Final Report
Noroton Heights Flood Mitigation Project
Darien, Connecticut
CIRCA Agreement No. 155194

Town of Darien

2 Renshaw Road
Darien, Connecticut

February 1, 2019

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Project No. 20160934.A20

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1 Acknowledgement

The Connecticut Institute for Resilience and Climate Adaptation (CIRCA) provided funding for this project under the Municipal Resilience Grant Program. Fuss & O'Neill completed the project under a contract with the Town of Darien.

This report summarizing the implementation of the work plan as outlined in the Grant RFP and the deliverables is being submitted to CIRCA under the Town of Darien's grant obligation. It is understood that CIRCA may edit the report for their future use.

2 Project Description

2.1 Introduction

Runoff from Heights Road, commercial properties and the remainder of 123-acre watershed north of the road are conveyed to a masonry culvert beneath the road and Connecticut Department of Transportation (CTDOT) rail corridor. The culvert discharges to a watercourse on the south side of the rail corridor. Drainage from the CTDOT train station parking lot, which has a 6.34 acre watershed including off-site areas, also enters catch basins and is conveyed to the same culvert. On a very frequent basis runoff exceeds the capacity of the culvert and causes flooding of Heights Road and the commercial properties. A traditional flood mitigation project consisting of replacement of the existing culvert with a much larger culvert had been proposed in previous studies. These traditional flood control methods would not reduce the volume of stormwater runoff, would require filling of wetlands, partially replace stream reaches with culvert and would move the flooding problem downstream. In addition, stormwater quality would not be improved using these traditional approaches to flood mitigation.

The Town of Darien retained Fuss & O'Neill, Inc. (F&O) to conduct a study and preliminary design of a stormwater management system that includes green/gray approach to reducing flooding. The study analyzed anecdotal storm events that caused severe flooding of Heights Road and commercial properties in the train station area, and reviewed options for storage and infiltration of runoff that would mitigate some flooding and decrease the frequency of significant flooding. Along with this flood study, F&O reviewed guidance and regulations regarding stormwater infiltration in contaminated soils (referred to as "polluted" soils in State of CT environmental regulatory vernacular) in the event that sampling and analysis required their consideration. An outcome of that review is a Design Guidance Checklist that other municipal or other entities can use when they consider stormwater infiltration in urban areas, which may be characterized by polluted soils.

2.2 Project Description and Objectives

The Town of Darien proposes to implement an alternative approach for flood mitigation of the Heights Road area by managing stormwater closer to its source consistent with the principles of Low Impact Development (LID). The flood mitigation consists of a combination of flood storage pipes beneath Heights Road and storage and infiltration structures within the fill beneath the train station parking lot.

These measures will help reduce the frequency of flooding in Heights Road and the train station area and will not convey the flooding problem downstream. Infiltration of stormwater also has the benefits of improved stormwater quality and recharge of groundwater to enhance base flow for the receiving watercourse. The project has two objectives:

Objective 1

The first objective was to maximize stormwater volume that is stored or infiltrated in order to provide greater flood resiliency to the existing stormwater system. Initially, part of this objective was to understand the level of resiliency that can be provided in the context of future climate change. Our strategy included collaborating with CIRCA/University of Connecticut researchers to better understand the ranges of increased stormwater volume that might be experienced in the future. Upon conferring with the researchers, it became evident that given the complexity of their hydrologic models, overlaying predictions of future climate change would require research and resources that are well beyond the scope of this project. At a future date, when predictive modeling can be conducted given additional available resources, methods for studying design alternatives that consider precipitation patterns and frequency resulting from climate change will be achievable for studies similar to this.

Objective 2

Currently, Connecticut's policies and regulations regarding stormwater quality, Low Impact Development (LID) practices, stormwater management and work in urban soils are in separate documents and permit programs. The second objective was to develop a Design Guidance Checklist that summarizes and guides project planners and designers through the requirements of applicable regulatory practices and policies. The Design Guidance Checklist was to clearly define the tasks that need to be undertaken to evaluate and design stormwater management in urban areas that may contain historical urban fill, which is a complex process that can be challenging given the many sometimes conflicting technical and regulatory requirements in Connecticut. This would have application to many flood mitigation projects in Connecticut.

3 Work Plan

3.1 Project Coordination

F&O initiate the project with meetings and a site visit to codify project-specific objectives. We held project initiation discussions and meetings with CIRCA/University staff and attended a coordination meeting with Town regulatory authorities. Mr. Ed Gentile, PE, Darien's Town Engineer, coordinated communications with the CTDOT Rail Division.

3.2 Review Existing Data

The review of existing data included collection of mapping, utility information, design concepts, permits, construction cost estimates and reports for flood mitigation efforts undertaken for the Heights Road area in the past. Previous efforts included replacing the culvert beneath Heights Road and the rail corridor using pipe jacking methods, and construction of a detention basin in a town park south of the rail corridor. These alternatives proved to be prohibitively expensive and in the case of the detention basin, not in the public's interest.

A recent developer-led design proposal to convert some of the existing commercial properties on the north side of Heights Road included improvements to the storm drainage system in Heights Road. At the direction of the Town of Darien, the developer's plan includes a new connection to the existing masonry culvert using a large vault that future systems could connect to. This vault proved to be a convenient location to connect piping associated with this project and is considered to be a component of "existing conditions".

3.3 Preliminary Base Mapping and Design

F&O surveyed field topography in the project area, conducted utility research and prepared base mapping for use in design and permitting.   .

We conducted preliminary design to reflect details of the proposed improvements including two flood mitigation main components; an underground storage and infiltration system on the CTDOT train station property to capture all of the runoff from the parking lot, and a system of oversized storage pipes beneath Heights Road. We designed new surface inlets in Heights Road to minimize ponding on the roadway for small rainfall events.

