems are often highly complex systems with varying hydraulic and storage capacities, regulator configurations, contributing drainage characteristics, and interconnections with many elements. Beyond the complexities of the combined sewer system, green infrastructure controls themselves can provide varying degrees of stormwater control. Generally, green infrastructure controls are designed to manage runoff from the first inch of rainfall. Most annual runoff is associated with these smaller storm events, which makes it practical to more cost effectively manage these potentially frequent CSO triggers. Depending upon the nature of a storm event and green infrastructure characteristics, it may be possible for individual controls to manage stormwater depths well beyond one inch, or effectively manage the one inch depth for a larger contributing drainage area.

Due to the complexities of combined sewer systems, computer models are often used to evaluate the performance of these systems and their response to various storm events. Within New Haven, a model of the combined sewer system was previously developed within Danish Hydraulic Institute's (DHI's) Model for Urban Sewers (MOUSE) framework. The New Haven MOUSE model was developed in the late 1990's as documented in "Technical Memorandum #3 – System Inventory and Model Results, December 1998, CH2MHill." The MOUSE model solves the fully dynamic St. Venant equations that result in a prediction of flows, velocities and levels of water throughout the modeled network for a range of storm event conditions. The output of the model includes graphical and time series data for flows, volumes, velocities and water levels at any location in the modeled sewer system. This output includes predictions of volumes of CSO discharge at each outfall in the system.

The existing MOUSE model was used to simulate CSO discharges from the combined sewer system before and after the implementation of green infrastructure. Similar to the nature of the combined sewer system itself, a MOUSE model is a complex system, requiring substantial effort to develop and maintain. This existing model can serve as a valuable tool for assessing the potential effects of green infrastructure implementation; however, due to the complexities of the combined sewer system, green infrastructure controls, and intricacies of the model itself, results are only expected to provide a basic context for impacts on CSO discharges. The model was simulated for a 1-year design storm event having a total depth of 1.6 inches and a peak intensity of 0.9 inches per hour. A second model simulation was performed by changing the model's hydrologic parameters to represent the effect of green infrastructure. The MOUSE model consists of a network of subcatchments (i.e. drainage areas), links (i.e. pipes), nodes (i.e. manholes), and outlets (i.e. CSO outfalls). Three subcatchments that fell within the proposed green infrastructure demonstration boundary were modified such that 10% of the impervious area was subjected to a modified rainfall pattern, with the remainder subjected to normal design storm rainfall. This modified rainfall pattern was developed by removing the first half-inch of rainfall from the 1-year design storm event. This modification simulates the impact of green infrastructure intercepting that portion of the rainfall/runoff before it can get into the combined sewer system. In reality, the green infrastructure may intercept 1 inch or more, and thus this modeling simulation represents a conservative estimate of the potential impacts.

Results of the model simulations are shown in Table 1 below. Various CSO locations exhibited reductions in predicted CSO volume, with one location exhibiting almost a 20% reduction. Modeled outlets with substantial CSO volume reductions were predominantly located at outfalls along East Street (Figure 6). The variability of changes in CSO volume at locations in the immediate vicinity and far away from the demonstration area are indicative of the complex interconnected nature of the combined sewer system and the model itself.

The modeling results indicate a real potential for CSO reduction benefits, considering the conservative nature of the simulation approach, and limited size of the green infrastructure demonstration area. Simulations were also attempted for a 2-yr design storm and the 1967 rainfall year; however, simulations were either not successful or not informative, likely due to inherent complexities and instabilities in the system model.

Table 1: One-year design storm simulation results for green infrastructure implementation at selected CSO outfalls

Model ID of CSO Outlet	Baseline (no GI)		With GI			
	Peak Flow Rate	Volume	Peak Flow Rate	Volume	Change in Volume	% Change
	[cfs]	[gal]	[cfs]	[gal]	[gal]	
NEWR011l1	153	4,430,091	153	4,367,737	-62,362	-1.41%
R12D010l1	39	522,937	39	513,369	-9,568	-1.83%
R14D040l1	36	323,561	36	295,971	-27,590	-8.53%
R14D050l1	30	569,551	29	523,086	-46,472	-8.16%
R16N140l2	25	839,099	22	734,522	-104,584	-12.46%
R19N070l1	35	869,636	32	697,169	-172,474	-19.83%

