Hazen

LOWELL WATER
Community ~ Health ~ Environment

Integrated Capital Plan

December 2019

LOWELL REGIONAL WASTEWATER UTILITY

WASTEWATER COLLECTION AND TREATMENT

MARK A. YOUNG
EXECUTIVE DIRECTOR

SERVING LOWELL
CHELMSFORD
DRACUT
TEWKSBURY
TYNGSBORO

TO: Douglas Koopman
USEPA Region 1
Water Technical Unit (SEW)
One Congress Street
Boston MA 02114

Kevin Brander
MADEP
Northeast Regional Office
205B Lowell Street
Wilmington MA 01887

SUBJECT: Integrated Capital Plan (IP) for Lowell, Massachusetts

DATE: December 23, 2019

Gentlemen:

In conformance with Administrative Order Docket No. CWA-AO-R01-FY17-016, dated October 2, 2017, and subsequent communication with the Environmental Protection Agency (EPA), the City of Lowell (Lowell) is submitting a Combined Sewer Overflow (CSO) Phase 3 Long Term Control Plan (LTCP) in the context of an Integrated Capital Plan (IP) for review and comment. This IP report includes all required LTCP elements, as prescribed by EPA's CSO Policy.

Over a period of several years, Lowell has developed a $160 million, 15-year IP for its wastewater and drinking water infrastructure. The IP includes Lowell's plan for its next phase of CSO control, in addition to projects that will allow it to protect public health and interests by making necessary upgrades and improvements to its drinking water treatment and distribution system. In total, the IP includes a $97 million commitment to wastewater projects (including $64 million for CSO control projects) and a $63 million commitment to drinking water projects.

The Phase 3 CSO control plan that is a part of the IP will allow Lowell to reduce untreated CSO discharges by 72% and achieve compliance with the Clean Water Act (CWA) based on the presumption approach, with a model predicted typical year wet weather capture exceeding 85%.

Development of Lowell's IP included an extensive effort to characterize existing conditions, including a system-wide temporary flow monitoring program with 26 meter installations, and improvements and recalibration of its sewer system model. Lowell also developed a framework to score and rank all IP projects (including CSO control, drinking water improvements, and wastewater transport and treatment upgrades) by developing economic, environmental, and social criteria to evaluate each project. These criteria were also weighted in order to establish relative importance, by conducting pairwise comparisons.

A detailed CSO control alternative analysis was performed to establish Lowell's Phase 3 LTCP. This alternative analysis included a complete assessment of 37 different CSO control technologies in order to determine the most applicable technologies, and simulation of retained alternatives using the recalibrated sewer system model. Citywide sewer separation, offline storage tanks, screening and disinfection, and several

FIRST STREET BOULEVARD (ROUTE 110) LOWELL, MA 01850 TEL# (978) 674 4248 FAX# (978) 459 3826

unique solutions specific to each sewershed were simulated. In addition, a unique systemwide CSO control alternative that involves a gravity-only screening and disinfection facility was simulated; this alternative was found to be highly effective in reducing CSO discharge volumes.

The CSO control alternative referred to in the IP as the North Bank WWTF is an integral element of Lowell's Phase 3 CSO control plan. The facility would take advantage of a 6-foot drop in the North Bank Interceptor to facilitate gravity-only operation of a screening and disinfection facility. The proposed facility will be designed to achieve disinfection at flow rates up to 90 MGD. Model predictions indicate that this facility would dramatically reduce the discharge of untreated CSOs on a systemwide basis, by not only treating wet-weather flow conveyed through the North Bank Interceptor, but also by allowing additional flow from the South Bank interceptor to be conveyed to the Duck Island WWTF for treatment.

In addition to the North Bank WWTF, Lowell's Phase 3 CSO control plan includes offline storage tanks, targeted sewer separation and green infrastructure, CSO station modifications for increased conveyance, and a project to increase wet weather treatment capacity at the Duck Island WWTF. All simulated alternatives were analyzed by plotting the estimated of cost of each project, along with the percent reduction of the Average Annual Overflow Volume (AAOV) associated with each project. This cost-benefit analysis resulted in a Phase 3 CSO control plan that will allow the City to reduce its model-predicted AAOV by 72% for hundreds of millions of dollars less than alternative CSO control methods, such as large-scale sewer separation.

As part of the IP development process, a financial capability assessment (FCA) was performed in order to assess the financial impact of the proposed Integrated Plan on the City of Lowell and its ratepayers. The FCA was performed in accordance with EPA guidelines and found that this IP will impose a high financial burden on Lowell's ratepayers. In addition to the static FCA, rate forecasting was performed to determine the impact of the IP on future sewer rates.

The rate forecast for Lowell's final 15-year IP indicates that local sewer rates will exceed affordability thresholds for much of its duration. The plan results in a sewer bill that is above 2% of the 40th percentile household income level for 13 years of the 15 years of IP implementation. These affordability metrics demonstrate Lowell's commitment to reducing CSO discharges as expeditiously as possible, without unduly burdening local ratepayers. It should be noted that the costs associated with IP drinking water projects were not accounted for in the affordability calculations, as prescribed in CSO regulatory guidance.

In order to ensure benefits of all IP projects are continuously maximized, while maintaining a cost-effective approach, Lowell will adaptively manage the IP. The IP contains a description of several triggers (such as an economic recession or new regulatory requirements) that may require certain elements of the IP to be reassessed. As CSO projects are completed, Lowell intends to quantify their benefits and use this information to adjust implementation of subsequent projects. This adaptive management approach will ensure that Lowell has the flexibility to respond to unanticipated conditions and adapt the IP to unforeseen future circumstances.

At the outset of Phase 3 of its CSO control plan, Lowell intends to implement a systemwide program to validate estimates of CSO discharge volumes. CSO discharge volumes are currently estimated using orifice and weir equations that approximate the hydraulic behavior of upward and downward-opening diversion gates. Validating and refining this methodology for CSO discharge estimates will allow Lowell to validate the baseline conditions with which future conditions can be compared.

Lowell also intends to produce a revised High Flow Management (HFM) plan that reflects current operational characteristics of the system during wet weather. Lowell's HFM team regularly meets to analyze system performance during wet weather conditions using system-wide data that is collected in real time. The analysis

of system performance includes a detailed examination of flow control and diversion gate positions, flow at the WWTF, CSO discharges, and more.

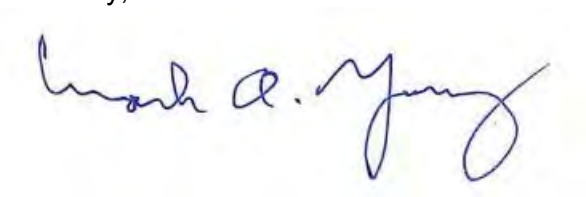
The HFM plan will be revised upon completion of the ongoing clarifier upgrades and the CSO discharge validation monitoring, and a revised HFM will be submitted to EPA and MassDEP in December 2021. The HFM plan will need to be updated again after major CSO control projects, such as the North Bank WWTF, are completed.

Lowell is pleased to submit this IP for your review and comment. This IP represents a major milestone for Lowell and is projected to result in a 72% reduction in typical year untreated CSO discharges. In addition, the IP attempts to balance the need to maintain a safe, resilient, and consistent drinking water supply, with the need to achieve additional CSO control and protect river health.

Throughout development of the IP, several meetings between Lowell, regulators, and the public occurred. These meetings were valuable opportunities for public comment and to request early feedback. I would like to propose another meeting between Lowell, MassDEP, and the EPA to highlight the critical elements of the IP being submitted for review. This meeting would be a valuable opportunity for further discussion between MassDEP, EPA, and Lowell as we undertake the process of implementing this next phase of CSO control.
In the interim, I welcome your feedback and ask that we continue our collaborative approach to improving water quality in the Merrimack River watershed. Should you have any questions, please do not hesitate to call me at 978-674-1601.

Respectfully,

Sincerely,



Mark A. Young
Executive Director

Table of Contents

Executive Summary ES-1
1. Introduction 1-1
1.1 Purpose of Report 1-2
1.2 Wastewater Collection and Treatment System Overview 1-2
1.3 Drinking Water Distribution System Overview 1-5
1.4 Phase 2 LTCP & Prior CSO Planning Work 1-5
1.5 Administrative Order on Consent 1-7
1.6 CSO Wet Weather Capture 1-7
1.7 IP Goals and Background 1-8
1.7.1 Integrated Planning Framework (IPF) and Purpose 1-8
1.7.2 Rate Payer Affordability 1-8
1.7.3 IPF Process 1-8
1.7.3.1 CSO Control Alternatives Analysis 1-9
1.7.3.2 Identification of Projects 1-9
1.7.3.3 Project Scoring and Ranking 1-9
1.7.3.4 Financial Capability Assessment 1-9
1.7.3.5 Implementation Scenario Development 1-9
1.7.3.6 Sewer Rate Modeling 1-9
1.7.3.7 Recommended Plan 1-10
1.7.3.8 Public Participation & Regulator Meetings 1-10
1.7.4 Adaptive Management 1-10
2. Regulatory Requirements 2-1
2.1 Clean Water Act (U.S. EPA, 1972-1987) 2-1
2.1.1 Total Maximum Daily Load (MassDEP) 2-2
2.1.2 National Pollutant Discharge Elimination System Program (EPA, 1972) 2-3
2.2 CSO Control Policy (EPA, April 1994) 2-4
2.2.1 Policy for Abatement of Pollution from Combined Sewer Overflows (MassDEP, August 1997) 2-5
2.2.2 Massachusetts Surface Water Quality Standards (MassDEP, December 2013) 2-5
2.2.2.1 Inland Water Classes 2-7

2.2.2.2 Coastal and Marine Classes 2-7
2.2.2.3 Massachusetts Consolidated Assessment and Listing Methodology (CALM) (MassDEP, 2016) 2-10
2.2.2.4 Minimum Standards for Bathing Beaches (Department of Public Health, 2014) 2-10
2.2.3 Assessment of Sensitive Areas 2-11
2.2.3.1 Designated Outstanding National Resource Waters 2-11
2.2.3.2 Office of National Marine Sanctuaries 2-12
2.2.3.3 Waters with Threatened or Endangered Species and Their Designated Critical Habitat 2-12
2.2.3.4 Waters with Primary Contact Recreation 2-15
2.2.3.5 Public Drinking Water Intakes or Their Designated Protection Areas 2-15
2.2.3.6 Shellfish Beds 2-16
3. Existing Conditions 3-1
3.1 Lowell Clean Stream Initiative Preliminary Overview 3-1
3.1.1 Ambient Bacteria Monitoring, 2018-2019 3-1
3.1.2 Sampling and Analysis Methods 3-1
3.1.3 Sampling Locations 3-3
3.1.4 Sampling Event Summary (2018) 3-5
3.1.5 Results and Discussion 3-6
3.2 Merrimack River Water Quality (2017 Watershed Assessment Study, Army Corps of Engineers) 3-14
3.3 Combined Sewer System 3-15
3.3.1 Major Interceptors and Conveyance 3-15
3.3.1.1 Upper Tilden Interceptor 3-16
3.3.1.2 Warren Interceptor 3-16
3.3.1.3 Marginal/Middlesex Interceptor 3-16
3.3.1.4 Merrimack West Interceptor 3-16
3.3.1.5 Merrimack East Interceptor 3-17
3.3.1.6 Barasford Interceptor 3-17
3.3.1.7 Walker Interceptor 3-17
3.3.1.8 Beaver Brook Interceptor 3-17

3.3.1.9 West Interceptor 3-18
3.3.1.10 Read Interceptor 3-18
3.3.1.11 Duck Island Interceptor 3-18
3.3.2 CSO Stations 3-18
3.3.2.1 Walker CSO Station 3-19
3.3.2.2 Beaver Brook CSO Station 3-21
3.3.2.3 West CSO Station 3-23
3.3.2.4 Read CSO Station 3-24
3.3.2.5 First CSO Station 3-26
3.3.2.6 Tilden CSO Station 3-27
3.3.2.7 Warren CSO Station 3-28
3.3.2.8 Barasford CSO Station 3-29
3.3.2.9 Merrimack CSO Station 3-31
3.4 High Flow Management (on-going) 3-32
3.5 Duck Island Wastewater Treatment Facility 3-33
3.5.1 Treatment Process 3-33
3.5.1.1 Headworks and Primary Influent 3-33
3.5.1.2 Primary Clarification 3-34
3.5.1.3 Aeration Basins 3-34
3.5.1.4 Secondary Clarification 3-34
3.5.1.5 Disinfection 3-34
3.5.1.6 Solids Handling 3-34
3.6 Pumping Stations 3-35
3.7 Drinking Water System 3-35
3.7.1 Distribution System Overview 3-35
3.7.2 Water Supply Source 3-37
3.7.3 Water Treatment Facility 3-38
3.7.4 Water Storage Facilities 3-38
3.7.4.1 Christian Hill Reservoir #1 and #2 3-38
3.7.4.2 Wedge Street Tank 3-38
3.7.4.3 Tenth Street Standpipe 3-38

3.7.5 Pump Stations 3-39
3.7.5.1 Raw Water Pump Station 3-39
3.7.5.2 Stackpole Street Booster Pump Station 3-39
3.7.5.3 Wedge Street Booster Pump Station 3-39
3.7.5.4 Newbridge Booster Pump Station 3-39
3.7.5.5 Trotting Park Booster Pump Station 3-39
3.7.5.6 Beacon Booster Pump Station 3-39
3.7.6 Interconnections 3-40
3.8 Drinking Water Infrastructure Needs 3-40
3.8.1 Redundant 24-inch Diameter Water Main 3-40
3.8.2 Water Treatment Plant Upgrades 3-40
3.8.3 New Finished Water Storage Tank 3-40
3.8.4 Distribution System Improvements (Control valves, etc.) 3-40
3.8.5 Lead Service Replacement 3-41
3.8.6 Water Meter Replacements 3-41
3.8.7 Backflow/Meter Survey 3-41
4. Sewer System Modeling and Characterization 4-1
4.1 Temporary Flow and Rainfall Monitoring Program 4-1
4.1.1 Overview of Program and Meter Locations 4-1
4.1.2 Rain Data and Storm Events 4-3
4.1.3 Flow Data Summary 4-7
4.1.4 Level Monitoring (On-Going) 4-9
4.2 Model Background 4-10
4.3 Model Improvements/Updates and Calibration 4-11
4.3.1 Model Updates & Improvements 4-11
4.3.1.1 System Controls and Updates 4-11
4.3.1.1.1 Walker CSO Station 4-11
4.3.1.1.2 Beaver Brook CSO Station 4-12
4.3.1.1.3 West CSO Station 4-15
4.3.1.1.4 Read Inline Flow Control Gate 4-15
4.3.1.1.5 Read CSO Station 4-16
4.3.1.1.6 Tilden CSO Station 4-17

4.3.1.1.7 Warren CSO Station 4-18
4.3.1.1.8 Barasford Street CSO Station....4-20
4.3.1.1.9 Merrimack CSO Station 4-21
4.3.2 Confirmation of Modeled Diversion Station Operation 4-23
4.4 Model Recalibration 4-25
4.4.1 Calibration Methodology 4-26
4.4.2 Dry Weather Calibration 4-26
4.4.3 Wet Weather Calibration and Validation....4-29
4.5 2018 Annual CSO discharges (modeled vs. calculated) 4-31
5. CSO Control Alternatives Analysis 5-1
5.1 Nine Minimum Controls and Best Management Practices 5-1
5.2 Available CSO Control Technologies 5-3
5.2.1 Description and Analysis 5-5
5.2.1.1 Best Management Practices (BMPs) 5-5
5.2.1.1.1 Air Pollution Reduction 5-5
5.2.1.1.2 Solid Waste Management....5-5
5.2.1.1.3 Fats, Oil, and Grease (FOG) Control Programs 5-5
5.2.1.1.4 Street Sweeping....5-6
5.2.1.1.5 Fertilizer/Pesticide Control....5-6
5.2.1.1.6 Snow Removal and Deicing Practices....5-6
5.2.1.1.7 Soil Erosion Control 5-6
5.2.1.1.8 Commercial/Industrial Runoff Control....5-7
5.2.1.1.9 Animal Waste Removal 5-7
5.2.1.1.10 Catch Basin Modifications 5-7
5.2.1.1.11 Catch Basin Cleaning 5-8
5.2.1.1.12 Sewer Cleaning/Flushing....5-8
5.2.1.1.13 Existing System Management 5-8
5.2.1.1.14 Regulator Modifications 5-9
5.2.1.1.15 Regulating Devices and Backwater Gates 5-9
5.2.1.1.16 Remote Monitoring and Control/Flow Diversion ...5-9
5.2.1.1.17 Rainfall Derived Infiltration/Inflow Control....5-10
5.2.1.2 Collection System Controls 5-10
5.2.1.2.1 Polymer Injection 5-10

5.2.1.2.2 Relocation of CSO Outfalls & Flow Conveyance..5-11
5.2.1.2.3 Sewer Separation 5-11
5.2.1.3 Green Infrastructure 5-11
5.2.1.3.1 Porous Pavement 5-11
5.2.1.3.2 Flow Detention/Retention 5-12
5.2.1.3.3 Roof Leader Disconnection/Rain Barrels 5-12
5.2.1.3.4 Utilization of Pervious Areas for Infiltration.....5-13
5.2.1.3.5 Surface Storage 5-13
5.2.1.4 Storage.....5-14
5.2.1.4.1 Inline Storage.....5-14
5.2.1.4.2 Offline Storage 5-14
5.2.1.5 Treatment Technologies 5-15
5.2.1.5.1 Wastewater Treatment Facility Improvements 5-15
5.2.1.5.2 Screening.....5-16
5.2.1.5.3 Sedimentation 5-16
5.2.1.5.4 Enhanced High-Rate Clarification.....5-17
5.2.1.5.5 Chemical Flocculation.....5-18
5.2.1.5.6 Dissolved Air Floatation 5-18
5.2.1.5.7 Swirl Concentrators.....5-18
5.2.1.5.8 Biological Treatment 5-19
5.2.1.5.9 Filtration 5-20
5.2.1.5.10 Disinfection 5-20
5.2.2 Feasibility Summary.....5-21
5.3 Analysis of Retained CSO Control Technologies 5-22
5.3.1 Constraints and Opportunities 5-22
5.3.2 Site Sheets.....5-23
5.4 Systemwide CSO Control Alternatives 5-34
5.4.1 North Bank WWTF.....5-34
5.4.2 Duck Island Improvements 5-38
5.5 Inflow and Infiltration Control 5-38
5.5.1 Site Stormwater Management and Private Inflow Removal 5-38
5.5.2 CIPP Lining 5-38
5.5.3 Conductance Testing.....5-39

5.6 Simulation of Alternatives and Model Investigations 5-39
5.6.1 Typical Rainfall Year 5-39
5.6.2 Existing Conditions – Typical Year System Performance 5-41
5.6.3 CSO Control Alternatives Simulations 5-41
5.6.3.1 North Bank WWTF 5-41
5.6.3.2 Sewer Separation 5-47
5.6.3.3 Offline Storage 5-48
5.6.3.4 Green Infrastructure 5-50
5.6.3.5 Walker CSO Station 5-51
5.6.3.6 Beaver Brook Station 5-52
5.6.3.7 West Station 5-53
5.6.3.8 Tilden Station 5-55
5.6.3.9 Warren Station 5-56
5.6.3.10 Barasford Station 5-58
5.6.3.11 Merrimack Station 5-59
5.6.3.12 Other 5-61
6. Cost Estimates 6-1
6.1 Estimating Methodology 6-1
6.2 Cost Estimates 6-1
6.2.1 Cost Curves 6-1
6.2.1.1 Sewer Separation 6-1
6.2.1.2 Offline CSO Storage Tanks 6-2
6.2.1.3 CSO Storage Tank with a Screening and Disinfection Facility 6-4
6.2.1.4 Green Infrastructure 6-6
6.2.2 Discrete Project Costs 6-6
6.2.2.1 Pevey Wet Weather Storage Facility 6-7
6.2.2.2 Douglas Wet Weather Storage Facility 6-7
6.2.2.3 Diversion Stations: Wet Weather Conveyance 6-8
6.2.2.4 Duck Island Peak Flow Optimization 6-8
6.2.2.5 Drinking Water Treatment Facility Upgrades 6-8
6.2.2.6 North Bank WWTF 6-9

6.2.2.7 Drinking Water Backflow and Meter Improvements 6-9
6.2.2.8 Duck Island WWTF Centrifuge 6-9
6.2.2.9 Duck Island WWTF Upgrades 6-10
6.2.2.10 Redundant Transmission Main 6-10
6.2.2.11 Tilden Sewer Separation and GI 6-10
6.2.2.12 200 MGD Treatment Facility at Duck Island 6-11
6.2.2.13 Distribution System Improvements 6-11
6.2.2.14 Walker Wet Weather Storage Facility 6-11
6.2.2.15 Satellite Station Upgrades 6-12
6.2.2.16 Finished Drinking Water Storage Tank 6-12
6.2.2.17 Duck Island Phosphorous Removal Project 6-12
6.2.2.18 Lead Service Replacements 6-13
6.2.2.19 Nitrogen Removal Upgrade 6-13
7. CSO Control Knee of the Curve Analysis 7-1
7.1 Cost Benefit Analysis 7-2
8. Financial Capability Assessment 8-1
8.1 FCA Methodology for Lowell, Massachusetts 8-3
8.2 Residential Indicator Calculation 8-4
8.2.1 Identification of Wastewater Management Costs 8-4
8.2.1.1 Current Wastewater Management Operation and Maintenance and Debt Service Costs 8-4
8.2.1.2 Integrated Plan Projected Capital, Operation and Maintenance and Debt Service Costs 8-6
8.2.1.3 Cost per Household Under the Integrated Plan 8-7
8.3 Municipal Financial Capability 8-9
8.3.1 Debt Indicators 8-10
8.3.1.1 Indicator 1: Bond Rating 8-10
8.3.1.2 Indicator 2: Net Debt as Percent of Full Market Value 8-10
8.3.2 Socioeconomic Indicators 8-10
8.3.2.1 Indicator 3: Unemployment Rate 8-10
8.3.2.2 Indicator 4: Median Household Income (MHI) 8-11
8.3.3 Financial Management Indicators 8-11

8.3.3.1 Indicator 5: Property Taxes as a Percent of Full Market Value 8-11
8.3.3.2 Indicator 6: Property Tax Collection Rate 8-11
8.4 Summary Rating (Combination of 6 Financial Strength Indicators with RI) 8-11
8.5 Supplemental Information for Assessing Financial Capability 8-12
8.5.1 Using Household Quintile Income Data for Calculating the Residential Indicator for the City of Lowell 8-12
8.5.2 Cost of Living Adjustment for City of Lowell 8-13
8.6 Proposed Modification of City of Lowell's Financial Capability Rating using Supplemental Information 8-15
8.7 Summary and Conclusions 8-16
9. Integrated Planning Framework 9-1
9.1 IP Project List 9-1
9.2 IPF Model Development 9-1
9.2.1 Criteria Development and Weighting 9-1
9.2.2 Project Scoring 9-3
9.3 Project Optimization and Scheduling 9-5
9.3.1 Ranking Evaluation and Refinement 9-6
9.4 Adaptive Management 9-6
9.5 Public participation 9-7
10. Recommended Plan 10-1
10.1 Rate Analysis and Scheduling 10-1
10.2 Implementation Schedule & Plan Benefits 10-4
10.3 Post-construction Monitoring 10-7
10.4 Operational Plan 10-7
10.5 Regulatory Approval 10-7
10.6 Interim Initiatives 10-7
10.6.1 CSO Discharge Validation/Additional Sewer System Characterization 10-7
10.6.2 Revised High Flow Management (HFM) Plan 10-8
10.7 Other Considerations 10-8
10.7.1 Merrimack River – Regional Asset & Federal Funding 10-8
11. Adaptive Management & Post-Construction Monitoring 11-1

This page intentionally left blank.