At the conclusion of preliminary design F&O prepared an opinion of probable construction cost.

Preliminary design drawings and opinion of probable construction cost are presented in *Appendix A*.

3.4 Field Data Collection

3.4.1 Sampling Program

F&O and their drilling subcontractor performed subsurface exploration on the CTDOT property including soil borings and limited monitoring well installation. Soil boring and monitoring well locations are depicted in the preliminary drawings.

Eleven soil borings, two of which were completed as monitoring wells, were advanced in the location of the proposed infiltration system and piping to evaluate soil and groundwater conditions in the proposed infiltration system area. Soil samples collected from the borings were evaluated as follows:

- Soil that would be excavated for installation of the proposed infiltration system - analyzed to determine if the soil could be removed and reused as clean fill or if contamination was present that would require disposal at a properly permitted disposal facility
- Soil located directly below the proposed infiltration system – analyzed to determine if stormwater discharged from the infiltration system has the potential leach out contamination (if present) from the soil and impact groundwater quality.

Groundwater samples collected from the monitoring wells were analyzed to evaluate existing impacts to groundwater, which could be mobilized by the addition of stormwater from the infiltration system to the aquifer.

The soil borings were inspected by a Fuss & O'Neill hydrogeologist for physical evidence of contamination, such as evidence of fill material, staining, or odors as well as screened in the field for volatile organic compounds (VOCs) using a photoionization detector (PID). The soil borings were also inspected to identify soil type and identify any confining layers such as bedrock or low permeability soils.

Six samples were collected from below the asphalt pavement (approximately 0.5-1 foot below ground surface) to the bottom of the proposed infiltration system (7-7.5 feet below ground surface) to characterize the soil that would be removed during installation of the proposed infiltration system. The characterization samples were analyzed for the following constituents:

- Volatile Organic Compounds (VOCs)
- Semi-Volatile Organic Compounds (SVOCs)
- Extractable Total Petroleum Hydrocarbons (ETPH)
- Total Resource Conservation and Recovery Act (RCRA) list of eight metals (Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Selenium, and Silver)
- Toxicity Characteristic Leaching Procedure (TCLP) RCRA 8 Metals
- Pesticides
- Herbicides
- Flashpoint
- Corrosivity
- Reactivity

Five soil samples were collected from below the bottom depth of the proposed infiltration system and above the groundwater table (between approximately 10 and 13 feet below ground surface) to evaluate the potential for contaminants to leach from the soil. These samples were analyzed using the synthetic precipitation leaching procedure (SPLP) which simulates the potential for contaminants to leach out of soil into stormwater that has infiltrated through the soil. These samples were analyzed for the following constituents:

- SPLP RCRA 8 Metals
- SPLP ETPH
- SPLP Polycyclic Aromatic Hydrocarbons (PAHs)

Two of the 11 soil borings were completed as monitoring wells. The monitoring wells were installed as a means of evaluating the groundwater and aquifer conditions including water table elevations, infiltration rates, and chemical analysis of groundwater samples. Two groundwater samples were collected and analyzed for the following constituents:

- VOCs
- RCRA 8 Metals
- ETPH
- PAHs

Groundwater and soil sample analysis was conducted by York Analytical Laboratory of Stratford Connecticut, a State of Connecticut certified environmental laboratory.

3.4.2 Baseline Criteria

The remediation standard regulations (RSRs) are the soil and groundwater clean-up standards in the State of Connecticut. The Site is not currently in a state regulated clean-up program and is therefore not subject to clean-up under RSRs. Baseline RSR criteria were used only as a frame of reference and to provide a relative understanding of potential environmental concerns and recommended actions based on the investigation results. In *Tables 1, 2, and 3* baseline RSR criteria are presented alongside the analytical data as a preliminary evaluative tool. We have also made comparisons to Connecticut Department of Energy and Environmental Protection (CTDEEP) recommended (non-promulgated) criteria where they exist. The following RSR criteria were used in evaluating the soil data.

RSR Criteria Overview

RSR Soil Criteria	**Description of Criteria Objectives**
Direct Exposure Criteria (DEC)	DEC are applicable to soil within 15 feet of the ground surface. Soil impacted by a release is typically compared to the residential (Res) DEC unless alternatives or variances are applied at sites subject to the RSRs.
Pollutant Mobility Criteria (PMC)	The PMC protect groundwater from constituents leaching out of impacted soil and are dependent upon the groundwater quality classification of a site. Since the Site is located in a GA-designated area, the GA pollutant PMC were used. The GA criteria apply only to soil located above the seasonal low water table.
RSR Groundwater Criteria	**Description of Criteria Objectives**
Background	The RSRs require that groundwater in a GA area be remediated to background concentrations, which are generally understood to be the concentrations at the nearest location upgradient of and unaffected by the release.
Groundwater Protection Criteria (GWPC)	The GWPC apply in GA areas where water distribution systems are available within 200 feet of the parcel, the groundwater plume is not located in an aquifer protection area, the plume is not located within an area of influence of a public water supply well, and the background concentration for groundwater is equal to or less than the groundwater protection criteria.
Surface Water Protection Criteria (SWPC)	The SWPC ensure that surface water quality is not impaired by the discharge of contaminated groundwater into a surface water body.

Volatilization Criteria (VC)	Volatilization criteria protect human health from volatile substances (i.e. VOCs) that may migrate into overlying buildings from shallow groundwater and apply to groundwater within 15 feet of the ground surface or a structure intended for human occupancy. At sites subject to the RSRs, the Res VC apply unless a land use restriction is recorded. Groundwater at the Site is within 15 feet of the ground surface.