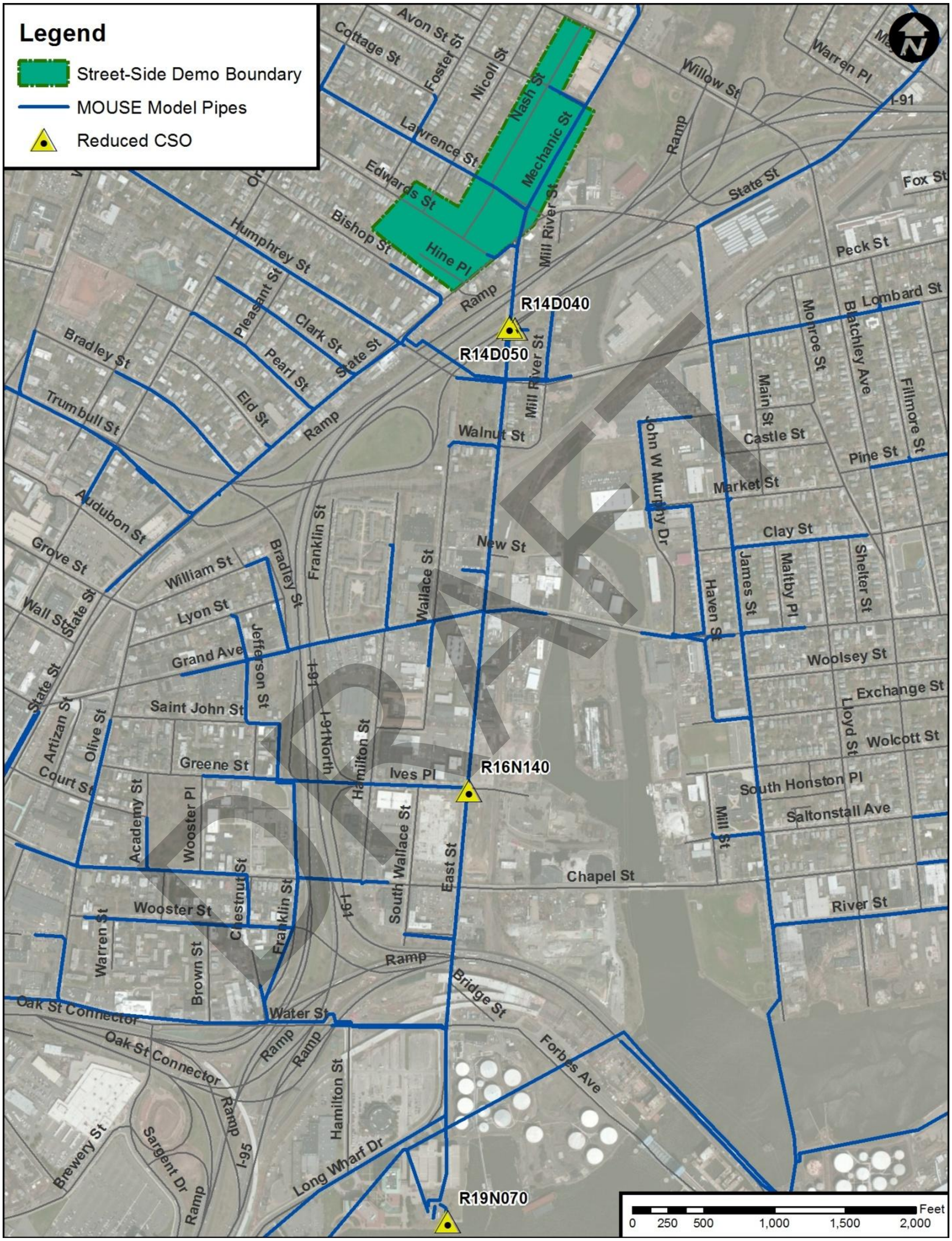

Figure 6: Location of outfalls within the MOUSE model where substantial CSO reductions were simulated

Green Infrastructure Monitoring Program

There is a wealth of practical information that can be gained from a green infrastructure demonstration program, including construction and maintenance logistics, and community perception. Beyond these qualitative aspects, quantitative evaluations of green infrastructure performance can provide real information on the effect of green infrastructure on sewer flows and CSOs, allowing these stormwater controls to be more effectively incorporated into future management efforts and long term control plans (LTCPs). These evaluations can expand beyond the preliminary modeling results discussed herein, providing detailed information for model inputs, or direct guidance on how green infrastructure should be designed and implemented within the City. Due to these benefits and more, a green infrastructure monitoring program is proposed for the East Rock demonstration to evaluate quantitative runoff management benefits.