List of Tables

Table ES-1: CSO Stations in Lowell and Model-Predicted Typical Year Overflows ES-3
Table ES-2: IP Scoring Criteria ES-8
Table ES-3: Criteria Weighting ES-9
Table ES-4: Model Predicted Typical Year CSO Performance with North Bank WWTF ES-11
Table ES-5: Model Predicted Typical Year CSO Performance for the Knee-of-the-Curve ES-19
Table ES-6: EPA Scorecard for Proposed Integrated Plan ES-21
Table ES-7: Forecasted Sewer Rates 2020-2035 (per hundred cubic feet) ES-24
Table ES-8: Projected Monthly Bills 2020-2035 ....ES-24
Table ES-9: Sewer Bills as Percentages of Monthly HHI with COLI Adjustment ES-25
Table ES-10: Adaptive Management and Review of IP Elements ES-28
Table 2-1: Integrated List of Waters in Lowell, MA 2-2
Table 2-2: Pathogen Source and Indicator Limits for SWQS Categories in the Merrimack River Watershed 2-3
Table 2-3: Massachusetts Surface Water Quality Standards 2-8
Table 2-4: Massachusetts State Narrative WQS 2-9
Table 2-5: Department of Public Health Recreational Water Quality Criteria 2-10
Table 2-6: USFWS Listed Threatened and Endangered Species with the Potential to Occur near Lowell 2-13
Table 2-7: Endangered and Rare Species in the Merrimack Watershed Communities 2-13
Table 2-8: Endangered and Rare Species in the Merrimack per Endangered Species Act (M.G.L. c. 131A) 2-14
Table 2-9: BioMap2 Cores that fall entirely or partially within Lowell, Massachusetts 2-14
Table 2-10: BioMap2 Listed Significant Natural Communities that fall entirely or partially within Lowell 2-15
Table 3-1: Lowell Monitoring Location ID and Description 3-4
Table 3-2: Wet and Dry Weather Sampling 3-5
Table 3-3: Merrimack River Water Main Crossings 3-37
Table 4-1: Observed Rainfall Events at Duck Island WWTF Gauge 4-3
Table 4-2: Observed Rainfall Events at Warren Gauge 4-4
Table 4-3: Observed Rainfall Events at River's Edge Gauge 4-5
Table 4-4: Observed Rainfall Events at WTF Gauge 4-6
Table 4-5: Calibration and Validation Storm Events (Warren Rain Gauge) 4-30
Table 5-1: NMC Measures 5-2
Table 5-2: Feasibility Table 5-21
Table 5-3: Representative Rainfall Years and Average Typical Year Conditions 5-40
Table 5-4: Representative Rainfall Years and Deviation from Average Typical Year Conditions 5-40
Table 5-5: Model Predicted Typical Year CSO Performance 5-41
Table 5-6: North Bank WWTF (8.3' influent weir, 0.956 MG tank volume) 5-43
Table 5-7: North Bank WWTF (7.3' influent weir, 0.849 MG tank volume) 5-44
Table 5-8: North Bank WWTF (6.8' influent weir, 0.797 MG tank volume) 5-45
Table 5-9: North Bank WWTF (6.3' influent weir, 0.744 MG tank volume) 5-45
Table 5-10: North Bank WWTF (5.8' influent weir, 0.690 MG tank volume) 5-46
Table 5-11: North Bank WWTF (5.3' influent weir, 0.637 MG tank volume) 5-46
Table 5-12: Results of Increased Conveyance Analyses at Beaver Brook 5-53
Table 5-13: Tilden Sewer Separation and GI Simulation 5-56
Table 5-14: Model Predictions for Improved Conveyance Through Warren Station 5-57
Table 5-15: Model Predictions for Widened Flow Control Gate and Siphon Channel at Warren Station 5-58
Table 5-16: Merrimack Station CSO Performance with Improvements at Duck Island and Station 5-61
Table 6-1: Costs for Sewer Separation 6-2
Table 6-2: Estimated Cost ($M) at Each CSO Station with Offline Storage Tanks 6-3
Table 6-3: Summary of Systemwide Costs for Offline CSO Storage Tanks 6-4
Table 6-4: Costs at Each CSO Station with Screening and Disinfection Facilities ($M) 6-5
Table 6-5: Estimated Costs for Systemwide CSO Control with Screening and Disinfection Facilities 6-6
Table 6-6: Costs for Pevey Wet Weather Storage Facility 6-7
Table 6-7: Costs for Douglas Wet Weather Storage Facility 6-8
Table 6-8: Costs for Diversion Stations: Wet Weather Conveyance 6-8
Table 6-9. Costs for Duck Island Peak Flow Optimization 6-8

Table 6-10. Costs for Drinking Water Treatment Facility Upgrades ... 6-9
Table 6-11. Costs for North Bank WWTF ... 6-9
Table 6-12. Costs for Drinking Water Backflow and Meter Improvements ... 6-9
Table 6-13. Costs for Duck Island WWTF Centrifuge ... 6-10
Table 6-14. Costs for Duck Island WWTF Upgrades ... 6-10
Table 6-15. Costs for Redundant Transmission Main ... 6-10
Table 6-16. Costs for Tilden Sewer Separation and GI ... 6-11
Table 6-17. Costs for Duck Island Wet Weather Treatment Facility ... 6-11
Table 6-18. Costs for Distribution System Improvements ... 6-11
Table 6-19. Costs for Walker Wet Weather Storage Facility ... 6-12
Table 6-20. Costs for Satellite Station Upgrades ... 6-12
Table 6-21. Costs for Finished Drinking Water Storage Tank ... 6-12
Table 6-22. Costs for Duck Island Phosphorous Removal Project ... 6-13
Table 6-23. Costs for Lead Service Replacements ... 6-13
Table 6-24. Costs for Nitrogen Removal Project ... 6-14
Table 7-1: Model Predicted Typical Year CSO Performance for the Knee-of-the-Curve ... 7-6
Table 8-1: Financial Impacts Categories ... 8-4
Table 8-2: FY2019 Operation and Maintenance Costs for Lowell's Wastewater Management Program ... 8-5
Table 8-3: Total Annual Cost for Lowell Wastewater Management Program ... 8-6
Table 8-4: Annual Projected Debt Service Costs ... 8-6
Table 8-5: Annual Projected Wastewater Management Program Service Costs under the Integrated Plan ... 8-7
Table 8-6: Wastewater Management Cost Allocation under the Integrated Plan ... 8-8
Table 8-7: Wastewater Management Cost Per Household under the Integrated Plan ... 8-8
Table 8-8: Calculated RI under the Integrated Plan ... 8-8
Table 8-9: City of Lowell Financial Capability Indicators ... 8-9
Table 8-10: EPA Benchmarks for Financial Capability Indicators ... 8-9
Table 8-11: Lowell City's Financial Capability Indicator Ratings and Scores ... 8-12
Table 8-12: Summary Financial Capability Table for Lowell City ... 8-12
Table 8-13: Calculation of the RI Using Household Income Quintile Data ... 8-13
Table 8-14: COLI Adjusted Median Household Income for Lowell Massachusetts ... 8-14
Table 8-15: COLI Adjusted Upper Limit Income Levels for City of Lowell ... 8-14
Table 8-16: COLI adjusted RI for Lowell Households ... 8-15
Table 8-17: Summary of COLI Adjusted Financial Capability Matrix for City of Lowell ... 8-16
Table 9-1: IP Projects and Programs ... 9-2
Table 9-2: Project Scoring Criteria and Weighting ... 9-2
Table 9-3: Project Scoring ... 9-4
Table 9-4: Project Benefits ... 9-5
Table 10-1: IP Project and Program Cost Summary ... 10-2
Table 10-2: Forecasted Sewer Rates 2020-2035 (per hundred cubic feet) ... 10-3
Table 10-3: Projected Monthly Bills 2020-2035 ... 10-3
Table 10-4: Sewer Bills as Percentages of Monthly HHI with COLI Adjustment ... 10-3
Table 11-1: Adaptive Management and Review of IP Elements ... 11-2

List of Figures

Figure ES-1: Lowell's Sewer Interceptor System ES-4
Figure ES-2: Temporary Flow Meter Installation Locations ES-7
Figure ES-3: Future Wet Weather Treatment Strategy with North Bank WWTF ES-13
Figure ES-4: TSS Removal Calculations for the North Bank WWTF ES-14
Figure ES-5: Volumetric CSO Control Cost Benefit Analysis ES-16
Figure ES-6: Volumetric CSO Control Cost Benefit Analysis (focused) ES-18
Figure ES-7: Schedule for IP Implementation ES-23
Figure ES-8: IP Implementation and Benefits ES-26
Figure 1-1: Lowell's Wastewater Collection and Treatment System 1-4
Figure 1-2: Timeline of CSO Control Initiatives in Lowell 1-6
Figure 2-1: Surface Water Quality Classification 2-6
Figure 3-1: Lowell Monitoring Locations 3-3
Figure 3-2: Box Plot of Main-Stem Sampling Locations 3-8
Figure 3-3: Bacteria Observed at MR00 3-9
Figure 3-4: Bacteria Overserved at MR07 3-10
Figure 3-5: Bacteria Observed at MR09 3-11
Figure 3-6: Bacteria Observed at MR12 3-12
Figure 3-7: Tributary and CSO Bacteria Discharge Loads 3-13
Figure 3-8: Google Earth View of Walker CSO Station 3-20
Figure 3-9: Siphon Influent Channels and Sluice Gates 3-20
Figure 3-10: Flow Control Slide Gate at Walker CSO Station 3-21
Figure 3-11: Google Earth View of Beaver Brook CSO Station 3-22
Figure 3-12: Flow Control Gate at Beaver Brook CSO Station 3-22
Figure 3-13: Google Earth View of West CSO Station 3-23
Figure 3-14: Slide Gate Actuator 3-24
Figure 3-15: Google Earth View of Read CSO Station 3-25
Figure 3-16: Google Street View of First CSO Station 3-26
Figure 3-17: Google Earth View of First CSO Station 3-26
Figure 3-18: Google Earth View of Tilden CSO Station 3-27
Figure 3-19: Motor and Pump of Tilden CSO Station 3-28
Figure 3-20: Google Earth View of Warren CSO Station 3-29
Figure 3-21: Barasford CSO Station 3-30
Figure 3-22: Google Earth View of Merrimack CSO Station 3-30
Figure 3-23: Gravity Diversion Gate 3-31
Figure 3-24: Flap Gate Covering a Gravity CSO Discharge Pipe at Merrimack CSO Station 3-32
Figure 3-25: Screw Pump at Duck Island WWTF 3-33
Figure 4-1: Temporary Flow Meter Locations 4-2
Figure 4-2: April 16, 2018 Storm Event Recurrence Interval Thresholds 4-7
Figure 4-3: Scattergraph of Flow Data Collected at Meter SB11 4-8
Figure 4-4: Flow Balance around Tilden Station Depicting a CSO Event 4-9
Figure 4-5: Modeled Schematic of Walker Street CSO Station 4-12
Figure 4-6: Walker CSO Station Pump Curve 4-12
Figure 4-7: Modeled Schematic of Beaver Brook CSO Station 4-14
Figure 4-8: Beaver Brook CSO Station Pump Curve 4-14
Figure 4-9: Modeled Schematic of West Street CSO Station 4-15
Figure 4-10: Modeled Schematic of Read Inline Flow Control Gate 4-16
Figure 4-11: Modeled Schematic of Read Street CSO Station 4-17
Figure 4-12: Modeled Schematic of Tilden Street CSO Station 4-18
Figure 4-13: Tilden CSO Station Pump Curve 4-18
Figure 4-14: Previous vs. Corrected Invert at Warren CSO Station 4-19
Figure 4-15: Model Schematic of Warren Street CSO Station 4-20
Figure 4-16: Model Schematic of Barasford Street CSO Station 4-21
Figure 4-17: Modeled Schematic of Merrimack CSO Station 4-22

Figure 4-18: Merrimack CSO Station Pump Curve 4-23
Figure 4-19: Modeled Operation of Merrimack CSO Station During Wet Weather 4-24
Figure 4-20: City of Lowell HFM Chart at Merrimack CSO Station During a Storm Event 4-25
Figure 4-21: Volumetric Dry Weather Model Calibration 4-28
Figure 4-22: Peak Flow Dry Weather Model Calibration 4-28
Figure 4-23: Model Predicted vs. Reported CSO Volumes (2018) 4-32
Figure 5-1: Beaver Brook Station CSO Control Alternatives 5-24
Figure 5-2: Walker Station CSO Control Alternatives 5-25
Figure 5-3: West Station CSO Control Alternatives 5-26
Figure 5-4: Read Station CSO Control Alternatives 5-27
Figure 5-5: First Station CSO Control Alternatives 5-28
Figure 5-6: Tilden Station CSO Control Alternatives 5-29
Figure 5-7: Warren Station CSO Control Alternatives 5-30
Figure 5-8: Barasford Station CSO Control Alternatives 5-31
Figure 5-9: Merrimack Station CSO Control Alternatives 5-32
Figure 5-10: Duck Island CSO Control Alternatives 5-33
Figure 5-11: Graphic of NB invert drop 5-35
Figure 5-12: Existing Wet Weather Transportation and Treatment Strategy 5-36
Figure 5-13: Future Wet Weather Transportation and Treatment Strategy 5-37
Figure 5-14: Modeled Configuration of North Bank WWTF 5-42
Figure 5-15: Systemwide Sewer Separation Model Predictions 5-48
Figure 5-16: Offline Storage Tank Sizes and CSO Performance at Each CSO Station 5-49
Figure 5-17: Model Predicted CSO Performance with Systemwide GI 5-50
Figure 5-18: Ranked Typical Year Overflow Events at Walker CSO Station 5-51
Figure 5-19: Model Predicted Typical Year Overflow Events at Beaver Brook CSO Station 5-52
Figure 5-20: Model Predicted Typical Year Overflow Events at West CSO Station 5-54
Figure 5-21: Model Predicted Typical Year Overflow Events at Tilden CSO Station 5-55
Figure 5-22: Model Predicted Typical Year Overflow Events at Warren CSO Station 5-57
Figure 5-23: Model Predicted Typical Year Overflow Events at Barasford CSO Station 5-59
Figure 5-24: Model Predicted Typical Year Overflow Events at Merrimack CSO Station 5-60
Figure 6-1: Cost Curve for Offline CSO Storage Tanks 6-3
Figure 6-2: Cost Curve for CSO Screening and Disinfection Facilities 6-5
Figure 7-1: Example Cost-Benefit Chart 7-1
Figure 7-2: Volumetric CSO Control Cost Benefit Chart 7-3
Figure 7-3: Focused Volumetric CSO Control Cost Benefit Chart 7-4
Figure 9-1: Sum of Weighted Score Equation 9-3
Figure 9-2: Project Benefits Equation 9-5
Figure 10-1: Sample Budget Loading 10-1
Figure 10-2: Recommended Plan Summary 10-5

List of Appendices

Appendix A: CSO Station Schematics

Appendix B: Interim High Flow Management Plan and Partial Update

Appendix C: Meter Installation Site Sheets

Appendix D: Meter Calibration Plots

Appendix E: Project Cost Estimates

Appendix F: Financial Capability Assessment EPA Guidance

Appendix G: Public Meeting Materials

List of Acronyms

Abbreviation	Definition
CSO	Combined Sewer Overflow
SSO	Sanitary Sewer Overflow
CSS	Combined Sewer System
NMC	Nine Minimum Controls
IP	Integrated Plan
WWTF	Wastewater Treatment Facility
WTF	Water Treatment Facility
EPA	Environmental Protection Agency
CWA	Clean Water Act
AOC	Administrative Order on Consent
RI	Residential Indicator
MHI	Median Household Income
SWMM	Storm Water Management Model
BMP	Best Management Practice
LTCP	Long Term Control Plan
CCTV	Closed Circuit Television
NOI	Notice of Intent
MS4	Municipal Separate Storm Sewer System
RWPS	Raw Water Pump Station
LSA	Low Service Area
HSA	High Service Area
AAOV	Average Annual Overflow Volume
FCA	Financial Capability Assessment
QA/QC	Quality Control/Quality Assurance
MGD	Million Gallons per Day
MG	Million Gallons

Abbreviation	Definition
TSS	Total Suspended Solids
COLI	Cost of Living Index
HHI	Household Income
HFM	High Flow Management
IPF	Integrated Planning Framework
AWWA	American Water Works Association
WEF	Water Environment Federation
TMDL	Total Maximum Daily Load
SWQS	Storm Water Quality Standards
NPDES	National Pollutant Discharge Elimination System
POTN	Publicly Owned Treatment Works
CMR	Code of Massachusetts Regulations
ORW	Outstanding Resource Waters
SSM	Single-Sample Maximum
TP	Total Phosphorus
TN	Total Nitrogen
HLSA	Highland Service Area
RWPS	Raw Water Pump Station
PLC	Programmable Logic Controller
GPM	Gallons per Minute
CHI	Computational Hydraulics International
PCSWMM	Personal Computer Storm Water Management Model (*name of software)*
RTC	Real Time Control
SCADA	Supervisory Control and Data Acquisition
GI	Green Infrastructure
FOG	Fats, Oils, and Grease
I/I	Inflow/Infiltration

Abbreviation	Definition
CIPP	Cured in Place Pipe
NOAA	National Oceanic and Atmospheric Administration
CMOM	Capacity, Management, Operations, and Maintenance
RDII	Rainfall Derived Infiltration and Inflow
SDF	Screening and Disinfection Facility
HGL	Hydraulic Grade Line
ENR	Engineering News Report
LF	Linear Foot
AACE	Association for the Advancement of Cost Engineering
M.G.L	Massachusetts General Law
HVAC	Heating, Ventilation, and Air Conditioning
AO	Anaerobic-oxic
A2O	Anaerobic-anoxic-oxic
SRT	Solids Retention Time
KOC	Knee-of-the-curve
SDWA	Safe Drinking Water Act
CPH	Cost per Household
O&M	Operation and Maintenance
MCWT	Massachusetts Clean Water Trust
ACS	American Community Survey
CPI	Consumer Price Index
S&P	Standard and Poors
GO	General Obligation
C2ER	Council for Community and Economic Research
CFO	Chief Financial Officer
BoC	Bureau of Census
MEPA	Massachusetts Environmental Policy Act

Abbreviation	Definition
ENF	Environmental Notification Form
EIR	Environmental Impact Report

This page intentionally left blank.

Executive Summary

The enclosed report describes the City of Lowell's (Lowell's) Integrated Capital Plan, also referred to as an Integrated Plan (IP), for its wastewater, drinking water, and stormwater infrastructure for the next 15 years. According to the Massachusetts Department of Environmental Protection (MassDEP), an IP is defined as "a plan that evaluates alternative means for addressing a community's current and future wastewater, drinking water, and stormwater needs and identifies the most economical and environmentally appropriate means of meeting those needs." Lowell's decision to develop an IP reflects a consensus among regulators and municipal planners that planning for regulatory compliance should not only consider the need to achieve standards set forth by the Clean Water Act (CWA), but also address the need to protect public health and facilitate environmental justice by not imposing unaffordable sewer rate increases on a community's most vulnerable residents.