3.4.3 Discussion of Analytical Results

Soil Disposal Characterization Samples

Analytical results are presented in *Tables 1, 2, and 3*. VOCs, SVOCs, ETPH, pesticides, and herbicides were not detected above laboratory minimum reporting limits in any of the soil samples collected. Total arsenic, barium, chromium, lead, and mercury were detected at concentrations consistent with the naturally occurring concentrations in Connecticut and below baseline RSR criteria. TCLP barium was present at levels below baseline RSR criteria. Based on the disposal characterization samples no evidence of any release of contaminants to soil was identified.

It is anticipated that soil removed as part of the infiltration system installation may be used as clean fill and does not require disposal at a permitted disposal facility.

Soil Samples from Below the Proposed Infiltration System

Various SPLP PAHs were observed at concentrations well below baseline RSR criteria. SPLP ETPH was also detected in three of the leaching samples at concentrations well below baseline RSR criteria. SPLP mercury was detected at a concentration well below baseline RSR criteria in the sample collected from SB-01. An elevated concentration of SPLP selenium was detected in the sample collected from SB-07. While the concentration is above the GA PMC, groundwater sampling results indicate selenium is not currently leaching into the groundwater at concentrations above baseline RSR criteria. In addition, no selenium was detected in the overlying soil at 0.5-7.5 feet below ground surface or any other soil sample collected at the site, suggesting the result may be due to naturally occurring sample heterogeneity and not a representative concentration of the leaching potential of selenium at the site. It is not anticipated that there would be any significant impact on groundwater quality at the site from stormwater being infiltrated through soil at the site.

Groundwater

PAHs were not detected above laboratory minimum reporting limits in any of the samples collected, and various metals were detected at concentrations well below baseline RSR criteria that are likely naturally occurring. Low levels of ETPH were detected in both ground water samples, and a low level of tetrachloroethylene (PCE) was detected in the sample collected from MW-01. PCE is a chlorinated solvent often used in dry cleaning and for degreasing. While these low levels of ETPH and PCE are above background concentrations, they are below baseline RSR criteria. The addition of stormwater to the groundwater aquifer in this area is not expected to result in the migration of impacted groundwater at levels exceeding baseline RSR criteria. In addition, a public water supply is available in the surrounding area, therefore groundwater in the area is not expected to be used for drinking water.

3.4.4 Monitoring Well Installation and Hydraulic Conductivity Testing

The work plan include advancing approximately 10 borings, conducting Standard Penetration Tests, collection of "Shelby Tube" samples to determine the vertical hydraulic conductivity of the fill and underlying natural materials, installation of three monitoring wells to determine groundwater depth, measurement of hydraulic conductivity and sampling groundwater quality.

During field work, we could not collect sufficient sample lengths in the Shelby Tubes. As an alternative method of measuring vertical hydraulic conductivity, constant-head tests were performed in the monitoring wells using Fuss & O'Neill's Standard Operating Procedure for hydraulic conductivity testing. Constant-head tests consist of pumping a well at three different rates and measuring the drawdown and flowrate. This information can be used to determine hydraulic conductivity. Vertical hydraulic conductivity was measured to be 0.293 inches per hour beneath the western gallery system and 1.075 inches per hour beneath the eastern gallery system.

3.5 Stormwater System Modeling & Design

The US Environmental Protection Agency Stormwater Management Model (PCSWMM) was used to help design the stormwater management improvements in Heights Road and in the CTDOT parking lot. The model was calibrated approximately by obtaining historical information about a single flood event in Heights Road and hourly rainfall values from the nearest NOAA monitoring station. We modeled proposed conditions including infiltration under different rainfall frequencies. A description of modeling methods and results follows.

3.5.1 Methodology

A stormwater model was prepared using Computational Hydraulics International (CHI) PCSWMM software to assess runoff and stormwater flows at the Noroton Heights Station. PCSWMM utilizes the EPA Storm Water Management Model (SWMM), a dynamic rainfall-runoff simulation model that calculates runoff quantity and quality within a user defined watershed. Runoff within the PCSWMM model is generated by an assortment of subcatchment areas that receive precipitation. The modeled runoff is transported through a system of user defined conduits such as pipes, channels, storage/treatment units, pumps, or regulators. The PCSWMM model calculates and records the quantity and quality of the modeled runoff, as well as the flow rate, flow depth, and quality of water within each conduit during the simulation.

3.5.2 Model Development

The hydrologic properties of the PCSWMM subcatchments within the modeled drainage basin were determined from available USGS topographic, land use, soils, and hydrography data. Infiltration was assessed using the Modified Green-Ampt Method. Storm hyetographs were based on 2-, 5-, and 10-year storm event precipitation depths and the 2nd Quartile 50-Percent Temporal Rainfall Distribution as determined from NOAA Atlas 14. Tidal information for high tide (HTL) and mean high water (MHW) were obtained from "The Connecticut Association of Land Surveyors Resources for Tidal and Navigable Waters in Connecticut".

A two-dimensional (2-D) surface was created within PCSWMM to model surface flooding caused by surcharging within the stormwater system. Elevation data for the 2-D surface was obtained from a topographical survey performed by Fuss & O'Neill, Inc. on May 10, 2018. One-dimensional (1-D) elements, including catch basins, manholes, and pipes, were located within the subcatchments during the Fuss & O'Neill 2018 survey.

A map of the 2-D PCSWMM models with integrated 1-D elements are presented in *Figure 1* and *Figure 2*. Backup data for the model elements, hydraulic and hydrologic parameters used in the PCSWMM model and model output files are available upon request.

3.5.3 Modeling Results

Existing Conditions and Approximate Model Calibration

The PCSWMM model of the Noroton Heights Station site was used to analyze flooding issues caused by deficiencies in the existing stormwater system. The existing conditions PCSWMM model identified key areas of flooding and stormwater system inadequacy. The PCSWMM models were calibrated to flooding depths observed at the site on June 28, 2018, and major blockages within the stormwater system observed by New England Pipe Cleaning Company on November 11, 2005. The observations made in 2005 noted the outfall conduit of the system was approximately 50% blocked with debris, significantly reducing the flow capacity of the system. This observed blockage was represented within the PCSWMM model by reducing the cross section of the outfall conduit by 50% of the surveyed dimensions.