A quantitative monitoring program generally relies upon remote monitoring equipment in order to evaluate performance continuously over time, across a range of conditions and storm characteristics. Remote monitoring equipment can consist of water level loggers, soil moisture sensors, and tipping bucket rain gauges, among other sensors. Water level loggers can be utilized directly to evaluate water storage within a green infrastructure control, or in conjunction with a weir or flume to measure flow rates. Frequently, these loggers measure the pressure at the sensor location and convert that pressure measurement to a depth of water. These depths are logged at a pre-defined interval, such as five minutes. Soil moisture sensors provide additional information on the movement and storage of water within a green infrastructure source control. Outside of the source control itself, a tipping bucket rain gauge provides information on both the depth and intensity of rainfall over time. Efforts during the design phase can be made to maximize the robustness of the monitoring equipment, including concealing and armoring equipment to minimize opportunities for vandalism and maintenance requirements. Generally, remote monitoring equipment is visited every few weeks to download data, maintain equipment, and perform any qualitative evaluations of source control performance.

The scale of monitoring efforts can vary from individual source controls, to individual streets, to overall sewersheds. Each of these aspects provides different, but valuable information about green infrastructure performance. At the individual bioswale scale, monitoring activities can quantify source control inflow and outflow, as well as general aspects of performance like storage capacity and drawdown rates. As direct inflow and outflow measurements may be difficult to obtain for street-side bioswales, these parameters can often be evaluated through the use of piezometers and soil moisture sensors, in conjunction with on-site testing. Results from these individual source control monitoring efforts can provide valuable information regarding bioswale functionality and the effect of various design elements on performance. While these evaluations can inform the ability of these source controls to retain runoff and reduce flows into the sewer system, they don't necessarily provide a comprehensive indication of the effect of green infrastructure on the sewer system.

At a larger scale, flow monitoring within the sewer system can provide information on the cumulative effect of green infrastructure on sewer flows and CSOs. Ideally, green infrastructure can be implemented throughout the entirety of a moderately sized and well-defined sewershed. Under this scenario, flow monitoring in the sewer at the downstream end of the sewershed can provide information on the effect of a certain degree of implementation, say 10% of impervious areas, on overall sewer flows and CSOs. In many cases, such as the East Rock demonstration area, sewersheds don't satisfy this ideal scenario, containing areas where sewers have been separated or the overall sewershed is too large to identify the specific effect of isolated green infrastructure implementation. In these situations, flow monitoring at the downstream end of the sewershed may not clearly show the effect of green infrastructure implementation. To address these concerns, sewer flow monitoring can be conducted at a smaller scale, such as at the downstream end of an individual street. Flow monitoring at this scale can provide a more comprehensive evaluation of the effect of green infrastructure on sewer flows than monitoring individual bioswales, but also minimize the logistical complexities of overall sewershed monitoring. Monitoring evaluations of green infrastructure can compare sewer flows before and after implementation or within sewersheds where green infrastructure has and has not been implemented.

Summary and Conclusions

Preliminary planning level evaluations indicate that there are opportunities to implement green infrastructure within the East Rock demonstration area discussed herein, providing CSO reduction benefits and valuable information to guide future stormwater management efforts throughout the City. Street-side bioswales are expected to serve as a valuable component of these demonstration efforts, with preliminary opportunities evident and simplified implementation logistics due to public right-of-way ownership. Initial CSO modeling efforts within the demonstration area indicate that the implementation of green infrastructure to manage runoff from 10% of impervious surfaces could reduce CSO volumes during a 1-year design storm by as much as 20% at some outfalls. Finally, conceptual planning and modeling efforts provide indications that a monitoring program for green infrastructure within the demonstration area could offer valuable information on green infrastructure performance at a range of scales.

Throughout the country, many cities are increasingly looking to green infrastructure in order to address stormwater and CSO management challenges. Like any new technology, there are valuable lessons that can be learned regarding local implementation of green infrastructure, better guiding future efforts and supporting incorporation into planning documents like the City's LTCP. The conceptual planning level efforts discussed within this memorandum suggest that a green infrastructure demonstration and monitoring program within the East Rock area would serve as a valuable tool in learning these lessons, optimizing stormwater and CSO management efforts within the City of New Haven and supporting healthier water resources as a result.