Since the implementation of Lowell's Phase 1 Combined Sewer Overflow (CSO) Control Program in 2003, Lowell has invested nearly $150 million in CSO control projects and has significantly decreased the Average Annual Overflow Volume (AAOV) of CSO, estimated to be an 80% overall reduction over the years. In 2014, Lowell submitted a Phase II CSO Long-Term Control Plan (LTCP) Update to the Environmental Protection Agency (EPA), and subsequently received comments. An Administrative Order on Consent (AOC) was issued requiring Lowell to achieve full compliance with the CWA, leading Lowell to initiate the IP process. The AOC requires Lowell to submit an IP by December 31, 2019 that includes a Phase 3 CSO control plan.

Through development of the Phase 3 CSO Control Plan utilizing the IP framework, Lowell has committed to an investment that will lead to significant reductions in untreated CSO discharges. This will allow for compliance with the CWA according to the EPA's presumptive approach based on model predictions, while responsibly allocating funds to also complete other necessary drinking water infrastructure projects. Failure to plan for the needs of both the wastewater and drinking water systems could lead to risks to public health and continued environmental impacts, as has been observed in other communities throughout the country.

The fact that Lowell is an economically disadvantaged community that is burdened with aging and outdated infrastructure was a key reason for the development of this IP. The enclosed Financial Capability Assessment (FCA) showed that, while Lowell's economy has been slowly improving in recent years, with decreasing unemployment levels, the economic reality for most residents is still characterized by stagnant household incomes that were substantially lower in 2018 than corresponding incomes were in 2009. This burden has been borne mostly by Lowell's most vulnerable residents (the bottom 40 percent of households), as they have faced even steeper income declines since the last recession ended.

When Lowell's existing network of large diameter sewer interceptors, CSO stations, and the Duck Island Wastewater Treatment Facility (WWTF) were constructed, a general consensus existed that the need to restore and protect the health of the Merrimack River was a regional challenge, deserving of funding from the State and Federal Governments. As such, support in the form of state and federal funding was made available to ensure the cost of constructing new infrastructure, designed primarily to protect the environment and health of the Merrimack River, did not result in unaffordable rate increases for economically disadvantaged residents. This funding strategy also ensured that Lowell was able to

continue to invest in drinking water infrastructure and remain committed to the protection of public health and the environment. At present, assistance in the form of Federal funding is largely unavailable, and thus the IP framework has been an essential tool that has allowed Lowell to cost-effectively balance competing priorities.

This IP is an important milestone for Lowell, as it represents the first comprehensive effort to develop a unified plan for its drinking water and wastewater infrastructure that also achieves substantially improved CSO control. The implementation plan within this IP maximizes environmental, social, and economic benefits as effectively as possible, without exceeding affordability thresholds by imposing unaffordable rate increases on local ratepayers.

Development of this IP was a two-year collaborative effort between Lowell's water professionals and its consultant (Hazen). The collaboration involved extensive analysis and investigations that characterized existing conditions and assessed the efficacy of a wide range of alternatives for CSO control. The following steps, summarized in this Executive Summary and described in detail in the main body of this report, were followed to complete the development of the IP:

- Existing conditions assessment and identification of non-CSO control projects
- System-wide temporary flow metering and rainfall gauging
- Development of the IP framework and scoring criteria
- Hydrologic/hydraulic model improvements and recalibration
- CSO control alternatives analysis and modeling
- Cost estimating
- Knee-of-the-Curve (KOC) cost-benefit analysis and development of a Phase 3 CSO Control Plan
- Financial Capability Assessment and Affordability Analysis
- Sewer rate modeling and project scheduling
- Implementation Plan and adaptive management plan

It should be noted that Lowell's IP is intended to be implemented with a focus on adaptive management. Adaptive management is an acknowledgement that, as the IP and CSO control plan are completed, changes may occur that impact the design and implementation of subsequent IP projects. For example, this IP contains CSO control projects that will impact the operation of the sewer collection system and wastewater treatment facility on a holistic basis. Although a calibrated hydrologic/hydraulic model was used to predict the benefits of these systemwide CSO control projects, the predictive accuracy of the model decreases as additional cumulative changes are simulated in the model. As such, the actual benefits of each project should be assessed (through monitoring) after key construction milestones are met and compared to the predicted benefits. A project having more or less benefit than was originally predicted may impact the design and implementation of subsequent projects. In addition, new technologies may

become available as the IP is implemented that may allow Lowell to achieve its goals more efficiently. These factors (and many others) underscore the importance of adaptive management as the IP is implemented.

Existing Conditions

Lowell owns and operates a combined sewer system which transports wastewater from the City (and four neighboring communities) to the Duck Island WWTF for treatment and discharge to the Merrimack River.

After the CWA was enacted, Lowell constructed large interceptor pipes that receive flow from the collection system and transport it to the Duck Island WWTF. The interceptor system was constructed with a number of regulators, or hydraulic relief points, which were designed to allow some portion of the combined sewage/stormwater flow to overflow to a receiving waterbody during intense rainfall events, when excess combined flow might otherwise result in sewage overflowing into city streets or causing sewer back-ups into homes and businesses. These regulators are each associated with a permitted discharge location and outfall and are often referred to as CSO stations. At present, there are nine permitted CSO stations that may discharge flow to the Merrimack or Concord River, or to Beaver Brook. Only eight of these stations are used at this time. Table ES-1 contains a summary of each CSO station, along with model-predicted typical-year CSO data for each station under existing conditions.

Table ES-1: CSO Stations in Lowell and Model-Predicted Typical Year Overflows

CSO Station	Active (Yes/No)	Interceptor System	AAOV (MG)	Frequency
West	Yes	North Bank	121.8	34
Merrimack	Yes	South Bank	115.2	21
Warren	Yes	South Bank	48.8	20
Tilden	Yes	South Bank	22.0	18
Read	Yes	North Bank	8.1	17
Walker	Yes	North Bank	7.0	8
Beaver Brook	Yes	North Bank	5.7	5
Barasford	Yes	South Bank	3.1	6
First	No	North Bank	0.0	0
Total CSO Volume			**331.7**	**N/A**

Flow within the collection system is primarily conveyed by one of two large-diameter sewer interceptor systems; the South Bank (SB) interceptor system or the North Bank (NB) system. Figure ES-1 depicts Lowell's sewer interceptor system.

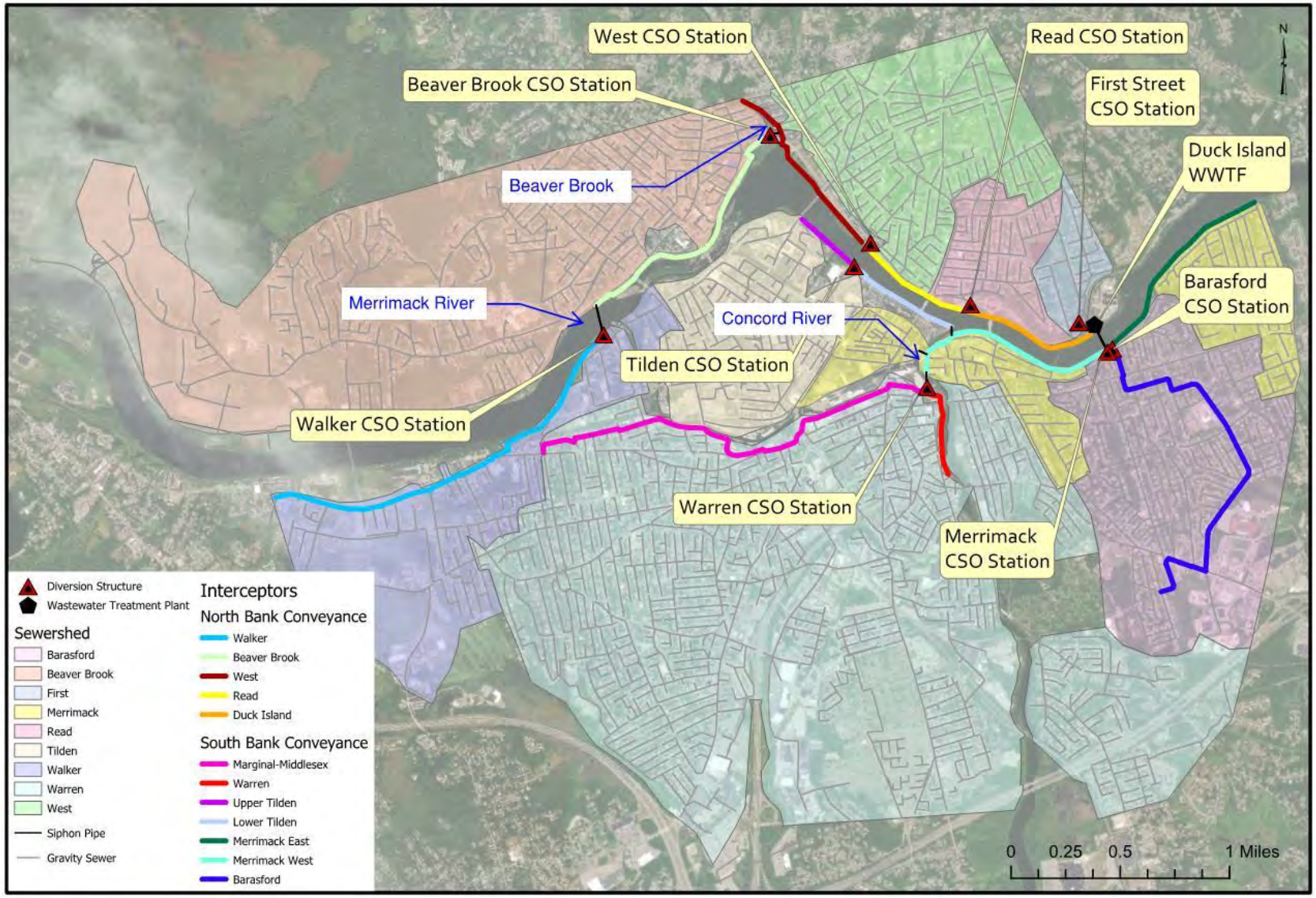


Figure ES-1: Lowell's Sewer Interceptor System

CSO control projects were identified through a thorough CSO control alternatives analysis, as summarized in Section 5 of this report. In addition to identification of CSO control projects through the alternatives analysis, non-CSO projects were identified through an assessment of Lowell's other infrastructure needs. The following list summarizes the non-CSO projects that were identified:

- Replacement of drinking water lead services
- Drinking water backflow & meter replacement
- Construction of a redundant drinking water transmission main
- Upgrades at the drinking water treatment facility
- Construction of a new finished drinking water storage tank
- Improvements to the drinking water distribution system
- Wastewater satellite (remote) station upgrades
- Duck Island WWTF improvements (phosphorus upgrade)

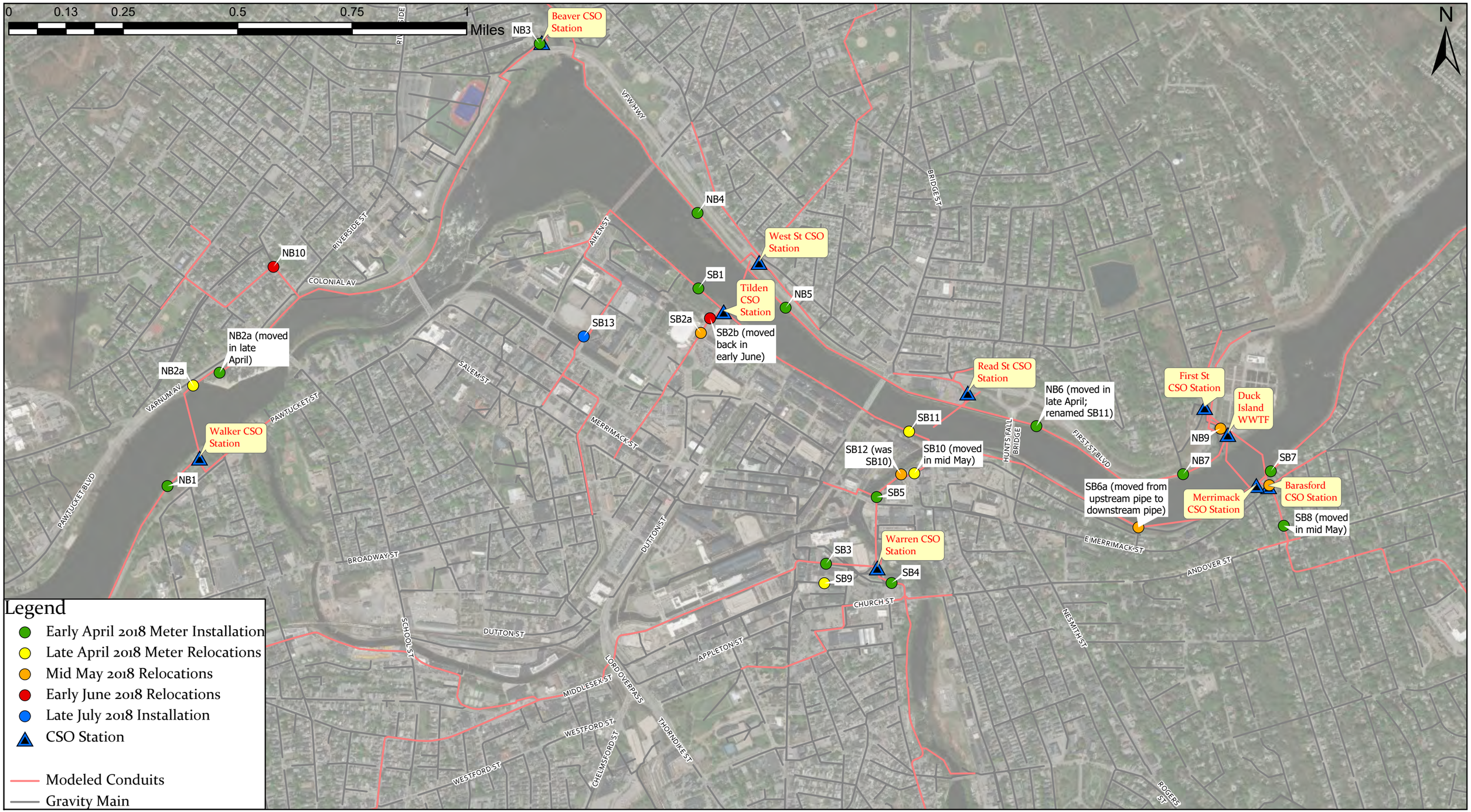
The scope of each of the above projects is described in detail in the main body of this report.

System-Wide Temporary Flow and Rainfall Monitoring

To support recalibration of Lowell's hydrologic/hydraulic model of its sewer collection system, for use in the CSO control alternatives analysis and to increase system understanding, temporary flow meters were installed at 26 individual locations from April 2018 – August 2018, as shown in Figure ES-2. The flow metering project was actively managed, and included bi-weekly meetings between Lowell staff, its consultant, and the metering subconsultant. As such, throughout the duration of the five-month program, meter placement was continuously optimized and assessed. QA/QC of meter data was provided throughout the monitoring period, so that irregularities and anomalous flow meter readings could be readily corrected. The flow metering program accomplished the following objectives:

1. Recalibrate the existing SWMM model to enable it to accurately predict CSO discharges
2. Increase sewer collection system understanding
3. Provide additional insight into the effectiveness of system controls (e.g., the movement of inline flow control gates for inline storage) and identify opportunities for further improvement
4. Characterize conditions in upstream portions of the system where CSO alternatives such as sewer separation or green infrastructure might be possible

Rainfall data was also collected from four city-maintained rain gauges throughout the duration of the monitoring project. A wide variety of rain events occurred during the monitoring period, allowing for reliable characterization of the system's response to wet weather.



Hazen

Lowell Water
Integrated Plan
Flow Meter Location Map

LOWELL WATER
Community ~ Health ~ Environment

Figure ES-2

Development of IP Framework and Scoring Criteria

Lowell identified criteria by which IP (CSO control and non-CSO control) projects were scored. City staff identified criteria that characterize each project's environmental and community benefits as shown in Table ES-2.

Table ES-2: IP Scoring Criteria

Category	Criterion	Description
Environmental	Protection of Aquatic Life	*Ability to support healthy flora and fauna*
	Recreational Use Attainability	*Ability to safely support recreational activities (swimming, boating, etc.)*
	Drinking Water Supply	*Protection of the Merrimack River's status as a drinking water supply*
Community	Public Health	*Protection of public health and quality of life for Lowell residents*
	Municipal Liability	*Vulnerability to litigation against Lowell*
	Ratepayer Satisfaction	*Protection of ratepayer interests, needs, and environmental justice*
	Property Protection	*Protection against building and property damage*
	Economic Development	*Potential for cleaner river to support growth of new businesses*
	Human Life/Safety	*Ability to mitigate catastrophic failures, accidents, and unforeseen events (drought, major flooding, etc.)*
	Funding/Financial Advantages	*Potential cost-benefit performance*
	System/Equipment Reliability	*Ability to support day-to-day reliability of water infrastructure*

After these criteria were identified, they were weighted to establish their relative importance. City staff voted, using pairwise comparisons, where voters were asked to numerically rate one criterion versus another. By following this process, the relative weight of each criterion was established as a percentage (out of 100% total). The weighting established through this process is shown below in Table ES-3.

Table ES-3: Criteria Weighting

Description	Score
Public Health	20.43%
System/Equipment Reliability	18.39%
Human Life/Safety	15.06%
Property Protection	8.04%
Funding/Financial Advantages	6.78%
Aquatic Life	6.20%
Economic Development	6.02%
Drinking Water Supply	5.50%
Ratepayer Satisfaction	5.14%
Municipal Liability	4.40%
Recreational Use	4.04%

In order to score each individual IP project, a rating system for measuring the effectiveness (positive impact) of each project, relative to each criterion, was developed. The rating system allowed for each criterion to be assigned three possible scores:

- 0 = no positive impact
- 1 = limited positive impact
- 2 = most significant positive impact

Several meetings occurred among City staff, and between City staff and Lowell's consultant, to develop scores for each criterion for each project. The score for each criterion was then multiplied by its weight, and the total project score was determined by the sum of weighted scores for each criterion.

Hydrologic/Hydraulic Model Improvements and Recalibration

In order to support an analysis of CSO control alternatives, Lowell's existing hydrologic/hydraulic model was improved and recalibrated using the data collected during the temporary flow/rainfall monitoring program. This process was accomplished over several months through careful adjustment of the parameters in the model that govern dry weather and wet weather behavior/response until model predictions matched observed data, within industry standards (*"Wastewater Planning Users Group Code of Practice for the Hydraulic Modelling of Wastewater Systems, November 2002"*) criteria. The model was successfully calibrated and validated to reliably predict the response of the system to dry and wet weather conditions.

In addition, Lowell and its consultant had several meetings where other elements of the model (inverts, control rules, etc.) were checked for accuracy. Through these meetings, multiple improvements were made to the model. This collaborative process resulted in a more robust model that is capable of accurately representing existing conditions and is a useful tool for analyzing potential improvements.

CSO Control Alternatives Analysis and Modeling

In order to develop strategies for CSO control, a thorough analysis of all available CSO control technologies was performed. CSO abatement technologies were divided into Operations and Maintenance Programs versus Capital Projects, and then further broken down into five general categories:

1. Best Management Practices (BMPs)
2. Collection System Controls
3. Green Infrastructure (GI)
4. Storage Technologies
5. Treatment Technologies

Every potential technology within each category was analyzed for applicability for CSO control in Lowell and classified as either "not applicable", "continue current practice", "update/initiate practice", or an "LTCP Technology". In total, 37 different technologies were analyzed and grouped into these classifications. An analysis of the selected CSO technologies was then performed, sewershed by sewershed, in order to determine feasible strategies within each area.

In addition, several systemwide CSO control technologies were identified, including the construction of a wet weather treatment facility along the North Bank interceptor and increasing wet weather treatment capacity at the Duck Island WWTF.

In order to provide a consistent basis for comparison, a typical rainfall year (2000) was identified through a statistical analysis of historical rainfall data from Boston Logan airport for the period of record from 1948-2013. All selected alternatives were then simulated using the calibrated model for the typical rainfall year to determine the effectiveness of each CSO control measure. After each simulation, the volume and frequency of CSO discharges at each CSO station were calculated and compared to the existing condition predictions to assess benefits.

Extensive testing was completed using the model to identify effective combinations of CSO control measures and other system improvements/optimization strategies to reduce CSOs. Scenarios that simulated 100% CSO control at all stations were also assessed.

In general, the CSO control alternatives analysis yielded the following conclusions/findings:

1. Green infrastructure is not a cost-effective stand-alone CSO control strategy.
2. Merrimack/Barasford, West, Warren, and Tilden stations discharge the most volume with the most frequency during the typical rainfall year and should be prioritized for control strategies.

3. Sewer separation and offline storage tanks were simulated in each sewershed, and the requisite tank sizes and amount of separation required to achieve 25%, 50%, 75%, and 100% CSO control were determined, respectively.

4. A wet weather treatment (screening and disinfection) facility along the North Bank interceptor (the "North Bank WWTF") has the potential to be operated using gravity only due a unique system feature (a 6-foot drop in an 8-foot diameter interceptor).

5. The North Bank WWTF has significant potential to reduce untreated CSO discharges on a system-wide basis and is a central element of Lowell's Phase 3 CSO control plan.

6. Increasing the wet weather treatment capacity at Duck Island, coupled with conveyance improvements at Merrimack Station, has significant potential to reduce CSO volume/frequency at this location, which includes both Merrimack and Barasford stations.

System-wide CSO control strategies are not effective at reducing CSO volume/frequency at Warren and Tilden stations without additional work at these stations; targeted CSO control strategies (station improvements and sewer separation with green infrastructure, respectively) should be planned at these locations.