The results of the existing conditions model showed peak flooding in the vicinity of 186 Heights Road towards the intersection of Edgerton Street and Heights Road for all storm scenarios. Peak runoff and flooding values at critical locations and structures are summarized in the table below:

Existing Conditions Approximate Calibration- Flooding at Catch Basin (CB19) at 186 Heights Road

		Contributing Area			Peak Values	
Storm Event Return Frequency	**Precipitation Depth**	**Total Area**	**Impervious Cover**	**Subcatchment Runoff Depth**	**Subcatchment Runoff Rate**	**Surcharge Depth @ Catch Basin**
-	*in.*	*ac.*	*ac.*	*in.*	*cfs*	*in.*
2-year	3.57	0.47	0.46	3.46	0.17	10.32
5-year	5.43	0.47	0.46	5.28	0.26	10.8
10-year	6.59	0.47	0.46	6.41	0.31	12.12

Proposed Conditions

Recommended improvements to the stormwater system, including additional catch basins, increased pipe diameters, and infiltration galleys, were modeled in a separate SWMM model to represent the proposed stormwater system. The severity of the known obstructions within the system may be investigated by the town at a later date, and the blockage may be deemed too significant to remediate. Therefore, two proposed alternatives were evaluated in PCSWMM: one simulation representing a system clear of debris and obstructions, and one simulation maintaining the existing level of blockage within the outfall conduit. The results of the proposed conditions model were compared to the existing conditions to assess the response and efficiency of the improved stormwater system. Results for the existing and proposed conditions SWMM models are provided in *Appendix B*.

The results of the proposed conditions model show a reduction in flooding on Heights Road and the surrounding properties, as well as an increase in drainage efficiency of the stormwater system. A summary of the proposed conditions results at the previously identified critical location is provided in the following table:

Proposed Conditions - Flooding at Catch Basin (CB19) at 186 Heights Road

		Contributing Area			Peak Values	
Storm Event Return Frequency	**Precipitation Depth**	**Total**	**Impervious**	**Subcatchment Runoff Depth**	**Subcatchment Runoff Rate**	**Surcharge Depth @ Catch Basin**
-	*in.*	*ac.*	*ac.*	*in.*	*cfs*	*in.*
2-year	3.57	0.47	0.46	3.46	0.17	9.72
5-year	5.43	0.47	0.46	5.28	0.26	10.68
10-year	6.59	0.47	0.46	6.41	0.31	10.92

3.5.4 Infiltration System Design

While the original design goal was to store all CTDOT parking lot runoff from a 2-year frequency storm for flood mitigation purposes, the chosen design configuration was based on:

- Design input from the town and CTDOT
- Necessity to keep parking lot operational during construction
- Available connection locations with the parking lot elevation substantially higher than Heights Road
- Providing as much on-site storage area as practicable to reduce flow rates to the culvert beneath the rail corridor and to mitigate effects of tailwater conditions in the receiving stream, which were not evaluated

Our stormwater design methodology included:

- Over-size the piping system in Heights Road
- Provide a new, over-sized storage and conveyance system within the CTDOT parking lot

- Take catch basins in the CTDOT parking lot off-line from the system in Heights Road, and instead connect them to the new storage and conveyance system within the parking lot. Heavy duty, precast concrete leaching galleries were chosen for this system.
- Connect parking lot catch basins to the new leaching gallery system and discharge stormwater directly to the existing culvert beneath the rail corridor.

The effects of removing the CTDOT parking lot runoff from the undersized inlets in Heights Road and providing an open-bottom and infiltration system for that runoff are:

- Recharge groundwater and improve discharge water quality through filtration and adsorption of nutrients
- Reduce peak discharges from smaller, high-frequency storms
- Stagger the timing of peak flow rates from the CTDOT parking lot and Heights road, thereby reducing the combined peak discharge rate

A significant portion (35%) of the watershed area connected directly to the CTDOT parking lot is from off-site. Achieving 100% of the 2-year runoff volume storage on-site for this entire watershed area was not feasible for this application. Rather, storage of 65% of the total runoff volume was provided to represent the on-site portion of the contributing drainage area. A HydroCAD (HydroCAD Software Solutions LLC) model, which uses the NRCS TR-55 Curve Number methodology, was used to predict the 2-year frequency runoff volume. :

2-Year Storm Frequency Runoff Analysis:

- The 3.45" (2-year frequency) runoff volume (WQV) for the 6.341 acre contributing drainage area is 1.098 acre-feet or 47,850 cubic feet
- Total on-site storage provided: 0.716 acre-feet or 31,180 cubic feet. Represents 65% of the 2-year runoff volume generated.

Hydrologic and hydraulic modeling of the leaching gallery system, which consists of the Eastern Gallery System and Western Gallery System, was conducted using a HydroCAD (HydroCAD Software Solutions LLC) model, which utilizes the NRCS TR-55 Curve Number methodology.

The gallery systems and outlets were sized to convey a 100-year frequency runoff event from the CTDOT parking lot to the culvert beneath the rail corridor. The model used to make this determination assumes free discharge at the culvert outlet.

HydroCAD modeling results are presented in *Appendix C.*

3.5.5 Water Quality Volume Calculations

The water quality volume (WQV) is the amount of stormwater runoff from any storm that should be captured and treated so that a majority of stormwater contaminants are removed on an annual basis. The recommended WQV is runoff associated with the first inch of rainfall (Connecticut Water Quality Manual, 2004 as revised).