While specific targeted CSO control strategies were found to be potentially effective in the model, many of these are beset with serious challenges that would limit effectiveness. Constructability is a significant challenge for CSO control techniques such as offline storage tanks and sewer separation. Offline storage tanks would require (in many cases) the invocation of eminent domain in order to acquire the requisite land for the large tanks necessary to significantly reduce CSO volume/frequency.

Model predictions indicated that system-wide improvements, such as the North Bank WWTF and additional peak wet weather treatment capacity at Duck Island, have the greatest potential to reduce untreated CSO discharges at most CSO stations. Table ES-4 contains model predictions from a simulation with the North Bank WWTF implemented.

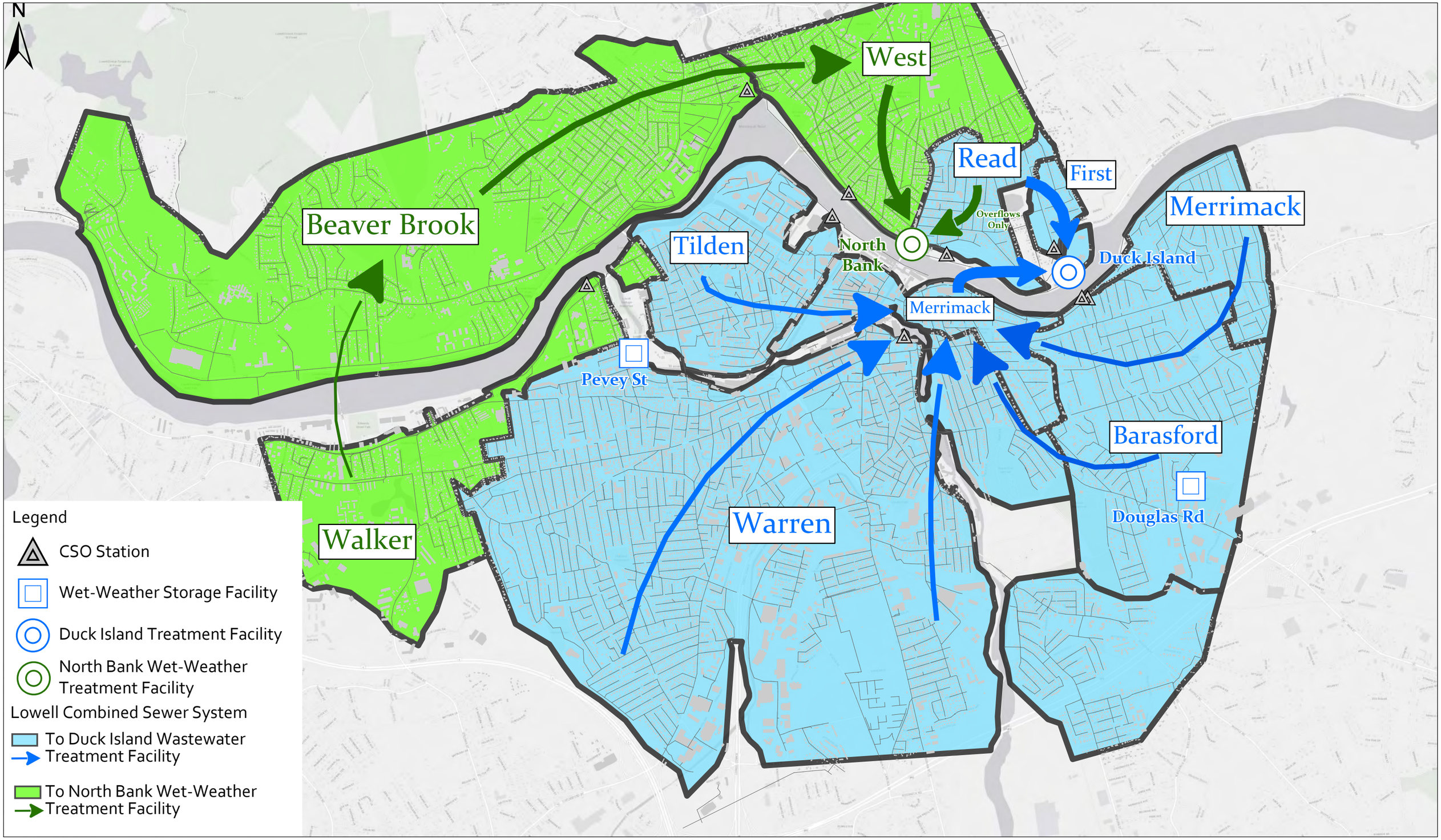
Table ES-4: Model Predicted Typical Year CSO Performance with North Bank WWTF

CSO Station	Existing Conditions		North Bank WWTF	
	AAOV (MG)	Frequency	AAOV (MG)	Frequency
West	121.8	34	13.9	11
Merrimack	115.2	21	58.0	11
Warren	48.8	20	49.3	20
Tilden	22.0	18	22.6	18
Read	8.1	17	0.0	0
Walker	7.0	8	6.7	8
Beaver Brook	5.7	5	2.9	3
Barasford	3.1	6	3.1	3
First	0.0	0	0.0	0
Total CSO Volume	**331.7**	**N/A**	**156.6**	**N/A**

As shown in Table ES-4, the North Bank WWTF has the potential to reduce total untreated CSO discharges from all Lowell CSO stations by approximately 53%. A schematic depicting a future wet weather treatment strategy, with the North Bank WWTF as a central element, is shown in Figure ES-3. As indicated in Figure ES-3, with the construction of the North Bank WWTF, a significant amount of wet weather flow in the North Bank system can be treated at this new facility. This not only eliminates untreated CSO discharges at Read Station (since overflows can be piped directly into the facility), and dramatically reduces untreated CSO volume discharged from West Station by up to 89%, but also significantly benefits Merrimack Station on the South Bank. This is because additional wet weather treatment capacity is made available at the Duck Island WWTF, allowing Merrimack Station to convey more flow to the WWTF for treatment and discharge.

The North Bank WWTF alternative takes advantage of a unique system feature (a sudden, 6-foot elevation drop in a 96-inch pipe) and would have the ability to utilize gravity to move flow through the proposed screening and disinfection facility. The proposed screening and disinfection facility would operate in an automated fashion and includes the following features (pending final design):

- Up to ~1 MG storage volume comprised of "plug flow" channels that accommodate disinfectant contact time and some settling of solids (pending final design), along with influent and effluent chambers
- Peak flow capacity (15-minute disinfection contact time) of up to 90 MGD.
- Additional treatment capacity may be achievable if a less stringent disinfection standard is applied beyond design capacity (90 MGD). This would result in partial disinfection of extremely high flow rates.
- Horizontally mounted CSO screen integrated with a static influent weir, keeping debris in the interceptor system so it can be conveyed to the Duck Island WWTF
- Static effluent weir set at an elevation that accommodates sufficient contact time within the tank channels for adequate disinfection
- Automatic, post-event draining of the facility by gravity to the interceptor (en route to the WWTF)
- Automatic cleaning of the facility with the use of tipping buckets and flush gates
- Chlorination and de-chlorination of wet-weather flows (pending selection of specific disinfectant method)



Hazen

City of Lowell Combined Sewer System
Wet Weather Transport and Treatment Alternative

LOWELL WATER
Community ~ Health ~ Environment

Figure ES-3

While the North Bank WWTF's primary purpose is removal of bacteria, a calculation was performed to estimate total suspended solids (TSS) removal as a secondary benefit. This calculation was performed by using model predictions of the flow rates and volume into and out of the facility during the typical rainfall year. For storms that were completely stored, 100% TSS removal is achieved. For storms that were not fully stored within the facility, 100% TSS removal is assumed for the volume stored and 50% TSS removal was assumed for the volume that is treated and discharged from the facility. Based on this calculation, it is estimated that during the typical year, an average of 55% TSS reduction will be achieved. A typical range of TSS removal was also calculated by determining the peak flow rate out of the facility during the typical rainfall year and calculating the surface overflow rate and TSS removal efficiency associated with each flow rate based on clarifier efficiency curves. These removal efficiencies were then ranked according to the percentage of time that the associated peak flow rate was exceeded. This range of TSS removal efficiency, and the 55% average expected efficiency, is shown in Figure ES-4.

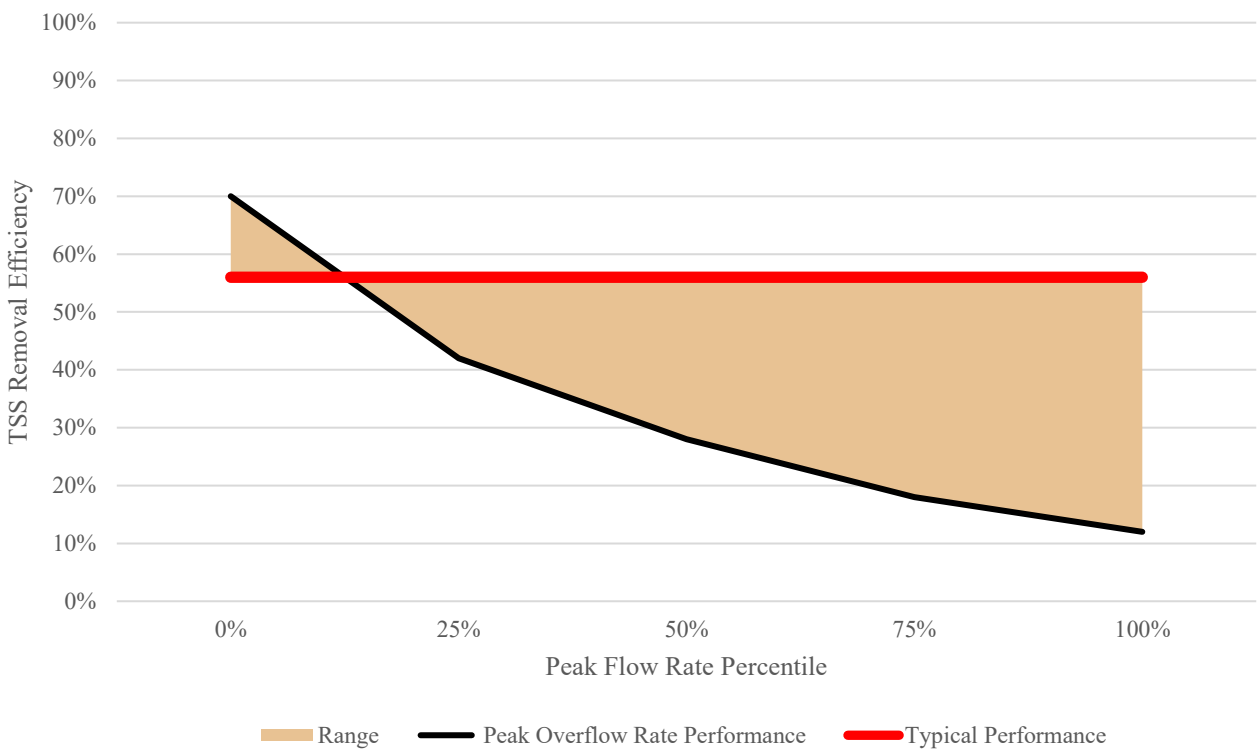


Figure ES-4: TSS Removal Calculations for the North Bank WWTF

As shown in Figure ES-4, the average expected TSS removal efficiency for the North Bank WWTF is 55%, with an efficiency of approximately 28% or better during 50% of peak flow conditions during the typical rainfall year.

Additional alternatives were simulated using the model (beyond the North Bank WWTF) to achieve further CSO control at other CSO stations inlcuding the following:

- Increasing Duck Island WWTF peak wet weather treatment capacity to 126 MGD
- Increasing Duck Island WWTF peak wet weather treatment capacity to 200 MGD
- Improved conveyance through Beaver, Warren, and Merrimack CSO stations
- Offline storage at Walker Station
- Targeted sewer separation and GI in the Tilden sewershed
- Targeted sewer separation in Barasford & Merrimack sewersheds
- System-wide public-side (no removal of private inflow) sewer separation in the Warren sewershed
- System-wide public-side sewer separation in the Beaver Brook sewershed
- Offline storage at all CSO stations with remaining CSO volumes

Different configurations and combinations of the above CSO control strategies were simulated in addition to the North Bank WWTF to achieve model-predicted complete CSO control at all locations. Costs were developed for each strategy. The cost-benefit performance of different CSO control strategies was then evaluated using a Knee-of-the-Curve (KOC) analysis.

Cost Estimating

In order to determine affordability of the IP, and to assess the cost-benefit performance of each CSO control project, an extensive effort was undertaken to develop cost estimates for all IP projects and all modeled CSO control technologies. This cost estimating effort utilized data from previous projects completed within Lowell, and data available to Lowell's consultant from other projects completed throughout the country. A construction cost was developed for each project before an allowance of 35% for design and engineering fees was added to each construction cost estimate. Design and construction durations were also estimated for each IP project. A detailed description of the cost estimating effort is included in Chapter 6 of this document.

Knee of the Curve (KOC) and Cost Benefit Analysis

To determine which CSO control projects have the maximum CSO control benefit per dollar spent, a cost benefit analysis was performed using estimated planning-level construction costs and model-predicted CSO benefits. Charts were developed to graphically represent this analysis. In Figure ES-5, each point represents a specific CSO control project (or group of projects) and is associated with a volumetric CSO control (percentage of the model-predicted total CSO volume eliminated) and the estimated cost to implement the project(s) associated with that point. Points along each line are cumulative, meaning the CSO volume reduction associated with each subsequent point includes the cumulative benefits of that project and all preceding projects.

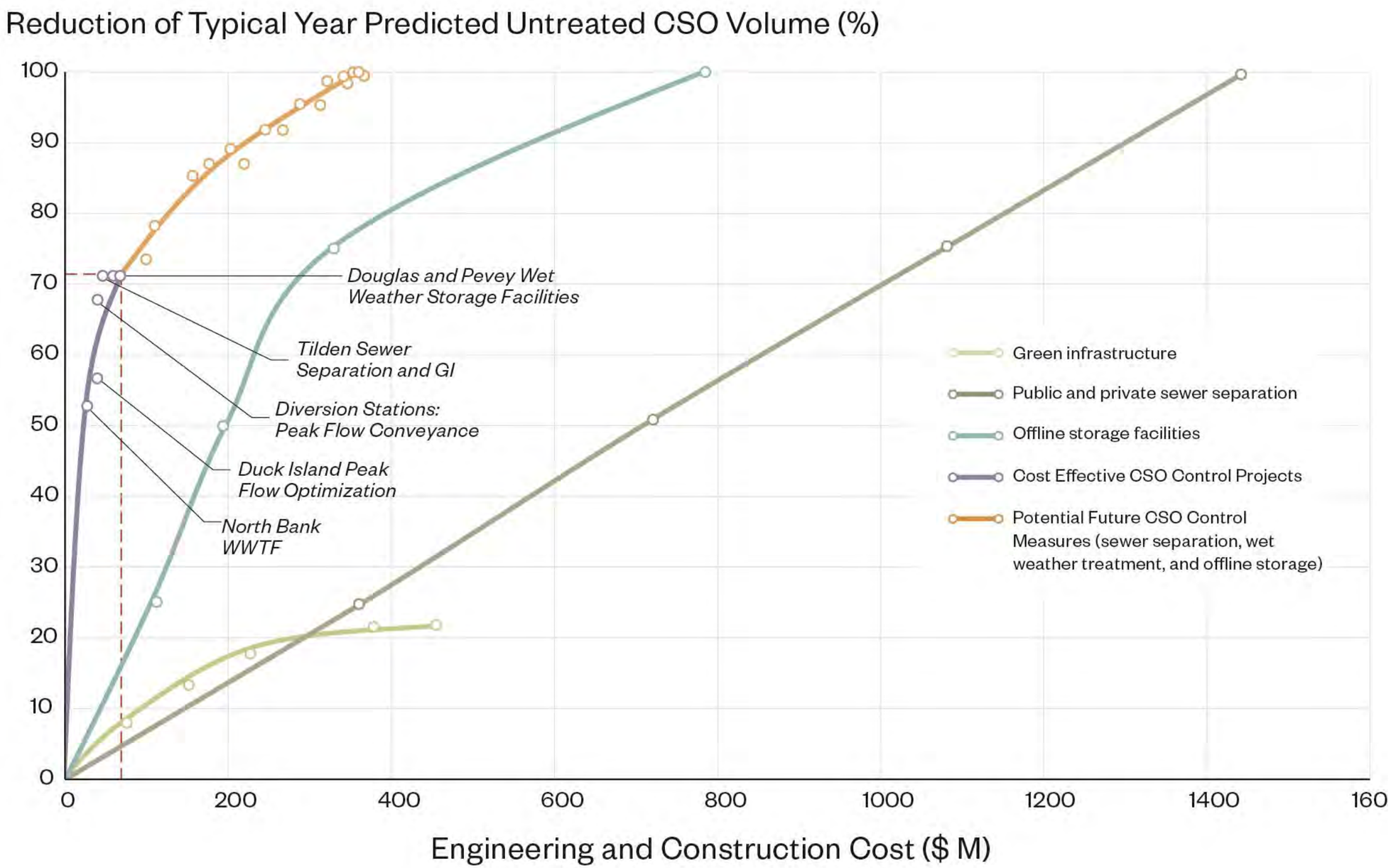


Figure ES-5: Volumetric CSO Control Cost Benefit Analysis

As shown in Figure ES-5, sewer separation and offline storage tank programs perform poorly from a cost-benefit perspective when implemented on a system-wide basis, relative to the hybrid program that features the North Bank WWTF. Figure ES-5 also demonstrates the poor performance of green infrastructure for CSO control from a cost-benefit perspective, as well as the overall level of control achieved. The point represented by the North Bank WWTF project in the hybrid program indicates a dramatically better cost-benefit performance than any other point. This point illustrates that untreated CSOs could be reduced by 53% for an estimated cost of $27M. It is worth noting that system-wide offline storage tank and sewer separation programs would require approximately $200M and $780M of investment, respectively, in order to achieve a similar level of CSO control (based on model predictions).

Other points on the curve represent additional CSO control projects in addition to the North Bank WWTF, including an upgrade to the peak wet weather treatment capacity at Duck Island to 126 MGD, conveyance enhancements at Merrimack and Warren stations, sewer separation and green infrastructure in the Tilden sewershed, and so on. Figure ES-6 is a more focused (zoomed in) chart depicting the same CSO control projects as above, showing a clear “knee” of the curve at the intersection of approximately 72% CSO control and $64M investment.

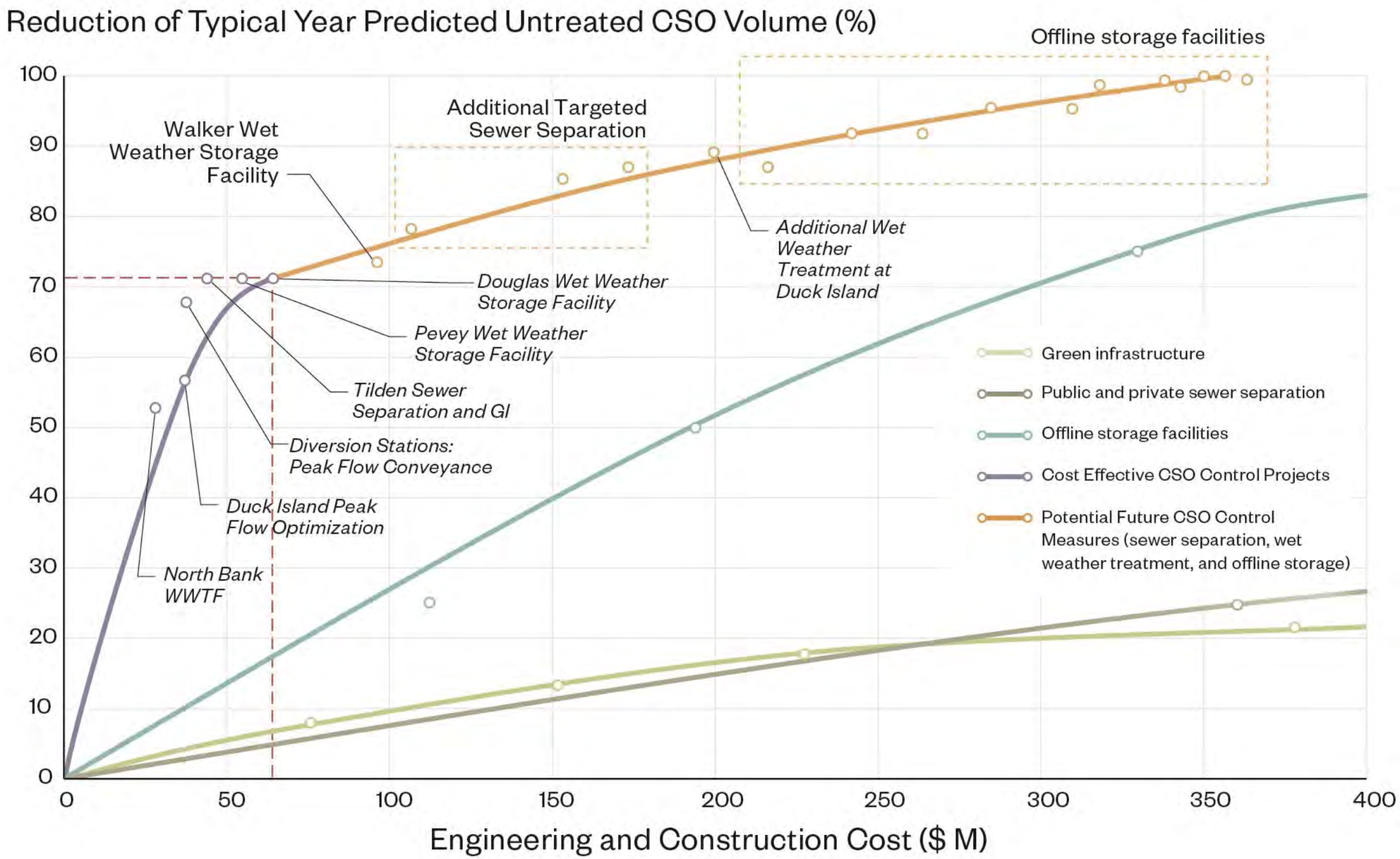


Figure ES-6: Volumetric CSO Control Cost Benefit Analysis (focused)

As shown in this focused cost-benefit chart, after implementation of the North Bank WWTF and several subsequent CSO control projects, the line depicting the relationship between cost and benefit begins to flatten, indicating higher additional costs for diminishing additional benefits. This region of the chart is also correlated with model simulations that have less predictive accuracy due to several cumulative major system changes. As such, projects in this region are considered beyond the "knee" of the curve and represent poor performance from a cost-benefit perspective.

This cost benefit analysis shows that the model predicts diminishing benefit for projects implemented after the storage tanks at Pevey Street and Douglas Road. As such, this region of the curve may be considered the "knee" of the curve. Table ES-5 contains the model predicted performance for each CSO station associated with this point. The point associated with the "knee" includes the North Bank WWTF, peak wet weather capacity upgrade to 126 MGD at the Duck Island WWTF, improvements (widened flow control gates) at Warren and Merrimack stations, targeted sewer separation and green infrastructure in the Tilden sewershed, and offline storage tanks at Pevey Street and Douglas Road.

Table ES-5: Model Predicted Typical Year CSO Performance for the Knee-of-the-Curve

CSO Station	Existing Conditions		Knee-of-the-Curve	
	AAOV (MG)	Frequency	AAOV (MG)	Frequency
West	121.8	34	15.8	12
Merrimack	115.2	21	45.7	8
Warren	48.8	20	11.9	5
Tilden	22.0	18	10.2	9
Read	8.1	17	0.0	0
Walker	7.0	8	7.1	8
Beaver Brook	5.7	5	1.8	2
Barasford	3.1	6	3.1	3
First	0.0	0	0.0	0
Total CSO Volume	**331.7**	**N/A**	**95.6**	**N/A**

On a system wide basis, total untreated CSO volume is reduced by approximately 72%, and the maximum number of activations (at West station) is reduced from 34 to 12. CSO volumes at West, Merrimack, Warren, and Tilden stations (which currently discharge 93% of typical year CSO volume) are reduced by 87%, 60%, 76%, and 54%, respectively. CSO discharges at the fifth largest station (Read) are eliminated for the typical year.

Model predictions also indicate that, with the projects associated with the "knee", 94.8% of combined sewage collected in the CSS during precipitation events is captured and conveyed to the WWTF for treatment on a systemwide annual average basis. Under existing conditions, this wet weather capture is 83.7% based on model predictions. This finding indicates that by constructing the projects associated with the knee-of-the-curve, Lowell may achieve compliance with the CWA according to the presumptive approach (85%). This finding, combined with the cost benefit analysis and uncertainty associated with additional cumulative changes in the model, indicates the "knee" is a reasonable point to achieve for Lowell's Phase 3 CSO control program, and implement as part of this IP.

As such, Lowell's Phase 3 CSO control program (that will be implemented as part of this IP) will include the following CSO control projects:

- Construction of the North Bank WWTF
- Upgrade peak wet weather treatment capacity at the Duck Island WWTF to 126 MGD
- Construction of enhancements at Warren and Merrimack Stations to improve conveyance
- Construction of sewer separation and green infrastructure in the Tilden sewershed
- Offline storage tank at Douglas Road
- Offline storage tank at Pevey Street

As previously stated, the above projects that will be completed as part of the Phase 3 CSO control program will allow Lowell to achieve compliance with the CWA according to the EPA's presumptive approach, with 94.8% capture of combined sewage for treatment during wet weather. After completion of the Phase 3 CSO control program, post construction monitoring will be undertaken to verify that CWA compliance been achieved.

The CSO control alternatives analysis included as part of this IP has already determined possible strategies to achieve additional CSO control beyond the projects that are part of the Phase 3 CSO control program. After post construction monitoring has been completed, if it is determined that Lowell must implement another phase (4) of CSO control projects to achieve compliance with the CWA, then these strategies should be reassessed with a recalibrated model. As previously stated, the predictive ability of the model diminishes with cumulative changes, and the projects that were simulated beyond the "knee" (Phase 3 CSO control program) should be re-evaluated after the model is recalibrated to reflect future conditions. In addition, new CSO control technologies and strategies may be available, so a thorough CSO control alternatives analysis should be undertaken at that time. Regardless, this IP establishes several possible strategies to achieve further CSO control and estimates the cost-benefit performance of each.

FCA

An FCA was performed to assess the financial impact of the proposed IP on the City of Lowell and its rate payers. The FCA employed the methodology provided for in EPA's 1997 Guidance for Financial Capability Assessment and Schedule Development supplemented by information allowed for consideration under the 2014 Final Guidance. To determine the financial impact of a control plan, the EPA uses a scorecard that combines the results of a calculated Residential Indicator that measures the household burden of a proposed plan with a financial management score that evaluates the stress the control plan would impose on the permittee's finances. These are then combined to determine the "level of financial burden" that the plan would impose.

Specifically, the FCA using the 1997 guidance calculates the Residential Indicator metric using Median Household Income (MHI) as stipulated under the EPA guidance. However, as allowed under the 2014 guidance, the FCA also calculated the RI using quintile income data for the bottom 40 percent and 20

percent of Lowell's Households. The FCA also assessed household financial impacts taking into account Lowell's relatively high cost of living index (i.e., Cost of living index (COLI) of 122 versus 100 for the national average)

In assessing cost per household impacts, the FCA included only the costs of the wastewater management components of the IP and only those costs that would be allocated to the residential ratepayers of Lowell. Water supply expenditures were excluded as were cost allocations to the surrounding towns and to Lowell's non-residential ratepayers.

The FCA found that using the MHI metric would yield a high economic impact based on an RI of 2.1 and a medium range financial management rating for Lowell. However, the burden is substantially increased due to the large skewedness in household incomes; the RI would be 2.9 at households at the upper limit of the 40th percentile and would reach 6.5 for those at the upper limit of the 20th percentile. Considering the high cost of living in Lowell, the RI for households at the MHI would increase from 2.1 to 2.5. The situation also worsens for the 40th and 20th quintiles. Therefore, the FCA indicates that the IP would be unaffordable to Lowell's households under a conventional schedule. Table ES-6 presents the EPA Scorecard results using the supplemental information allowed under the 2014 Final Guidance.

Table ES-6: EPA Scorecard for Proposed Integrated Plan

Permittee Financial Capability Indicators Average Score	Residential Indicator (Cost Per Household as a Percentage of MHI)		
	Low (Below 1%)	Mid-Range (Between 1 and 2%)	High (Above 2.0%)
Weak (Below 1.5)	Medium Burden	High Burden	High Burden
Mid-Range (Between 1.5 and 2.5)	Low Burden	Medium Burden	High Burden
Strong (Above 2.5)	Low Burden	Low Burden	Medium Burden

Schedule for IP Implementation & Rate Modeling

An initial schedule for implementation of the IP was developed based on the raw score of each IP project, the duration of each project, and bundling of linked projects. This strategy allowed for benefits to be maximized early-on. The phosphorus removal project was scheduled to occur early in IP implementation due to regulatory requirements, despite this project having received a low score and having a relatively small benefit compared to other high-ranking IP projects. More detail regarding the raw score and sequencing of each project is provided in Chapter 9 of this document.

The initial IP implementation schedule was not constrained by affordability, and consideration was only given to the ability of Lowell to implement multiple projects at once. Impacts of the proposed IP on ratepayer affordability were assessed under this "unconstrained scenario". The "unconstrained scenario" assumes that annual capital utility expenditures on the IP are not constrained by financial considerations, but only by the capacity of Lowell to implement IP Projects. By conducting several iterations of the affordability analyses described below, a final schedule for IP implementation was developed. Since the IP contains critical projects for public health and environmental protection, the schedule which was

developed represents the fastest possible schedule for implementation that does not severely exceed affordability thresholds, as shown in Figure ES-7 below. It should be noted that the analyses below do not account for the cost of drinking water projects and programs, as per EPA guidance. As such, ratepayers are likely to face a more severe burden due to rate increases than is forecasted in this report.

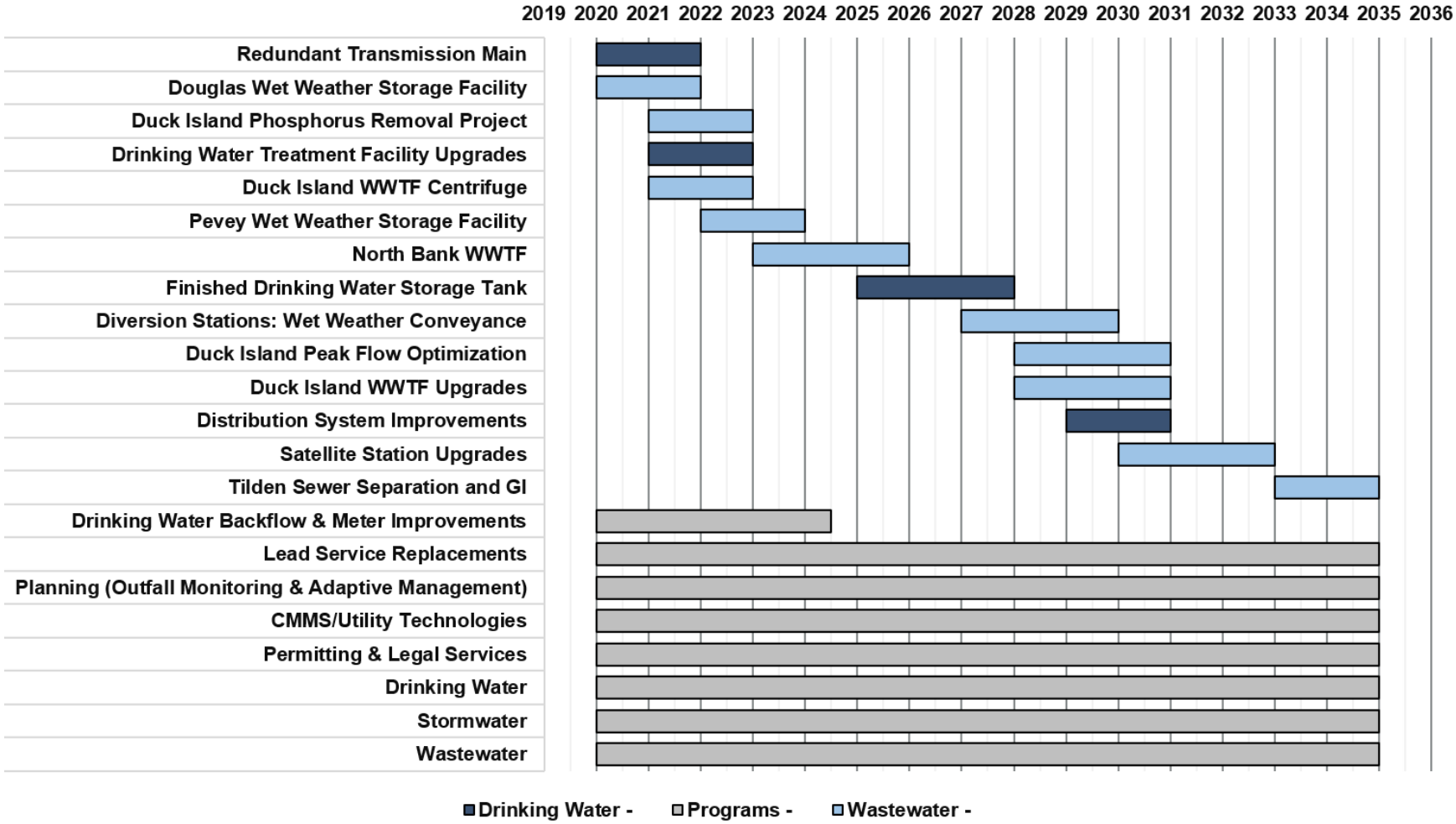


Figure ES-7: Schedule for IP Implementation

Using a $97.5 million capital cost (wastewater expenditures only, adjusted for inflation) expended over a 15-year period, Lowell forecasted annual sewer rates required to generate the revenue to pay for the associated debt service. The forecasted rates are shown in Table ES-7.

Table ES-7: Forecasted Sewer Rates 2020-2035 (per hundred cubic feet)

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Rate	$4.72	$5.10	$5.56	$6.23	$6.60	$7.06	$7.28	$7.28	$7.46	7.65	7.95	$7.95	$7.95	$8.19	$8.19	$8.19

Using these rates and an average household monthly consumption of 10 hundred cubic feet (7,500 gallons) per month, an average monthly bill was estimated for each, as shown in Table ES-8.

Table ES-8: Projected Monthly Bills 2020-2035

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Bill	$47	$51	$56	$62	$66	$71	$73	$73	$75	$76	$79	$79	$79	$82	$82	$82

To assess affordability, Lowell residential incomes were forecasted for the 15-year period ending in 2035. A review of historical data from the Census Department shows that Lowell incomes have been in an almost constant state of decline for more than a decade. Household incomes, especially in the lower income brackets, continued to decline even well after the official Great Recession ended in 2009. For example, incomes at the upper limit of the 40th percentile decreased from $45,600 in 2012 to $36,854 in 2017 (using 2019 dollars). For the bottom 20th percentile, household incomes dropped from $21,582 to $16,175. Median household incomes (MHI) decreased by 20 percent in real dollars from 2009-2017.

It is difficult to project whether stagnant incomes will persist over the next decade or return to a positive trajectory. However, despite recent robust growth in national household incomes, Lowell MHI actually decreased from 2015-2017. Unless structural changes occur in the Lowell economy, near term high household income growth is not likely to materialize.

The affordability analysis assumes a positive but slow growth rate of 1 percent. There is and will remain a large disparity in income among the different quintile income groups with the bottom 20th percentile earning less than a third of the MHI. Hence, incomes are quite skewed in Lowell.

Lowell has been (and remains) a relatively high cost of living city with the most recent cost of living index (COLI) estimated at 122, or 22 percent higher than the average American city. This translates into lower purchasing power for both nondiscretionary and discretionary goods and services. Therefore, the reduced purchasing power Lowell residents experience relative to the average US household must be considered. Application of the COLI factor results in a Residential Indicator as shown in Table ES-9.

Table ES-9: Sewer Bills as Percentages of Monthly HHI with COLI Adjustment

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
MHI	1.3%	1.4%	1.5%	1.7%	1.8%	1.9%	1.9%	1.9%	1.9%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
40th Percentile	1.8%	1.9%	2.1%	2.3%	2.4%	2.6%	2.6%	2.6%	2.7%	2.7%	2.8%	2.7%	2.7%	2.8%	2.7%	2.7%
20th Percentile	4.1%	4.4%	4.8%	5.3%	5.6%	5.9%	6.0%	6.0%	6.0%	6.1%	6.3%	6.3%	6.2%	6.3%	6.3%	6.2%

This RI indicates that for all households at the upper limit of the 40th percentile, and lower, the IP is close to, or above, the affordability threshold for almost the entire 15-year period. The income growth rates used in the analysis are conservative since they assume positive growth rates that have not been achieved in more than a decade. Furthermore, the affordability analysis does not consider the significant IP expenditures dedicated to water infrastructure upgrades. These expenditures are equal to about 65% of the wastewater projects and will impact water rates. If these expenditures were to be accounted for, unaffordability of the IP would increase even more, further demonstrating that a faster implementation of the IP is not possible.

Figure ES-8 depicts implementation of the IP and shows accumulation of benefits and expenditures. As shown in the schedule, implementation of the IP under this scenario will result in rapid accumulation of benefits and achieve a high level of CSO control early on. The North Bank WWTF is scheduled to be completed by 2026. According to model predictions, this will result in more than a 50% reduction of untreated CSO discharges within the first six years of IP implementation. In addition, other critical projects necessary for the protection of public health and the drinking water supply, including the construction of a redundant transmission main and a lead service replacement program, will also be undertaken early on in IP implementation. It should be noted that the phosphorus removal project at Duck Island is only scheduled to occur early-on in the IP due to regulatory requirements. This project has a low ranking and small benefit score.

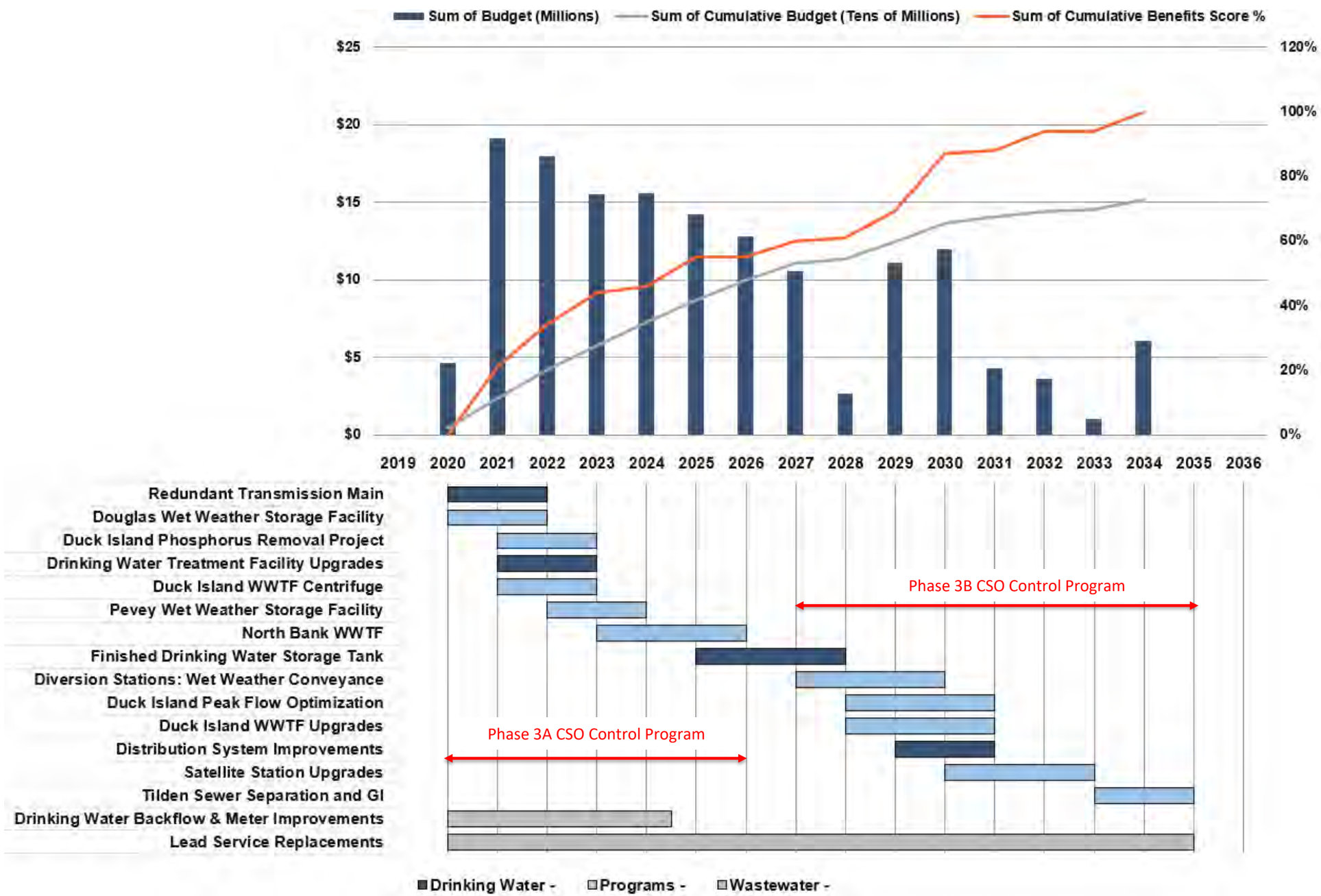


Figure ES-8: IP Implementation and Benefits

Adaptive Management & Post Construction Monitoring

In order to ensure benefits are realized, while maintaining a cost-effective approach, it is important to Lowell that adaptive management be applied on a regular basis. Inevitably, not all capital projects within the proposed plan are fully defined through design and construction. Furthermore, projects not yet started or those in an initial study phase may result in better, more cost-effective capital projects that could produce even greater benefits than currently planned projects. As such, periodic (as-needed) review and refinement would prove beneficial to Lowell in terms of the environment and the community. To achieve this, IP selection criteria, criteria weighting, project definition & scoring, project benefits, affordability, and the implementation schedule should be re-assessed as needed. These IP elements may need to be reassessed if a new regulatory requirement were to take effect, a key infrastructure need (failure, vulnerability, etc.) develops, or some other event occurs that would require changes to the IP to ensure benefits continue to be maximized and that public health is protected.

In addition to reassessing all IP elements as needed, it is recommended that Lowell plan to reassess certain IP elements at critical milestones or events, as shown in Table ES-10, below.