To ensure the design of the new CTDOT parking lot drainage system achieves water quality goals, the one-inch rainfall runoff volume from the parking lot was calculated. The infiltration gallery system proposed for the CTDOT parking lot has a storage capacity (0.72 acre-feet) that exceeds the one-inch runoff volume (0.32 acre-feet). Supporting calculations are presented in *Appendix D-1*.

The WQV for the entire Heights Road watershed (4.27 acre-feet) far exceeds the storage capacity of the leaching gallery system proposed for the CTDOT parking lot. However, it is not reasonable to assume this storage capacity could be provided on this site. Supporting calculations are presented in *Appendix D-2*.

3.5.6 Hydraulic Conductivity Testing

The hydraulic conductivity values derived from the constant-head test provided an infiltration rate for the SWMM hydrologic model. Results for the two proposed gallery systems were as follows:

Eastern System Infiltration rate: 1.075 inches/hour
Western System Infiltration rate: 0.293 inches/hour

Supporting calculations of hydraulic conductivity are presented in *Appendix E*.

3.5.7 Groundwater Elevation Data

Groundwater monitoring wells indicated the following groundwater elevations relative to bottom of the proposed leaching galleries. Elevations are on the NAVD88 vertical datum:

Western system bottom elevation:	69.0 feet
Western system GW elevation per MW:	63.6 feet
Eastern system bottom elevation:	71.0 feet
Eastern system GW elevation per MW:	65.2 feet

3.6 Collaboration with CIRCA

Hydrologic modeling was compared to modeling data prepared by with Manos Anognostou, PhD whose team at the University of Connecticut (UCONN). We compared the UCONN team's data to results we obtained using the PCSWMM method. The two results differed considerably, and a possible explanation is provided herein. [1]

Hydrologic modeling verification was executed in collaboration with the UCONN team, which utilized the newest Coupled Routing and Excess Storage model, version 3.0 which considers soil, vegetation, atmosphere, and snow layers. (CREST-SVAS) (Shen and Anagnostou, 2017). CREST-SVAS is a computationally efficient, fully distributed hydrological model designed to simulate flow discharges for large watersheds at a fine spatiotemporal resolution (30 m to 1 km spatial grid resolution and hourly time steps). CREST-SVAS includes a routing module to simulate channel discharge at each time step and a runoff generation model that considers energy and water balances in four different medium: atmosphere, canopy, snow pack and layered soil, by solving water and energy balances coupled equations simultaneously. It takes dynamic (precipitation, radiation, humidity, wind speed, leaf area index) and static (land cover, soil properties, impervious ratios) input variables. CREST-SVAS is capable of producing long term, high-resolution hydrological simulations at various basin scales and types.

The UCONN team provided their model results, surface routing hourly time series spanning over 39 years at the outlet of their largest subcatchment (101 ac) within the watershed, as a reference to verify the PCSWMM model against. A day of heavy precipitation/runoff was chosen from this times series (June 28th, 2018). Observed precipitation depths in Darien, CT from that day were retrieved from "KCTDARIE19" private weather station (N 41.08666667° W 73.47416667°). These depths were assigned to National Oceanic and Atmospheric Administration (NOAA) Atlas 14 distribution, and used to force the PCSWMM model.

Peak runoff simulated by F&O's PCSWMM model from that subcatchment (16.58 cfs) were then compared against peak surface runoff from the UCONN team's model simulation (3.11 cfs). The seemingly large discrepancy between these two values have a few possible explanations:

1. The sources and formats of the precipitation data forcing the two models are different. CREST-SVAS is forced by NLDAS reanalysis meteorological data. This data is available in an hourly time step and ~5 mile grid coverage across North American. Conversely, the SWMM model utilized observed precipitation depths with a NOAA Atlas 14 distribution, and a 15min time step. As a point of reference, over the first 3 hours of June 28th, 2018, the CREST-SVAS model would receive approximately 1 in of total precipitation from its data source while the SWMM model would receive 1.5 in of total precipitation from its data source. This 50% increase in precipitation is a direct influence on total surface runoff generated out of the subcatchment on which this precipitation falls.

[1] Reference: Shen, X., Anagnostou, E., 2017. A Framework to Improve Hyper-Resolution Hydrologic Simulation in Snow-Affected Regions", Journal of Hydrology, vol.552, pp.1- 12, DOI:10.1016/j.jhydrol.2017.05.048.

2. The CREST-SVAS model is a spatially distributed hydrological model meaning that it operates on a 30 meter grid and receives separate inputs (land cover, impervious, etc.) from each cell on that grid. This aids its ability to accurately calculate surface runoff in large and complex watersheds. Within PCSWMM the user is forced to assign single individual attributes (land cover, impervious, slope) to an entire subcatchment. In cases where the subcatchment is large, averaged values can misrepresent realistic scenarios, particularly with impervious and land cover which directly affect modeled infiltration rates, thereby increasing or decreasing runoff that is able to leave that subcatchment. In this case the runoff volume that left the F&O subcatchment was significantly less that the runoff volume that left the UCONN subcatchment, resulting in significantly higher discharges calculated by F&O.

3. The spatial component of the CREST-SVAS model also allows for movement of surface water within the subcatchment. With a subcatchment this large, it may be unrealistic to expect all of the surface runoff to pass through a given point in order to accurately capture the peak runoff. In contrast, SWMM has no intra-subcatchment routing, so any precipitation that falls onto a subcatchment, that isn't infiltrated or evaporated, will make it to its designated outlet point. This would also explain why the UCONN model predicted that significantly more precipitation would leave the subcatchment as runoff.

3.7 Design Guidance Checklist

A Design Guidance Checklist was developed that outlines the steps necessary to perform an LID storm drainage management project in an urban area in Connecticut, and in particular in areas suspected to be located or constructed in urban fill. The CTDOT railroad station parking area was suspected to be in such an area, although the sampling program indicated that soils are clean. The Checklist is presented in *Appendix F*.