Table ES-10: Adaptive Management and Review of IP Elements

IP Element	Milestone/Event
CSO Control Alternatives Analysis	• Phase 3A CSO Control Plan Implemented • New CSO control technology available
Affordability Metrics	• Economic recession • Federal assistance made available • Change in municipal financial capability • Phase 3A CSO Control Plan Implemented
Updated Criteria & Weighting	• Economic recession • Urgent public health concern • New regulatory requirement and/or supporting data (e.g., Clean Stream Initiative completed)
Benefits Calculation	• Economic recession • Urgent public health concern • New regulatory requirement and/or supporting data • Updated CSO Control Plan
IP Implementation and Schedule	• Phase 3A CSO Control Plan Implemented • Federal funding made available • Major equipment failure • Economic recession • Urgent public health concern • New regulatory requirement and/or supporting data • Updated CSO Control Plan • Unexpected/differing project benefits

Reassessment of the CSO control alternatives analysis should be completed as needed based on completion of CSO control projects, updates to the High Flow Management (HFM) Plan, and as new CSO control technologies are made available. The benefits of each CSO control project in this plan were predicted using a calibrated sewer system model. Although the model was sufficiently calibrated to characterize existing conditions, and predict the effect of potential CSO control projects, the predictive accuracy of the model decreases as the number of cumulative changes increases. In addition, Lowell manages its sewer system with a significant number of active controls (using dynamic flow control and CSO diversion gates). After the completion of projects, such as construction of the North Bank WWTF, that will significantly impact the operation of the entire sewer system, extensive efforts to optimize operation of the system will need to be undertaken. It is likely that this process of optimization and updated HFM will further reduce untreated CSO discharges. As such, it will be important to perform sewer system characterization studies after construction of each major CSO control project to accurately assess their respective benefits and determine (or adjust as needed) the predicted benefits of subsequent projects. Post construction monitoring will also characterize the impact of system improvements on water quality. As Lowell moves towards compliance with the CWA, post construction monitoring will allow it to assess the effectiveness of each project and adapt implementation of additional CSO control projects if needed.

1. Introduction

In 2017 the City of Lowell (Lowell) began development of an Integrated Capital Plan, also referred to as an Integrated Plan (IP), for Lowell's sewer, stormwater, and drinking water infrastructure needs. Lowell's decision to develop an IP reflects a consensus among regulators and municipal planners that planning for regulatory compliance should not only consider the need to achieve environmental protection and meet the standards set forth by the Clean Water Act, but also the need to protect public health and environmental justice. As such, alongside planning for CSO control and elimination, this IP considers the needs of Lowell's drinking water distribution system and upgrades that the system will require to protect public health. Failure to plan for the needs of both the wastewater and drinking water systems could lead to risks to public health and continued environmental impacts.

Lowell has been committed to achieving the standards of the Clean Water Act since it was enacted in 1972. To that end, Lowell has invested hundreds of millions of dollars in projects designed to ensure treatment of raw sewage before its discharge to any waterway, including the Merrimack and Concord Rivers. This process started shortly after the enactment of the Clean Water Act when Lowell utilized federal funding to construct a system of combined sewer interceptors and the Duck Island Wastewater Treatment Facility (WWTF). Since that time, Lowell has worked diligently to reduce and eliminate remaining Combined Sewer Overflows (CSO) that continue to occur at designated and permitted hydraulic relief structures in the interceptor system. These CSO stations were, and continue to be, critical points in the system where combined stormwater and wastewater flows are regulated to prevent sewer backups into homes and streets, or damage (and possibly destruction) of the treatment process at the WWTF during intense wet weather. Although it is Lowell's goal to significantly reduce the occurrence of CSOs, several barriers have historically, and continue to, make this a difficult goal to achieve:

- Traditional CSO control measures, such as sewer separation, are prohibitively expensive, and support in the form of federal funding has not been available.
- Construction of some CSO control measures, such as sewer separation or offline storage tanks, is not feasible in much of the City of Lowell.
- The cost of achieving 100% CSO control (by way of traditional methods) in the City of Lowell would result in rate increases that would be excessively burdensome for low income families and compromise environmental justice in Lowell.
- Lowell is an economically disadvantaged community that is heavily burdened with the costs of maintaining and operating decades old infrastructure, including an aging drinking water treatment and distribution system. Lowell must allocate its limited resources to ensure that public health is not compromised by neglecting these assets by over-allocating funds to CSO control.

With the promulgation of the Integrated Planning framework, Congress and the EPA have recognized that Towns and Cities such as Lowell are often beset with the challenges and competing priorities described above. The IP framework provided a path forward for communities wishing to achieve much higher levels

of CSO control while considering the necessity of other projects required to protect and preserve public health.

The IP described herein will allow Lowell to drastically reduce the occurrence of CSOs while protecting public health by considering other necessary projects, such as upgrades to the drinking water treatment and distribution system. An extensive alternatives analysis was conducted to develop a comprehensive CSO control plan that will significantly reduce untreated CSO discharges, improve water quality, and maximize the effectiveness of Lowell's existing infrastructure. The implementation plan included in this report has been carefully developed such that projects are sequenced by priority, constructability, and to avoid excessive rate increases for Lowell's residents.

1.1 Purpose of Report

This report contains a description of Lowell's IP. The report also contains a schedule for the implementation of Lowell's next phase of CSO control (Phase 3), along with a schedule for the implementation of other necessary projects that will protect public health and safety within the City of Lowell. This report also includes a plan for post construction monitoring, and assessment of the effectiveness of this next phase of CSO control. The post construction monitoring measures described in this document are an integral part of the IP, and they will be used to help determine what, if any, additional CSO control measures may be necessary after the implementation of the IP.

This report outlines the steps taken to achieve development of the IP, the resulting IP, and contains a schedule for implementation of the IP. This report also provides an overview of previous CSO control efforts and planning work, including the Phase 2 LTCP, which was submitted in 2014.

1.2 Wastewater Collection and Treatment System Overview

Lowell's wastewater collection and treatment system is comprised of of the following key components:

1. Duck Island Wastewater Treatment Facility (WWTF)
2. Major sewer interceptors that convey wastewater and stormwater to the WWTF along either the North or South Bank of the Merrimack River
3. Collection systems in Lowell, Tyngsboro, Chelmsford, Dracut, and Tewksbury that collect wastewater (and stormwater) and convey it to the interceptors

The interceptors were originally designed with a number of relief points (CSOs) to prevent the occurrence of sewer backups and Sanitary Sewer Overflows (SSOs) during intense wet weather events. Although many of these CSOs have since been closed and abandoned, nine permitted CSO stations remain today. These stations serve as crucial hydraulic relief points and prevent sewer backups into buildings and streets during wet weather. Six CSO stations discharge directly to the Merrimack River, one station discharges to the Concord River (near its confluence with the Merrimack River), and one discharges to a Merrimack River tributary named Beaver Brook. One permitted CSO station, First Station, remains a permitted relief

point that could discharge to the Merrimack River, but at present, this station is not in use and has not discharged in several years.

The Duck Island WWTF is capable of providing secondary treatment of wastewater up to 32 MGD (average daily flow) and 52 MGD (max daily flow). Average daily flows currently range from 22 to 30 MGD. During wet weather, the WWTF can provide primary treatment and disinfection up to approximately 110 to 115 MGD.

Figure 1-1 is a depiction of Lowell's existing wastewater collection and treatment system. A more detailed description of this infrastructure is included in Section 3 of this report.

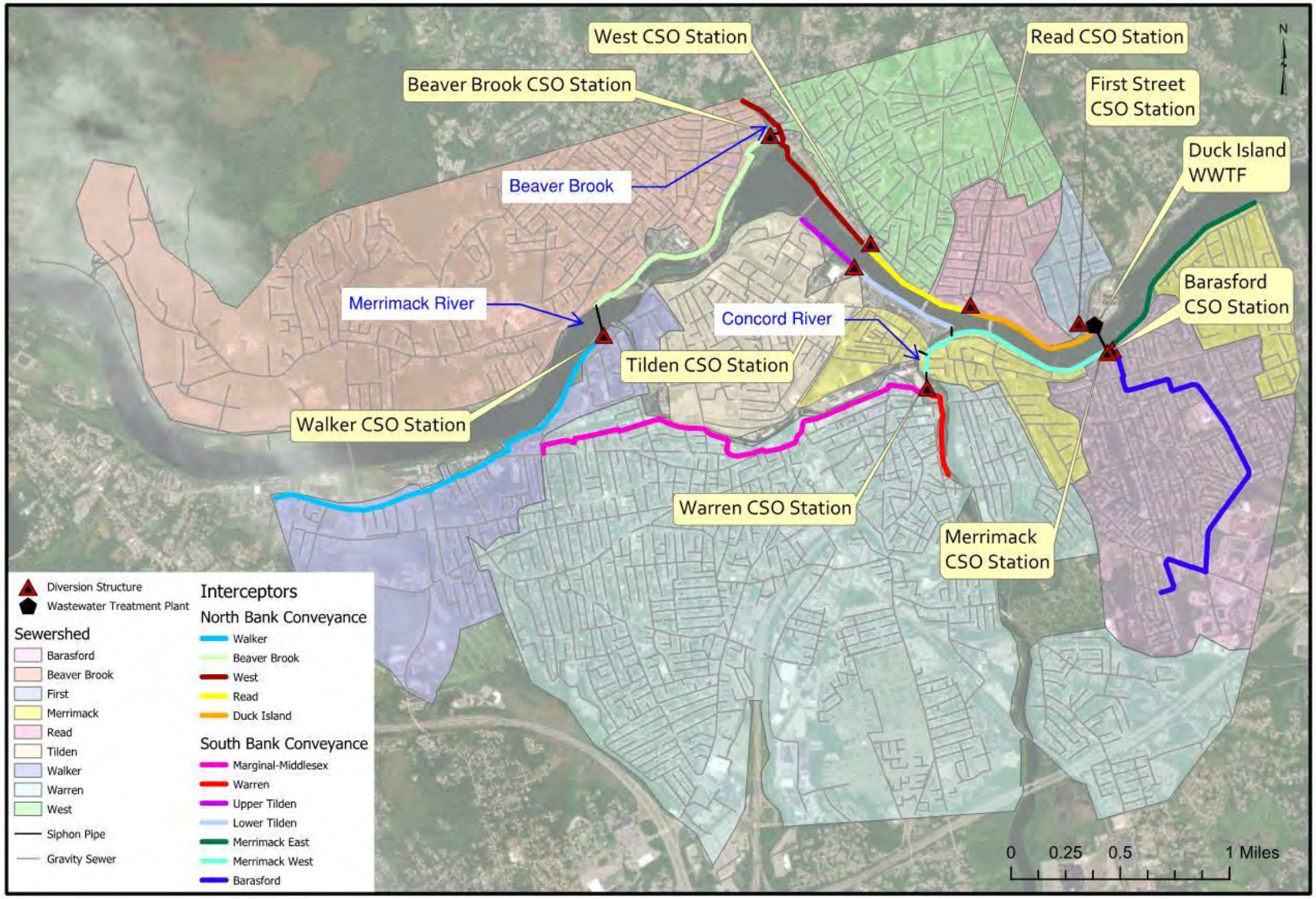


Figure 1-1: Lowell's Wastewater Collection and Treatment System

1.3 Drinking Water Distribution System Overview

The City of Lowell's water distribution system is comprised of approximately 215 miles of water main, approximately 5,300 valves, and 2,300 hydrants, and approximately 24,352 metered service connections. The distribution system is supplied by raw water from the Merrimack River. A raw water intake is located in the Merrimack River where water is gravity fed to the Raw Water Pump Station (RWPS), chlorinated and then pumped to the 30 million gallon per day (MGD) Water Treatment Facility (WTF). The water distribution system includes three service areas, the Low Service Area (LSA), High Service Area (HAS), and the Highlands Service Area (HLSA). It includes four booster pump stations, four water storage tanks, twelve river crossings, and twelve interconnections with surrounding communities. A more detailed description of the distribution system is included in Section 3 of this report.

1.4 Phase 2 LTCP & Prior CSO Planning Work

In 1998, the City of Lowell submitted a report on Nine Minimum Control (NMC) measures to the EPA. These NMC measures form the foundation of Lowell's CSO control strategy and are summarized in Section 5.1.

As indicated in Section 5.1, Lowell's current implementation of the NMCs has been effective, and no updates are recommended to most of the current practices. In some circumstances, the CSO Control Alternatives Analysis (Section 5) has resulted in possible strategies and capital projects that would result in updates to the current NMCs (in addition to other technologies that were assessed as part of the LTCP update). A full analysis of CSO technologies is included in Section 5.

Since the report on NMCs was submitted, Lowell has reduced systemwide CSO discharges by over 80%. Figure 1-2 is a timeline showing CSO control measures and initiatives implemented since 1998.

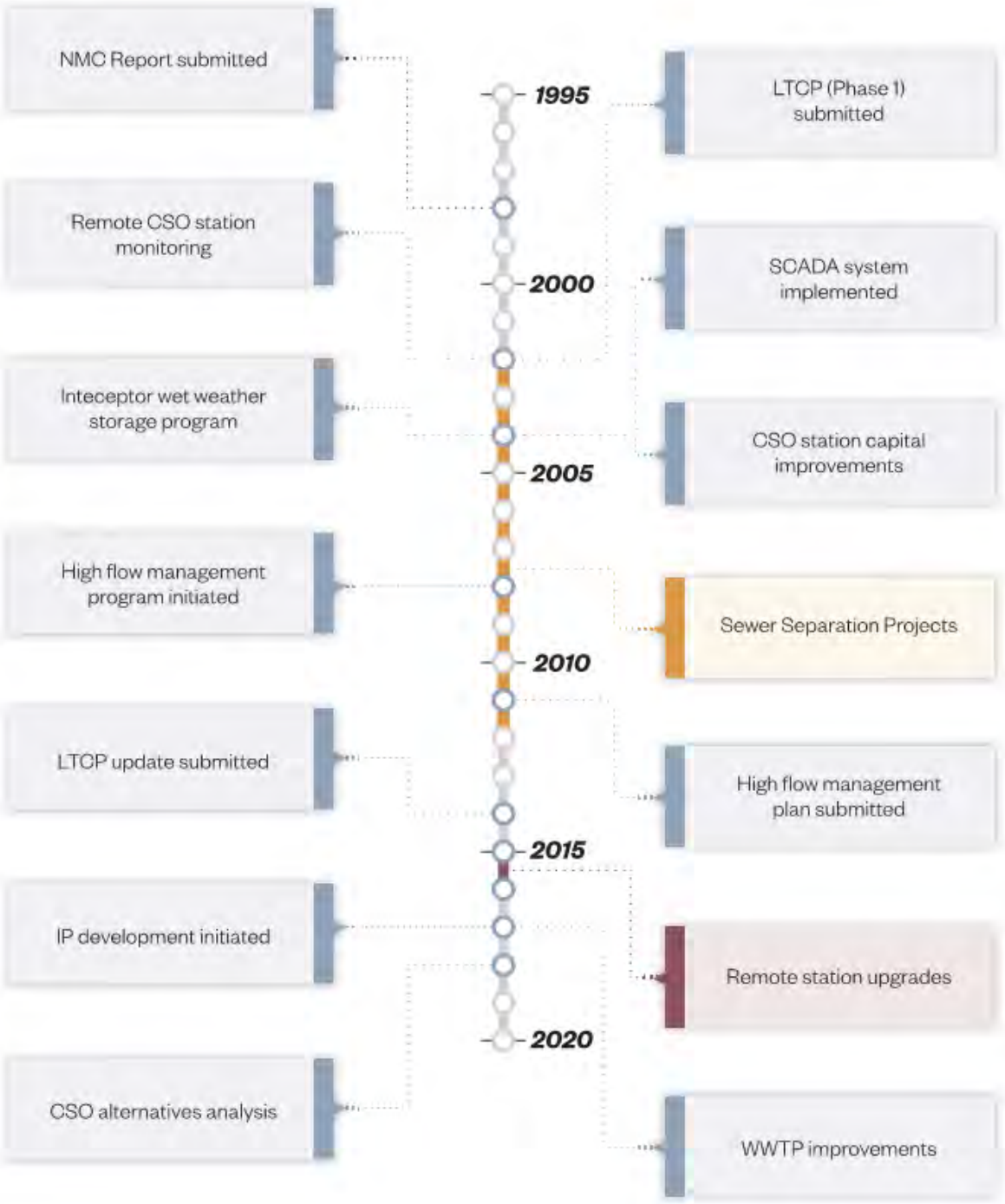


Figure 1-2: Timeline of CSO Control Initiatives in Lowell

In 2014, Lowell submitted a CSO Long-Term Control Plan Update to the Environmental Protection Agency (EPA), and subsequently received comments. An Administrative Order on Consent (AOC) was issued requiring Lowell to achieve full compliance with the Clean Water Act (CWA), leading Lowell to initiate the IP process.

1.5 Administrative Order on Consent

In 2017, the EPA and the City of Lowell entered into an AOC. The AOC requires Lowell to submit an Integrated Plan that includes a plan for Lowell's next phase (Phase 3) of CSO control. The AOC also established several interim actions/submissions leading up to the IP:

- March 31, 2018: Draft Financial Capability Assessment (FCA)
- December 31, 2018: CSO Model Update and CSO Alternatives Analysis
- December 31, 2018: Conceptual design report for elimination of flooding in the Middlesex Street area
- March 31, 2019: Complete upgrades to primary and secondary clarifiers (schedule amended to reflect construction delays)
- December 31, 2019: Integrated Plan

1.6 CSO Wet Weather Capture

Based on the US EPA CSO Control Policy (1994), Lowell may achieve compliance with the CWA by demonstrating adequate CSO control through either the demonstration approach or the presumption approach. The presumption approach requires that no less than 85% by volume of the combined sewage collected in the CSS during precipitation events on a systemwide annual average basis is captured and conveyed to a WWTF for treatment. Based on predictions from the calibrated hydraulic model (documented in detail in Chapters 4 and 5), Lowell's sewer system would discharge approximately 331.7 MG of CSO during a typical rainfall year under existing (baseline) conditions. The model also predicts that during a typical rainfall year, the sewer system collects 2,034 MG of combined sanitary flow and rainfall runoff.

Based on these model predictions, the existing sewer system conveys approximately 1,702 MG of combined sewage to the Duck Island WWTF for treatment, or 83.7% of the combined sewage collected systemwide during an annual average basis. In Section 4.5 the percent capture is recalculated based on the inclusion of the recommended CSO control plan that is a part of this IP.

1.7 IP Goals and Background

1.7.1 Integrated Planning Framework (IPF) and Purpose

The overall purpose of this IP has been to identify, prioritize, and provide a plan for implementation for the infrastructure needs of Lowell related to the water and wastewater systems. The IP is based on a set of procedures that generally sought to follow the EPA's 2011 Guidance for an Integrated Planning Framework. In order to prioritize capital projects and set forth an effective and achievable implementation plan, Lowell developed a set of criteria based on environmental and community (social and economic) factors that apply specifically to Lowell and its community. In accordance with the AOC, this IP addresses both Clean Water Act requirements in addition to other regulations and overall system needs of the drinking water and wastewater systems.

1.7.2 Rate Payer Affordability

Traditionally the financial capability assessment that is performed as part of the development of an LTCP was based on the EPA's *Combined Sewer Overflows – Guidance for Financial Capability Assessment and Schedule Development* document from 1997. The approach outlined in this document defines 2% of median household income (MHI) as the threshold for an affordable sewer rate. This is known as the Residential Indicator (RI). However, this definition of ratepayer affordability has been significantly criticized and re-examined recently as it neglects to consider the impacts of unaffordable rates for the poorest and most vulnerable persons living in a community, where 2% of the MHI may comprise a much more significant burden to the bottom 25% of earners in a community. As such, the American Water Works Association (AWWA) and Water Environmental Federation (WEF) have recommended alternative approaches.

As such, as part of the IPF that the EPA has developed, the Agency acknowledges that the RI based on a percentage of MHI should not be the only measure to define ratepayer affordability and has stated that it is a "common misperception that the EPA requires communities to spend to a level of 2% of the MHI to meet CWA obligations". The EPA has further stated that the RI as a percentage of MHI should be considered along with "a suite of other financial indicators to assess the overall burden on a community". Some of the factors that should be considered when assessing affordability include the following:

- Burdens on low income households
- Unemployment rates
- Percent of population requiring public assistance
- Percentage of household income spent on non-discretionary necessities

1.7.3 IPF Process

The process of developing an IP with the EPA-provided framework involved several key steps as outlined below. Each of these steps is described in detail throughout this report.

1.7.3.1 CSO Control Alternatives Analysis

An extensive effort was undertaken to develop a CSO control plan that maximizes CSO reductions while minimizing costs. This process considered the applicability of all available CSO control technologies and included a sewershed by sewershed assessment of potentially feasible alternatives using a calibrated hydrologic/hydraulic SWMM model. This analysis included a five-month flow and rainfall monitoring effort which was undertaken to recalibrate the SWMM model and enhance system understanding. The results of the modeling were assessed by comparing benefits to estimated project costs through a Knee-of-the-Curve (KOC) analysis. This analysis resulted in a Phase 3 CSO control plan which will achieve substantial reductions of untreated CSOs and be implemented as part of this IP.

1.7.3.2 Identification of Projects

City Staff identified several CSO control, wastewater, and drinking water projects for inclusion in the IP. The projects that were identified to be in the IP were selected because of their potential to achieve significant CSO control or because they were determined to be necessary to protect, maintain, or enhance public health.

1.7.3.3 Project Scoring and Ranking

Not all projects identified can be implemented while meeting affordability criteria. As such, a project ranking system was developed to prioritize projects and determine which projects could be deferred to a future IP or an update to this IP. Criteria to score projects against were developed to assess each projects' potential to provide maximum environmental and community benefits.

1.7.3.4 Financial Capability Assessment

A Financial Capability Assessment (FCA) was performed as an initial step in understanding Lowell's ability to fund the projects. The FCA was determined by examining many indicators of financial health.

1.7.3.5 Implementation Scenario Development

After projects were ranked, design and construction costs/schedules were estimated. Using this information, several implementation scenarios were analyzed using a tool that was designed to optimize project scheduling. These scenarios included analyses of constraints based on affordability, schedule, planning horizon, and several other factors. These scenarios provided an estimate of total yearly expenditures on IP projects in addition to on-going O&M programs and activities.

1.7.3.6 Sewer Rate Modeling

Using data from the implementation scenarios, the expected rate impact of retained scenarios was examined using Lowell's rate model. This allowed for an analysis of each implementation scenario in terms of rate impacts to residents. The rate modeling allowed for a detailed understanding of the

affordability of each scenario, how burdensome each scenario is, and if any scenario exceeded affordability thresholds.

1.7.3.7 Recommended Plan

Based on the results of the CSO control alternatives analysis, implementation scenario analysis, and rate modeling, a plan for IP implementation was developed for the next 15 years. The recommended plan includes a schedule for project implementation and provisions for adaptive management, which is an important element of this IP as described in Section 1.6.4. The recommended plan also includes recommendations for post construction monitoring and assessment that will be used to evaluate compliance with the CWA.

1.7.3.8 Public Participation & Regulator Meetings

Public forums and meetings with regulators from EPA and MassDEP occurred throughout the project. The meetings with regulators were important opportunities to ensure that development of this IP was being undertaken in a manner consistent with regulatory requirements. The public meetings that occurred were also valuable opportunities to update residents, stakeholders, community leaders, and environmental advocates about Lowell's efforts to achieve CSO control, barriers to doing so, and development of the IP. Through these public meetings, it was found that most advocates and stakeholders desire higher levels of CSO control but are aware that other projects must also be prioritized for the protection of public health. Public sentiment is also consistent with Lowell's opinion that federal funding should be provided to low income CSO communities, like Lowell, to further reduce (or even eliminate) CSOs and allow Lowell to prioritize other projects without placing unsustainable burdens on ratepayers.

1.7.4 Adaptive Management

An important element of Lowell's IP is the inclusion of an adaptive management approach. This approach to IP implementation provides that as projects are implemented, Lowell will monitor and quantify the benefits of that project relative to its goals. As some projects are likely to result in greater or fewer benefits than were predicted within this document, it is important that Lowell consistently monitor the impact of each project and adapt the design and implementation of remaining IP projects accordingly. The benefits of CSO control projects in this document have been estimated using a computerized hydrologic/hydraulic model of the sewer system. Although this model is capable of predicting relative performance of changes to the existing sewer system, the accuracy of the model decreases as cumulative changes are added. Thus, the model's predictions are most accurate for projects scheduled to be implemented in the near term. It is important to assess whether or not a project's benefits are similar to the model's predictions after it is actually implemented. If the model's predictions are not accurate, it is likely that the predicted benefits of subsequent projects will also be under or overestimated, and the model should be recalibrated before constructing the next project to determine if changes should be made to that project to maximize its benefit. This adaptive management approach to implementation ensures that the benefits of each project are maximized, and wasteful spending is minimized.

2. Regulatory Requirements

The waters of Lowell, MA are subject to Federal and Massachusetts State laws and regulations. Particularly relevant to this report is the Clean Water Act, which provides guidance in the development of Total Maximum Daily Loads (TMDL) for impaired water bodies, and the EPA's CSO Control Policy, which provides guidance on the development and implementation of a LTCP, and the promulgation of Surface Water Quality Standards (SWQS).

2.1 Clean Water Act (U.S. EPA, 1972-1987)

The Federal Water Pollution Control Act of 1972 (FWPCA) and subsequent Amendments in 1977, 1981 and 1987 are collectively known as the Clean Water Act (CWA). The objective of this statute is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. As one step toward meeting this goal, each state must monitor and assess the quality of its surface and ground waters and provide periodic status reports to the EPA, the U.S. Congress, and the public. The CWA codifies the process whereby waters are evaluated with respect to their capacity to support designated uses as defined in each of the states' SWQS. These uses include aquatic life support, fish and shellfish consumption, drinking water supply, and primary (e.g., swimming) and secondary (e.g., boating) contact-recreation.

Section 303(d) of the CWA requires states to identify those water bodies that are anticipated to fall short of their SWQS even after implementation of technology-based controls. Water bodies that are impaired by such water quality issues are included on the "303(d) list", also known as the "Integrated List of Waters". Once a water body is identified as impaired, MassDEP is required by the CWA to develop a "pollution budget" designed to restore the health of the impaired body of water. The process of developing this budget, generally referred to as a Total Maximum Daily Load (TMDL), includes identifying the source(s) of the pollutant from direct discharges (point sources) and indirect discharges (non-point sources), determining the maximum amount of the pollutant that can be discharged to a specific water body to meet water quality standards, and assigning pollutant load allocations to the sources. A plan to implement the necessary pollutant reductions is essential to the ultimate achievement of meeting the water quality standards.

Table 2-1 identifies the Integrated List of Waters in the vicinity of Lowell, Massachusetts:

Table 2-1: Integrated List of Waters in Lowell, MA

Water body	Segment ID	Description	Length (miles)	Impairment
Merrimack River	MA84A-01	State line at Hudson, NH to Pawtucket Dam, Lowell.	9	E. Coli; Fecal Coliform Mercury in Fish Tissue
Merrimack River	MA84A-02	Pawtucket Dam, Lowell to Lowell Regional Wastewater Utilities outfall at Duck Island, Lowell.	3.2	(Low flow alterations*) E. Coli; Mercury in Fish Tissue Phosphorus (Total)
Merrimack River	MA84A-03	Lowell Regional Wastewater Utilities outfall at Duck Island, Lowell to Essex Dam, Lawrence.	8.8	E. Coli; Mercury in Fish Tissue PCB in Fish Tissue Phosphorus (Total)
Beaver Brook	MA84A-11	New Hampshire state line, Dracut to confluence with Merrimack River, Lowell.	4.8	(Debris/Floatables/Trash*) (Physical substrate habitat alterations*) Aquatic Macroinvertebrate Bioassessments E. Coli; Taste and Odor; Turbidity
Concord River	MA82A-09	From Rogers Street bridge, Lowell to mouth at confluence with the Merrimack River, Lowell.	0.9	(Debris/Floatables/Trash*); Turbidity E. Coli; Excess Algal Growth Fecal Coliform; Mercury in Fish Tissue

*TMDL not required

2.1.1 Total Maximum Daily Load (MassDEP)

The TMDL process establishes the maximum allowable loading of pollutants that a water body can receive and still meet the SWQS established by the State for protecting public health and maintaining the designated uses of those waters. Through this process, water quality-based controls to reduce pollutant loadings from both point and non-point sources and restore and maintain the quality of their water resources are implemented. TMDL implementation is accomplished through adherence to prevailing regulations and program requirements such as those governing the National Pollutant Discharge Elimination System (NPDES) permits for point source control and the stormwater management performance standards maintained by conservation commissions under the Wetlands Protection Act.

Table 2-2 summarizes the draft TMDL for pathogen indicators (e.g. fecal coliform, E. coli, and enterococcus bacteria) in the Merrimack River watershed, pending EPA approval. Certain bacteria, such as Fecal coliform, E. coli, and Enterococcus bacteria, are indicators of contamination from sewage and/or the feces of warm-blooded wildlife (mammals and birds). Such contamination may pose a risk to human health. Therefore, in order to prevent further degradation in water quality and to ensure that water bodies within the watershed meet water quality standards, the TMDL establishes indicator bacteria limits and outlines corrective actions to achieve that goal. The TMDL applies to all of the water bodies listed in the Integrated List of Waters near Lowell in Table 2-2, as well as the remaining 18 pathogen impaired segments of the Merrimack River watershed.

Table 2-2: Pathogen Source and Indicator Limits for SWQS Categories in the Merrimack River Watershed

Surface Water Quality Standard Classification	Pathogen Source	Load Allocation Indicator Bacteria (cfu/100mL)	
A, B, SA, SB	Illicit discharges to storm drains	0	
	Leaking sanitary sewer lines		
	Failing septic systems		
A	NPDES - WWTF	≤ 20[1] ≤ 100[2]	
	Storm water runoff Phase I and II		
	Direct storm water runoff not regulated by NPDES; livestock, wildlife & pets		
B, SA, SB (Not designated for shellfishing areas)	CSOs	≤ 200[3] ≤ 400[2]	
	NPDES - WWTF		
	Storm water runoff Phase I and II		
	Direct storm water runoff not regulated by NPDES; livestock, wildlife & pets		
SA (Designated shellfishing areas)	NPDES - WWTF	≤ 14[3] ≤ 43[2]	
	Storm water runoff Phase I and II		
	Direct storm water runoff not regulated by NPDES; livestock, wildlife & pets		
SB (Designated shellfishing areas)	CSOs	≤ 88[3] ≤ 260[2]	
	NPDES - WWTF		
	Storm water runoff Phase I and II		
	Direct storm water runoff not regulated by NPDES; livestock, wildlife & pets		
Marine Beaches	All sources	≤ 35[3] ≤ 104[4]	
Fresh Water Beaches	All sources	Enterococci ≤ 33[3] ≤ 61[4]	E. Coli ≤ 126[3] ≤ 235[4]

[1]Arithmetic mean in any set of representative samples
[2]90th percentile of sample set
[3]Geometric mean in any set of representative samples
[4]Acute standard (single sample maximum)

2.1.2 National Pollutant Discharge Elimination System Program (EPA, 1972)

The CWA prohibits discharge into any waters of the United States, any pollutants through a point source unless a permit is acquired. The NPDES Program regulates the permitting process to enforce the CWA. Under the NPDES program, all point source discharges to surface waters must apply for an NPDES permit, and that permit must be renewed periodically. This permit facilitates two types of control: technology-based limitations (based on technological and economic ability of dischargers to control discharge of pollutants) and water quality-based limitations (to protect the quality of the specific water body receiving the discharge). Some states have NPDES programs which meet EPA qualifications and have been delegated authority to issue NPDES permits directly; however, in Massachusetts, NPDES or MA Surface Water Discharge permits are issued jointly by the EPA and MassDEP.

2.2 CSO Control Policy (EPA, April 1994)

The CSO policy provides for a phased process to bring communities with combined sewer systems into compliance with the technology-based and water quality-based requirements of the CWA. A two part approach to CSO control is incorporated into the policy: (1) the implementation of best management practices called the Nine Minimum Controls (NMCs), and (2) the development and implementation of LTCPs, provided that the implementation of the NMCs are not adequate on their own to meet state SWQS.

- The Nine Minimum Controls may be summarized as; appropriate operation and maintenance, maximize storage, minimize overflows, maximize flows to Publicly Owned Treatment Works (POTW), prohibit dry weather CSO's, control solids and floatables, institute pollution prevention programs, notify the public of impacts, and observe monitoring and reporting requirements.
- Long Term Control Plans – The CSO policy calls for initial ("Phase I") NPDES permits to require development of an LTCP as soon as practicable. This plan should include measures to provide for compliance with technology-based and water quality-based requirements of the CWA, including attainment of water quality standards under either the 'presumption approach' or the 'demonstration approach'. The subsequent ("Phase II") permit should require immediate implementation of the control measures in the LTCP. The Phase II Long Term Control Plan for Lowell, MA was submitted to the U.S. EPA in August 2014.
    - Presumption Approach – This is based on the presumption that achieving certain performance criteria with CSO control will be sufficient to meet required WQS. Generally, the presumptive approach should include at least one of the following criteria: reducing overflows to no more than 4 events per year; capturing at least 85% of overflow volume; or elimination of at least the mass of pollutants identified as causing WQS impairment. Sufficient evidence should be available to indicate that these levels of control should be able to meet WQS.
    - Demonstration Approach – This was developed to address instances where compliance with the presumption approach would result in greater investments in control than necessary to achieve WQS. Under this approach, sufficient evidence should be available to show that the proposed alternative is adequate to meet the appropriate WQS. Use of the demonstration approach requires one of the following four criteria to be true: CSO control measure will protect WQS unless this standard cannot be met due to natural conditions/other pollution sources; Overflows remaining after CSO control will not prevent attainment of WQS; CSO control will achieve the maximum pollution reduction benefits reasonably attainable; or CSO control will allow for cost effective expansion and retrofitting if additional controls are required to meet WQS.

2.2.1 Policy for Abatement of Pollution from Combined Sewer Overflows (MassDEP, August 1997)

This Commonwealth issued policy is similar to the CSO Control Policy by the EPA in many respects. It promulgated regulation of discharges of pollutants to eliminate adverse CSO impacts to the receiving water bodies and to attain the highest water quality achievable of the surrounding waters. CSO discharges are required to have an NPDES/MA Surface Water Discharge Permit under federal regulations and 314 CMR 3.00, which are issued jointly by the EPA and MassDEP. In all such cases, the NPDES/MS permits require the outfalls to implement the nine minimum controls necessary to meet technology-based limitations as specified in the CSO Control Policy by the EPA. In addition to these minimum controls, additional treatment requirements, such as screening and disinfection may also be employed.

States, with the approval of the EPA, are required to develop SWQS applicable to their water bodies. These standards contain classifications of water bodies, designation of uses, criteria to protect the uses, and antidegradation provisions. The Massachusetts SWQS, described in detail in the next sub-section, establishes goals for waters of the Commonwealth, and provide the basis for water quality-based effluent limitations in NPDES permits. Any discharge, including CSO discharges, is allowed only if it meets the criteria and the antidegradation standard for the receiving water body. The regulatory options for CSO control based on these classifications are as follows:

- SWQS Class B or SB – CSOs are eliminated
- SWQS Class B (CSO) or SB (CSO) – CSOs remain but must be compatible with water quality goals of the receiving water. The water body must meet uses more than 95 percent of the time.
- Variance – CSOs remain when allowed under a short term modification of SWQS through an NPDES/MS permit
- Partial Use Designation – CSOs remain with moderate impacts resulting in intermittent impairment of water quality goals
- SWQS Class C – CSOs remain causing permanent and sustained impairment so that Class B goals cannot be met

2.2.2 Massachusetts Surface Water Quality Standards (MassDEP, December 2013)

In accordance with the provisions of the CWA, the State of Massachusetts has established SWQS for all water resources of the Commonwealth. MassDEP has developed a system of water body classifications to designate the most sensitive uses for which the surface waters of the Commonwealth shall be enhanced, maintained and protected; prescribe minimum water quality criteria required to sustain the designated uses; and include provisions for the prohibition of discharges. Fresh waters and marine waters are classified into three groups each. Classes A, B, SA and SB support primary and secondary contact recreation and fishing. Classes C and SC support secondary recreation and aquatic life and recreation, but the primary recreational uses of the water body are limited due to other factors. MassDEP has classified the Merrimack River from the State boundary to the Merrimack River Basin as a Class B water body and Beaver Brook and Concord River at their confluence with the Merrimack River at Lowell, also as Class

B, as shown in Figure 2-1. All of the outfalls of the City of Lowell discharge to the Merrimack River, or its tributaries, and are thus subject to Class B water body regulations.

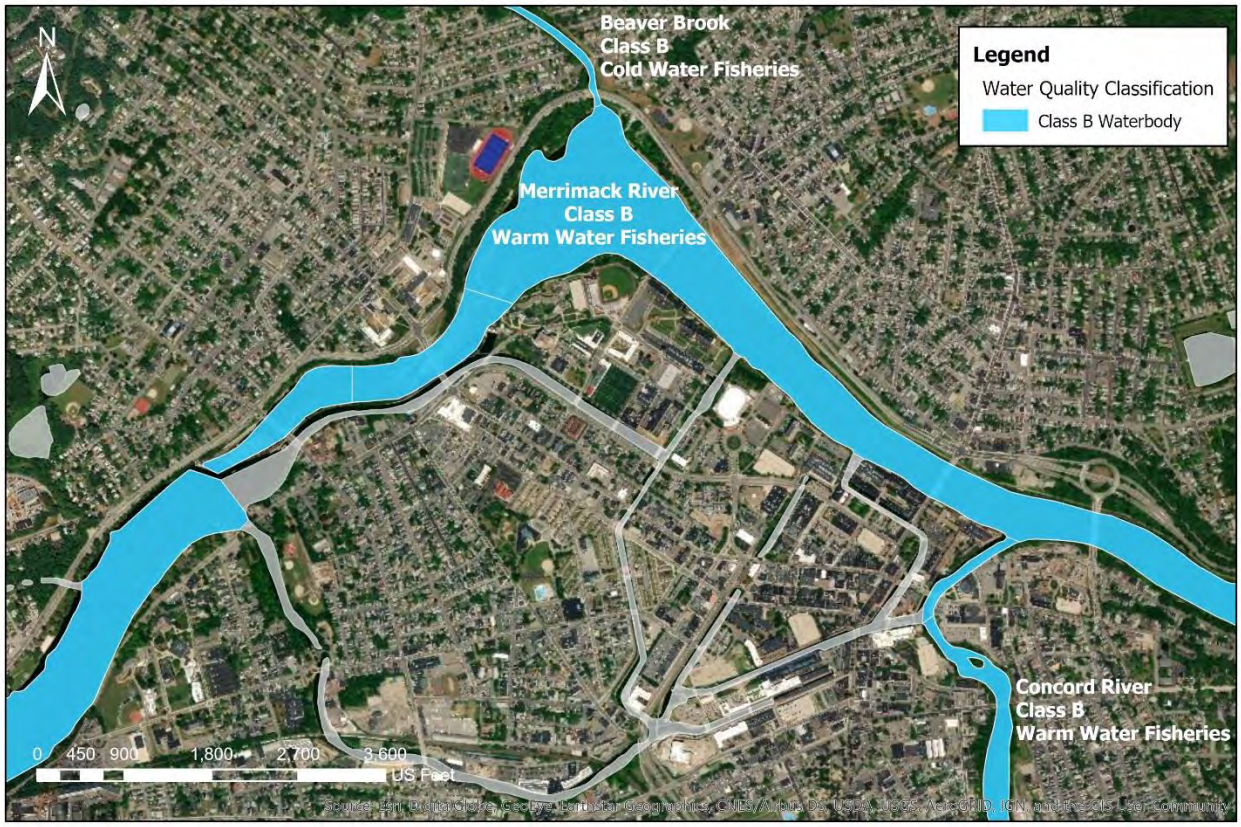


Figure 2-1: Surface Water Quality Classification

2.2.2.1 *Inland Water Classes*

- Class A – These waters are designated as a source of public water supply. They are an excellent habitat for fish, other aquatic life and wildlife, and suitable for primary and secondary contact recreation. They also have excellent aesthetic value. These waters are designated for protection as Outstanding Resource Waters (ORWs) under 314 Code of Massachusetts Regulations (CMR) 4.04(3).
- Class B – These waters are designated as a habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation. They are suitable as a source of water supply after appropriate treatment. They are also suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses. These waters have consistently good aesthetic value.
- Class C – These waters are designated as a habitat for fish, other aquatic life and wildlife, and for secondary contact recreation. These waters shall be suitable for the irrigation of crops used for consumption after cooking and for compatible industrial cooling and process uses. These waters shall have good aesthetic value.

2.2.2.2 *Coastal and Marine Classes*

- Class SA – These waters are designated as an excellent habitat for fish, other aquatic life and wildlife and for primary and secondary recreation. In approved areas they are suitable for shellfish harvesting without depuration (Open Shellfishing Areas). These waters also have excellent aesthetic value.
- Class SB – These waters are designated as a habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas they are suitable for shellfish harvesting with depuration (Restricted Shellfishing Areas). These waters have consistently good aesthetic value.
- Class SC – These waters are designated as a habitat for fish, other aquatic life, and wildlife and for secondary contact recreation. They shall also be suitable for certain industrial cooling and process uses. These waters have good aesthetic value.

Numerical standards corresponding to these water body classifications are shown in Table 2-3. Dissolved oxygen is the numerical standard that the State uses to establish whether a water body supports aquatic life uses. Total and fecal coliform bacteria concentrations are the numerical criteria that the State uses to establish whether a water body supports recreational uses.

In addition to numerical standards, MassDEP has narrative criteria to protect aesthetics in all waters within its jurisdiction, regardless of classification, as described in Table 2-4.