The Design Guidance Checklist is based upon the tasks described in the Work Plan. There are numerous guidance documents, regulatory programs and policies that apply to LID, stormwater quality, storm drainage, flood mitigation, impacted soils, and beneficial soil reuse in Connecticut. However, there is not one guidance document that combines all of these considerations into one document that is focused on improving resiliency to flooding that can be referred to by Town engineers and by the engineering community. The purpose of the Checklist is to make more consistent how planners and designers are evaluating and designing LID and resilient flooding and stormwater measures in the municipalities of Connecticut. The process of undertaking this design and the required permitting may point out areas of guidance, policy or the permitting process that can be improved in Connecticut to allow the broader implementation of flood resiliency improvement in urban communities. On a continuing basis, towns and other stakeholders may conference call or meet with CTDEEP and CIRCA staff to discuss individual applications and to come to agreement as to how the Checklist can be used to guide site design and how it can be improved. It is understood that the involvement of various regulatory agencies may not result in the formal adoption of this Checklist, but will provide for a better design documents that better reflect the concerns of regulatory authorities on the design of flood resiliency systems.

Tables

Table 1
Constituents Detected in Groundwater
Noroton Heights Train Station
325 Heights Road
Darien, Connecticut

Site ID Sample ID Sampling Date Sample Depth (ft)	CTDEP RSR Volatization Criteria for Groundwater Residential	CTDEP RSR Groundwater Protection	CTDEP RSR Surface-Water Protection	MW-01 1347181016-02 10/16/2018 10:40:00 AM 15.9	MW-02 1347181017-05 10/17/2018 10:59:00 AM 16
Compound	Res VC	GA GPC	SWPC	Primary	Primary
Volatile Organics, CT RCP List	ug/L	ug/L	ug/L	ug/L	ug/L
Tetrachloroethylene	1500	5	88	3.1E	ND (<0.50)
Semi-Volatiles, CT RCP PAH List				ug/L	ug/L
SVOCs	**	**	**	ND	ND
Extractable Total Petroleum Hydrocarbons (ETPH)	ug/L	ug/L	ug/L	ug/L	ug/L
CT ETPH	[[250]]	250	[250]	106	136
RCRA Metals		ug/L	ug/L	ug/L	ug/L
Barium	~	1000	[2,200]	640	116
Cadmium	~	5	6	0.564	0.556
Chromium	~	50	110H	1.110	2.880
Selenium	~	50	50	3.290	1.110

NOTES:
[Green Text] = DEEP fast-track approvable additional polluting substances and alternative criteria; DEEP approval required
[[Blue Text]] = DEEP-recommended additional polluting substance values not included on the fast-track form; DEEP approval required
NT = the analyte was not a target for this sample
ND = not detected above laboratory reporting limits
~ = no regulatory limit has been established for this analyte
** = multiple values
H = no established criteria for total chromium, hexavalent chromium criteria used for comparison purposes (conservative criteria)
E = the value reported was estimated due to its behavior during intial calibration verification (recovery exceeded 20% of expected value)

Table 2
Constituents Detected in Soil
Disposal Characterization
Noroton Heights Train Station
325 Heights Road, Darien, Connecticut

Site ID Sample ID Sampling Date Sample Depth (ft)	CT DEEP Residential Direct Exposure Criteria	CT DEEP GA Pollutant Mobility Criteria	EPA Hazardous	SB-01 1347180904-02 9/4/2018 9:30:00 AM 0.5 - 7.5	MW-01 1347180904-03 9/4/2018 11:15:00 AM 0.5 - 7	MW-01 1347180904-04 9/4/2018 11:20:00 AM 0.5 - 7	SB-05 1347180904-06 9/4/2018 3:20:00 PM 0.5 - 7.5	SB-07 1347180905-10 9/5/2018 9:00:00 AM 1 - 7.5	MW-02 1347180905-12 9/5/2018 9:20:00 AM 1 - 7.5
Compound				Primary	Primary	Duplicate	Primary	Primary	Primary
Volatile Organics, CT RCP List (mg/kg)									
No VOCs were detected above laboratory reporting limit	--	--	--	ND	ND	ND	ND	ND	ND
Semi-Volatiles, CT RCP BNA List (mg/kg)									
No SVOCs were detected above laboratory reporting limit	--	--	--	ND	ND	ND	ND	ND	ND
Pesticides, CT RCP Target List (mg/kg)									
No pesticides were detected above laboratory reporting limit	--	--	--	ND	ND	ND	ND	ND	NT
Herbicides, CT RCP (mg/kg)									
No herbicides were detected above laboratory reporting limit	--	--	--	ND	ND	ND	ND	ND	ND
Extractable Total Petroleum Hydrocarbons (mg/kg)									
CT ETPH	500	2500	~	ND	ND	ND	ND	ND	ND
Metals, RCRA (mg/kg)									
Arsenic	10	~	~	2.980	2.590	2.440	3.730	1.840	2.270
Barium	4700	~	~	54.500	44.900	36.500	75.400	45.300	46
Chromium	100[H]	~	~	37.900	19.500	14.800	13.600	14.300	17.300
Lead	400	~	~	41.900	19.800	22	19.900	7.510	8.510
Mercury	20	~	~	0.0509	ND (<0.0331)	ND (<0.0333)	ND (<0.0323)	ND (<0.0324)	ND (<0.0340)
Metals, TCLP RCRA (mg/L)									
Barium	~	1	100	ND (<0.25)	0.252	ND (<0.25)	ND (<0.25)	0.292	0.340
Corrosivity (pH)									
pH	~	~	<2 or >12.5	7.960	8.070	7.610	7.560	7.220	6.540
Ignitability									
Ignitability	~	~	Ignitable	Non-Ignit.	Non-Ignit.	Non-Ignit.	Non-Ignit.	Non-Ignit.	Non-Ignit.
Reactivity-Cyanide (mg/kg)									
Reactivity-Cyanide	~	~	~	ND	ND	ND	ND	ND	ND
Reactivity-Sulfide (mg/kg)									
Reactivity-Sulfide	~	~	~	ND	ND	ND	ND	ND	ND

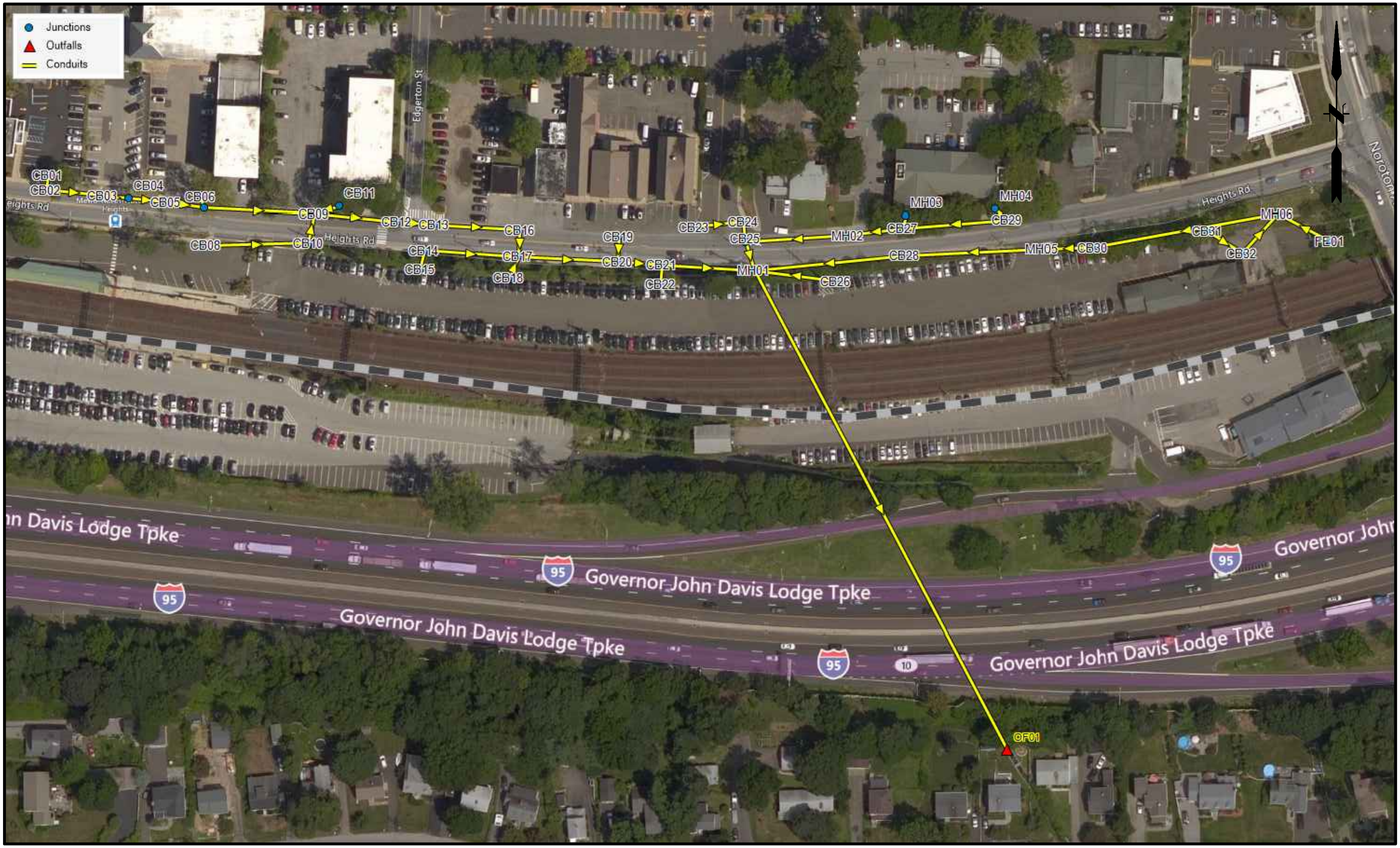
NOTES:
NT=this indicates the analyte was not a target for this sample
ND = analyte not detected above laboratory reporting limits
~=this indicates that no regulatory limit has been established for this analyte
H = no criteria extablished for total chromium, hexavalent chromium was used as a conservative measure
Bold Values = detected concentration exceeds one or more regulatory criteria

Table 2
Constituents Detected in Soil
Soil Samples from Below the Proposed Infiltration System
Noroton Heights Train Station
325 Heights Road
Darien, Connecticut

Site ID Sample ID Sampling Date Sample Depth (ft)	CT DEEP GA Pollutant Mobility Criteria	CT DEEP Ground Water Protection	SB-01 1347180904-01 9/4/2018 9:50:00 AM 10 - 12.5	MW-01 1347180904-05 9/4/2018 11:25:00 AM 10 - 13	SB-05 1347180904-07 9/4/2018 3:25:00 PM 10 - 13	SB-07 1347180905-11 9/5/2018 9:05:00 AM 10 - 12.5	MW-02 1347180905-13 9/5/2018 9:25:00 AM 10 - 12.5
Compound			Primary	Primary	Primary	Primary	Primary
PAHs, SVOCs (mg/L)							
Acenaphthene	~	0.42	ND (<0.00005)	0.00006	ND (<0.00005)	ND (<0.00005)	ND (<0.00005)
Fluorene	~	0.28	ND (<0.00005)	0.00010	ND (<0.00005)	ND (<0.00005)	ND (<0.00005)
Naphthalene	~	0.28	ND (<0.00005)	0.00008	0.00005	0.00005	ND (<0.00005)
Phenanthrene	~	0.2	0.00006	0.00008	0.00010	ND (<0.00005)	ND (<0.00005)
Extractable Total Petroleum Hydrocarbons , SPLP (mg/L)							
CT ETPH	~	0.5	ND (<0.075)	ND (<0.075)	0.0768	0.0862	0.0840
Metals, SPLP RCRA (mg/L)							
Mercury	0.002	~	0.00020	ND (<0.0002)	ND (<0.0002)	ND (<0.0002)	ND (<0.0002)
Selenium	0.05	~	ND (<0.1)	ND (<0.1)	ND (<0.1)	0.115	ND (<0.1)

NOTES:
NT=this indicates the analyte was not a target for this sample
ND = analyte not detected above laboratory reporting limits
~=this indicates that no regulatory limit has been established for this analyte
H = no criteria extablished for total chromium, hexavalent chromium was used as a conservative measure
Bold Values = detected concentration exceeds one or more regulatory criteria

Figures



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GRAPHIC SCALE

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MANCHESTER, CONNECTICUT 06040
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TOWN OF DARIEN

SWMM MODEL OVERVIEW MAP - EXISTING CONDITIONS

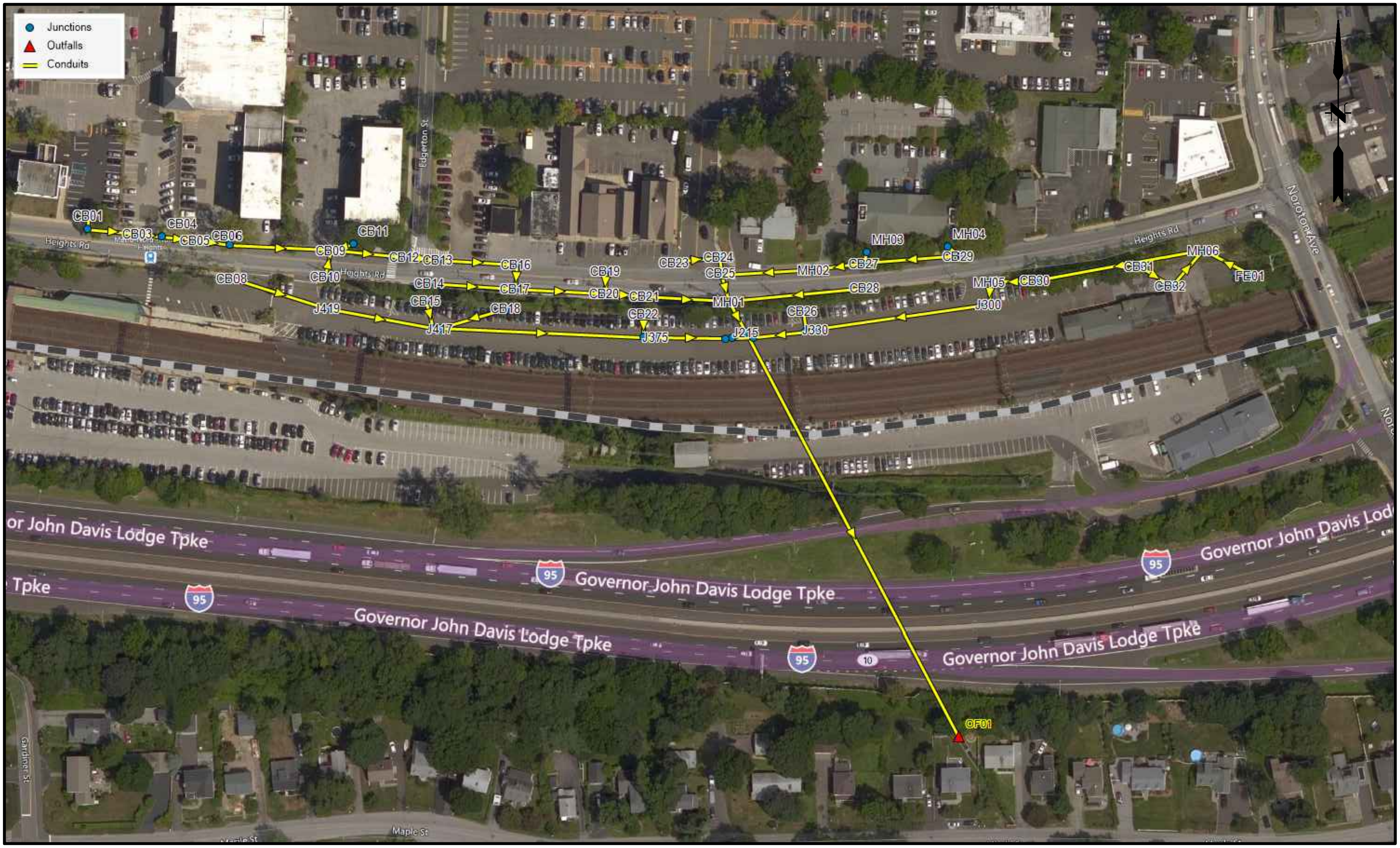
NOROTON HEIGHTS FLOODING

DARIEN

NOT TO SCALE

PROJ. No.: 20160934.A20
DATE: JANUARY 2019

FIG. 1



File Path: J:\DWG\P2016\0934\A20\Civil\Plan\20160934.A20_SWMM-Map-Figures.dwg Layout: FIGURE 2 Plotted: Fri, January 25, 2019 - 11:57 AM User: sking
Plotter: DWG TO PDF.PC3 CTB File: FO.STB
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TOWN OF DARIEN

SWMM MODEL OVERVIEW MAP - PROPOSED CONDITIONS

NOROTON HEIGHTS FLOODING

DARIEN

NOT TO SCALE

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FIG. 2