Table 2-3: Massachusetts Surface Water Quality Standards

Class	Usage	Dissolved Oxygen (mg/L)	Total Coliform (cfu/100mL)	Fecal Coliform (cfu/100mL)	E. Coli (cfu/100mL)	Enterococci (cfu/100mL)(7)
A	Source of public water supply, primary and secondary contact recreation. Suitable for fish, other aquatic life and wildlife propagation and survival.	≥ 6.0[1] (cold water fisheries) ≥ 5.0[1] (warm water fisheries)	Water Supply Intakes			
			≤ 100[2]	≤ 20[3]	NA	NA
			Bathing Beaches During Recreational Season			
			NA	NA	≤ 126[4] ≤ 235[3]	≤ 33[4] ≤ 61[3]
			Bathing Beaches During Non-Recreational Season; Other Waters			
			NA	NA	≤ 126[4] ≤ 235[3]	≤ 33[4] ≤ 61[3]
B	Primary and secondary contact recreation and fishing. Suitable as a source of public water supply with appropriate treatment. Suitable for fish and other aquatic life and wildlife propagation and survival. Suitable for irrigation and other agricultural uses and for industrial cooling and other processes.	≥ 6.0[1] (cold water fisheries) ≥ 5.0[1] (warm water fisheries)	Bathing Beaches During Recreational Season			
			NA	NA	≤ 126[4] ≤ 235[3]	≤ 33[4] ≤ 61[3]
			Bathing Beaches During Non-Recreational Season; Other Waters			
			NA	NA	≤ 126[4] ≤ 235[3]	≤ 33[4] ≤ 61[3]
C	Secondary contact recreation and fishing. Suitable for fish, shellfish and wildlife propagation and survival. Suitable for irrigation and for industrial cooling and other processes.	≥ 5.0[1] (for at least 16-hrs of any 24-hr period) ≥ 3.0[3]	NA	NA	≤ 630[4] ≤ 1260[2]	NA
SA	Shellfishing for market purposes, primary and secondary contact recreation, fishing. Suitable for fish, shellfish and wildlife propagation and survival.	≥ 6.0[1]	Waters Designated for Shell fishing			
			NA	≤ 14[5] ≤ 28[6]	NA	NA
			Bathing Beaches During Recreational Season			
			NA	NA	NA	≤ 35[4] ≤ 104[3]
			Bathing Beaches During Non-Recreational Season; Other Waters			
			NA	NA	NA	≤ 35[4] ≤ 104[3]
SB	Primary and secondary contact recreation and fishing. Suitable for fish, shellfish and wildlife propagation and survival.	≥ 5.0[1]	Waters Designated for Shell fishing			
			NA	≤ 88[5] ≤ 260[6]	NA	NA
			Bathing Beaches During Recreational Season			
			NA	NA	NA	≤ 35[4] ≤ 104[3]
			Bathing Beaches During Non-Recreational Season; Other Waters			
			NA	NA	NA	≤ 35[4] ≤ 104[3]
SC	Secondary contact recreation. Suitable for fish, shellfish and wildlife propagation and survival. Suitable for industrial cooling and other processes.	≥ 5.0[1] (for at least 16-hrs of any 24-hr period) ≥ 4.0[3]	NA	NA	NA	≤ 175[4] ≤ 350[2]

[1]Chronic standard based on daily average
[2]90th percentile of sample set
[3]Acute standard (single sample maximum)
[4]Monthly Geomean of five most recent samples
[5]Monthly Geomean Most Probable Number
[6]90th percentile of Monthly Geomean Most Probable Number

Table 2-4: Massachusetts State Narrative WQS

Parameter	Indicator
Aesthetics	All surface waters shall be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris, scum or other form nuisances; produce objectionable odor, color, taste or turbidity; or produce undesirable or nuisance species of aquatic life
Bottom Pollutants or Alterations	All surface waters shall be free from pollutants in concentrations or combinations or from alterations that adversely affect the physical or chemical nature of the bottom, interfere with the propagation of fish or shellfish, or adversely affect populations of non-mobile or sessile benthic organisms.
Nutrients	Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses and shall not exceed the site-specific criteria developed in the TMDL or as otherwise established by MassDEP. Any existing point source discharge containing nutrients in concentrations that would cause or contribute to cultural eutrophication, including the excessive growth of aquatic plants or algae, in any surface water shall be provided with the most appropriate treatment as determined by MassDEP, including, where necessary, highest and best practical treatment (HBPT) for Publicly Owned Treatment Works (POTWs) and Best Available Treatment Technology (BAT) for non POTWs, to remove such nutrients to ensure protection of existing and designated uses. Human activities that result in the nonpoint source discharge of nutrients to any surface water may be required to be provided with cost effective and reasonable best management practices for nonpoint source control.
Radioactivity	All surface waters shall be free from radioactive substances in concentrations or combinations that would be harmful to human, animal or aquatic life or the most sensitive designated use; result in radionuclides in aquatic life exceeding the recommended limits for consumption by humans; or exceed Massachusetts Drinking Water Regulations
Toxic Pollutants	All surface waters shall be free from pollutants in concentrations or combinations that are toxic to humans, aquatic life or wildlife. For pollutants not otherwise listed in 314 CMR 4.00, the *National Recommended Water Quality Criteria: 2002, EPA 822-R-02-047, November 2002* published by U.S. EPA pursuant to Section 304(a) of the FWPCA, are the allowable receiving water concentrations for the affected waters, unless MassDEP either establishes a site specific criterion or determines that naturally occurring background concentrations are higher.

2.2.2.3 Massachusetts Consolidated Assessment and Listing Methodology (CALM) (MassDEP, 2016)

In 2002, EPA published a CALM document aimed at improving states' monitoring and assessment programs and making data and information more available to the public. The document provides guidance to the states on how to update and clarify the decision-making process for assessing the attainment of SWQS. In 2016, MassDEP published its own CALM document, superseding the previous one by the EPA, to provide quantitative and qualitative measures for interpreting the Massachusetts State Narrative WQS. It also provides guidance on water body compliance to designated uses assessed against benthic macroinvertebrates, fish community, primary producer abundance (chlorophyll-a, benthic algae, and macrophytes), habitat alteration, non-native species, pH, DO, temperature and sediment/tissue residue data.

2.2.2.4 Minimum Standards for Bathing Beaches (Department of Public Health, 2014)

To minimize swimming-associated illnesses and to notify the public about the quality of beach water, the Department of Public Health (DPH) regulations require regular water quality monitoring and public notification of unsafe conditions. All public and semi-public bathing beaches in Massachusetts are monitored for fecal indicator bacteria (FIB), and on occasion, harmful algae. Monitoring occurs during the beach season which generally begins when the school year finishes in mid-June and ends during the weekend of Labor Day. DPH adopted the EPA criteria for Enterococci and E.coli in marine-and fresh-waters in 2001. These criteria consist of both a single sample and geometric mean (geomean) value reported as colony forming units per 100 milliliters of water (cfu/100mL) as shown in Table 2-5. When beach water exceeds these water quality standards, DPH requires that the beach be posted with a notice alerting the public to the possible risk of swimming. At a majority of beaches in Massachusetts, water quality is considered to be unacceptable when two samples collected on consecutive days exceed the water quality standards. Beaches with a history of multi-day elevated bacteria levels are required to post after a single exceedance. Posting is also required when the geomean of the five most recent samples exceeds the geomean standard.

Table 2-5: Department of Public Health Recreational Water Quality Criteria

Beach Type	Indicator	Single Sample (cfu/100mL)	Geomean Standard (cfu/100mL)
Marine	Enterococci	> 104	> 35
Freshwater	Enterococci	> 61	> 33
	E. coli	> 235	> 126

2.2.3 Assessment of Sensitive Areas

This report evaluates CSO control projects, which will build upon the implementation of the U.S. Environmental Protection Agency's (EPA) Nine Minimum Controls and existing projects.

Federal CSO Policy requires that the highest priority be given to controlling overflows to Sensitive Areas (USEPA, 1995). The Policy defines Sensitive Areas as:

1. Designated Outstanding National Resource Waters (ONRW)
2. National Marine Sanctuaries
3. Waters with threatened or endangered species and their habitat
4. Waters with primary contact recreation
5. Public drinking water intakes and their designated protection areas
6. Shellfish beds

Information and data regarding Sensitive Areas within the watershed were obtained via online websites and databases. The following sources were used to compile information on the presence of Sensitive Areas located within the project area:

- United States Fish and Wildlife Service
  - Information for Planning and Consultation (IPaC) database search
- National Oceanic and Atmospheric Association
  - Section 7 (threatened and endangered species) mapper
  - 2016 Environmental Sensitivity Index Maps
- United States Environmental Protection Agency
  - Outstanding Natural Resource Waters
- Office on National Marine Sanctuaries
- Commonwealth of Massachusetts
  - MassWildlife - Natural Heritage & Endangered Species Program (NHESP)
  - Division of Fisheries & Wildlife – BioMap2
  - Executive Office of Energy and Environmental Affairs - Merrimack River Watershed Assessment Report
  - Massachusetts Endangered Species Act (MESA)
  - Massachusetts Surface Water Quality Standards (314 CMR 4.00)

2.2.3.1 Designated Outstanding National Resource Waters

Under the Clean Water Act, Outstanding National Resource Waters (ONRW) are provided Tier 3 level protection by the USEPA's Anti-degradation Policy whereby only minor and temporary decreases in water quality are allowed. Only waters of "exceptional ecological significance" qualify for designation as ONRW and States and Tribes are the responsible parties for determining whether a water body is classified as an

ONRW. The USEPA does not list any ONRW within or adjacent to Lowell, Massachusetts. In addition, the digital data available from Bureau of Geographic Information does not list any ONRW in the Merrimack Basin in the vicinity of Lowell.

2.2.3.2 Office of National Marine Sanctuaries

The Office of National Marine Sanctuaries (ONMS), part of the National Oceanic and Atmospheric Administration (NOAA), manages a national system of 14 underwater-protected areas. Since 1972, the ONMS has worked cooperatively with the public and federal, state, and local officials to promote conservation while allowing compatible commercial and recreational activities. Increasing public awareness of our marine heritage, scientific research, monitoring, exploration, educational programs, and outreach are just a few of the ways the ONMS fulfills its mission to the American people.

Sanctuaries are established to protect areas that encompass unique or significant natural and cultural features. The primary objective of the program is to protect the natural and cultural features of the sanctuary while allowing people to use and enjoy the ocean in a sustainable way. Local, state, and federal agencies may have overlapping regulations or other management authorities aimed at protecting specific marine resources. However, no other federal agency is directly mandated to comprehensively conserve and manage special areas of the marine environment like the ONMS. Coordination and cooperation among the responsible government agencies is key to successful sanctuary management.

There are no National Marine Sanctuaries located within or adjacent to the Merrimack Basin at Lowell.

2.2.3.3 Waters with Threatened or Endangered Species and Their Designated Critical Habitat

The Federal CSO Policy states that waters with threatened or endangered species or their designated critical habitat are considered a Sensitive Area (USEPA, 1995). Information on federally listed threatened and endangered species and their designated critical habitat was obtained through online database searches of the USFWS and the NOAA. The USFWS' Information for Planning and Consultation (IPaC) web site identified eleven (11) threatened or endangered species near Lowell as shown in Table 2-6. NOAA's Endangered Species Act Section 7 Mapper for the Greater Atlantic Region did not identify any threatened or endangered species within the Merrimack River at Lowell.

Information on Massachusetts State listed threatened and endangered species and significant natural communities was obtained through online database searches of MassWildlife's Natural Heritage and Endangered Species Program, Division of Fisheries and Wildlife, and Executive Office of Energy and Environmental Affairs (EEA). The EEA's Merrimack River: A Comprehensive Watershed Assessment Report, 2001 identified twelve (12) threatened or endangered species as shown in Table 2-7, while the Massachusetts Endangered Species Act (M.G.L. c. 131A) identified eight (8) threatened or endangered species within the Lowell City limits as shown in Table 2-8. The Massachusetts Department of Fish & Game, through the Division of Fisheries and Wildlife's Natural Heritage & Endangered Species Program (NHESP), and The Nature Conservancy's Massachusetts Program developed BioMap2 to protect the state's biodiversity in the context of climate change. BioMap2 identified seventeen (17) threatened or endangered

species that fall partially or completely within Lowell, shown in Table 2-9. BioMap2 also identifies significant natural communities within the Lowell project area as shown in Table 2-10.

Table 2-6: USFWS Listed Threatened and Endangered Species with the Potential to Occur near Lowell

Common Name	Scientific Name	Federal Status	Critical Habitat Present within Project Area
Birds			
Bald Eagle	*Haliaeetus leucocephalus*	Non-Bird of Conservation Concern Vulnerable, but warrants attention because of Eagle Act or potential susceptibilities in offshore areas from certain types of development or activities	No
Black-billed Cuckoo	*Coccyzus erythropthalmus*	Bird of Conservation Concern	No
Bobolink	*Dolichonyx oryzivorus*	Bird of Conservation Concern	No
Canada Warbler	*Cardellina canadensis*	Bird of Conservation Concern	No
Eastern Whip-poor-will	*Antrostomus vociferus*	Bird of Conservation Concern	No
Prairie Warbler	*Dendroica discolor*	Bird of Conservation Concern	No
Red-headed Woodpecker	*Melanerpes erythrocephalus*	Bird of Conservation Concern	No
Rusty Blackbird	*Euphagus carolinus*	Bird of Conservation Concern	No
Snowy Owl	*Bubo scandiacus*	Bird of Conservation Concern	No
Wood Thrush	*Hylocichla mustelina*	Bird of Conservation Concern	No
Mammals			
Northern Long-eared Bat	*Myotis septentrionalis*	Threatened	No

Table 2-7: Endangered and Rare Species in the Merrimack Watershed Communities

Common Name	Scientific Name	State Status
Birds		
Common Moorhen	*Gallinula chloropus*	Special Concern
Mammals		
Spotted Turtle	*Clemmys guttata*	Special Concern
Fish		
Burbot	*Lota lota*	Special Concern
Insects (Odonata)		
Riverine Clubtail	*Stylurus amnicola*	Endangered
Vascular Plants		
Green Dragon	*Arisaema dracontium*	Threatened
Gray's Sedge	*Carex grayi*	Threatened
Narrow-Leaved Spring Beauty	*Claytonia virginica*	Threatened
Frank's Lovegrass	*Eragrostis frankii*	Special Concern
Many-Fruited False-Loosestrife	*Ludwigia polycarpa*	Threatened
Winged Monkey-Flower	*Mimulus alatus*	Endangered

Philadelphia Panic-Grass	*Panicum philadelphicum*	Special Concern
Swamp Dock	*Rumex verticillatus*	Threatened

Table 2-8: Endangered and Rare Species in the Merrimack per the Endangered Species Act (M.G.L. c. 131A)

Common Name	Scientific Name	Status
Birds		
Common Moorhen	*Falco peregrinus*	Threatened
Reptiles		
Blanding's Turtle	*Emydoidea blandingii*	Threatened
Insects		
Melsheimer's Sack Bearer	*Cicinnus melsheimeri*	Threatened
Cobra Clubtail	*Gomphus vastus*	Special Concern
Umber Shadowdragon	*Neurocordulia obsoleta*	Special Concern
Vascular Plants		
Tufted Hairgrass	*Deschampsia cespitosa ssp. glauca*	Endangered
Hairy Wild Rye	*Elymus villosus*	Endangered
New England Blazing Star	*Liatris scariosa var. novae-angliae*	Special Concern

Table 2-9: BioMap2 Cores that fall entirely or partially within Lowell, Massachusetts

Common Name	Scientific Name	Status
Molluscs		
New England Siltsnail	*Floridobia winkleyi*	Special Concern
Mammals		
Blanding's Turtle	*Emydoidea blandingii*	Threatened
Insects		
Arrow Clubtail	*Stylurus spiniceps*	Non-listed SWAP
Cobra Clubtail	*Gomphus vastus*	Special Concern
Riverine Clubtail	*Stylurus amnicola*	Endangered
Umber Shadowdragon	*Neurocordulia obsoleta*	Special Concern
Birds		
Coppery Emerald	*Somatochlora georgiana*	Endangered
Bald Eagle	*Haliaeetus leucocephalus*	Threatened
Fish		
Atlantic Sturgeon	*Acipenser oxyrinchus*	Endangered
Shortnose Sturgeon	*Acipenser brevirostrum*	Endangered
Plants		
American Waterwort	*Elatine americana*	Endangered
Eaton's Beggar-ticks	*Bidens eatonii*	Endangered
Engelmann's Umbrella-sedge	*Cyperus engelmannii*	Threatened
Estuary Arrowhead	*Sagittaria montevidensis ssp. spongiosa*	Endangered

Parker's Pipewort	*Eriocaulon parkeri*	Endangered
Seabeach Dock	*Rumex pallidus*	Threatened
Vasey's Pondweed	*Potamogeton vaseyi*	Endangered

Table 2-10: BioMap2 Listed Significant Natural Communities that fall entirely or partially within Lowell

Significant Natural Community Type
Wetland Core
Acidic Shrub Fen
Aquatic Core
Coastal Adaptation Area
Landscape Block
Tern Foraging Area

A total of forty-three (43) threatened and endangered species occur within the waters and adjacent uplands of Lowell. Based on the state and federal databases that were consulted for this analysis, there is no indication that any endangered or threatened species is located in a specific region of the Merrimack River, Concord River, or Beaver Brook, that would necessitate prioritization of CSO control. Achieving systemwide reduction of untreated CSO discharges is therefore considered the most effective strategy to mitigate impacts to any sensitive areas due to endangered or threatened species.

2.2.3.4 Waters with Primary Contact Recreation

Massachusetts State classifies Merrimack River waters near Lowell as Class B with Warm/Cold Water Fisheries. The Codes, Rules, and Regulations of the State of Massachusetts define the best usages of Class B waters as primary and secondary contact recreation and fishing, which are suitable for fish, shellfish, and wildlife propagation and survival.

There is a public beach at the Lowell Heritage State Park, along Pawtucket Boulevard, which is upstream of Lowell's CSO and SW discharges. Accordingly, this beach is generally only impacted by pollutant sources upstream of Lowell. Bacteria are used as indicators to identify potential health risks to swimmers. As described in section 2.2.2.4, no single E. Coli sample shall exceed 235 colonies per 100 mL, or no single Entercocci sample shall exceed 61 colonies per 100 mL. Flags indicating water quality are posted at this Lowell Heritage State Park beach and the UMass Lowell Bellegarde Boathouse. There are no designated swimming areas within the study area downstream of the CSO outfalls from Lowell.

2.2.3.5 Public Drinking Water Intakes or Their Designated Protection Areas

The Codes, Rules, and Regulations of the State of Massachusetts (314 CMR 4.06) designates the sections of the Merrimack River viable as a source of public water supply after appropriate treatment (Treated Water Supply), in accordance with Massachusetts Drinking Water Regulations (310 CMR 22.00). This section

extends from the upstream most point of the Merrimack River at the State Line to the Essex Dam at Lawrence.

The Lowell Water Treatment Plant draws its supply exclusively from the Merrimack River, upstream of any of Lowell's CSO or SW discharges. There are no municipal water withdrawals for drinking water from the lower segment of the Concord River or Beaver Brook. However, Tewksbury, Andover and Methuen draw part of their drinking water supply from the Merrimack River downstream of the outfalls at Lowell. As such, the most effective strategy to mitigate impacts to this potentially sensitive area would be one that achieves systemwide reductions of untreated CSO discharges.

2.2.3.6 Shellfish Beds

There are no certified shellfish beds within Lowell, Massachusetts.

3. Existing Conditions

At present, the "backbone" of Lowell's sewer system is a network of large diameter interceptor pipes. These interceptors were constructed with federal assistance to transport combined sanitary flows and stormwater runoff to the Duck Island WWTF for treatment instead of allowing local collection systems to discharge directly to the Merrimack River. The interceptors were designed with hydraulic relief points (CSO stations) to prevent excessive surcharging and sewer backups during wet weather. After the interceptors were constructed, the Clean Water Act (CWA) was enacted, thereby requiring Lowell to reduce CSO discharges and adhere to more stringent water quality standards. Since that time, Lowell has steadily reduced the volume and frequency of CSO discharges through infrastructure improvements, system optimization, high flow management, and other initiatives.

This Section provides an overview of Lowell's existing CSO, wastewater, drinking water, and stormwater infrastructure. A description of the Merrimack River and its present-day water quality is also included. Balancing the needs of the infrastructure described in this Chapter with the need to significantly improve CSO control is a central goal of this IP.

3.1 Lowell Clean Stream Initiative Preliminary Overview

3.1.1 Ambient Bacteria Monitoring, 2018-2019

Lowell has conducted ambient monitoring of in-stream bacteria (*E. coli*) in the Merrimack River during several wet and dry weather periods during the recreational season (April-October) in 2018 and 2019. Sampling in 2018 included targeted sampling during wet weather events to bracket the periods before, during and after CSO events in order to improve understanding of the magnitude and duration of impacts related to CSOs and stormwater runoff. Sampling in 2019 focused on dry weather conditions, defined as periods with a minimum of 72 hours since the most recent rainfall event exceeding 0.05 inches of total rainfall in a day. This section presents a brief summary of the methods and results of this monitoring program.

3.1.2 Sampling and Analysis Methods

The wet weather sampling program was designed to allow multiple repeated samples at a given location over the course of a storm event. A storm event is defined as the 48-hour window following the first rainfall of a given storm.

The expected values of in-stream bacteria concentrations before, during and after CSO events are on the order of 10^3 and 10^4, or greater, and may be expected to persist for 48-72 hours after discharge (CDM, 2017). Accordingly, the objective of documenting the general order of magnitude and duration of bacteria concentrations in the river supported center-channel sampling at a depth appropriate to public health concerns regarding exposure during primary- or secondary-contact recreation (3-5 feet). The exception to this technique was the collection of samples by Lowell's drinking water personnel via the raw-water

intake line, which is located on the North bank of the river upstream of Lowell, at the Ferry Crossing Drinking Water Treatment Facility.

Samples were collected by two teams. One team sampled from the center span of local bridges using a horizontal Van Dorn sampler. The other operated from a pontoon boat traversing the length of the Merrimack between Lawrence (at the Essex Dam) to Lowell (at the Duck Island WWTF while collecting samples with a vertical Van Dorn sampler.

Samples were also collected from two CSO discharge points during these events (West and Merrimack stations). Automatic samplers were used to facilitate discharge sampling, which were activated at the start of a discharge and collected at 15-minute intervals.

Dry weather sampling was conducted differently, as the objective was to collect a single sample from each location with a goal of maximizing representativeness of the sample with respect to the location transect. Samples were collected at three equal-width intervals (EWI composite method) across the transect using a 12-foot-long vertical 'straw' sampler and composited in proportion to the flow through each transect interval (for example, 30% from each side interval, 40% from center-channel interval), as determined by measurements of the river flow with an acoustic Doppler current profiler.

Regardless of technique, consistent quality-control protocols were followed. Sampling equipment was decontaminated between locations with 10% hydrochloric acid, followed by a triple rinse with deionized water. Sampling equipment was then rinsed three times with site water before sample collection following decontamination to remove all possible acid residual. Field blanks were collected by each team during each sampling round to verify cleanliness of technique, and duplicate samples were collected by each team for every event to quantify reproducibility of laboratory results (acceptable reproducibility was defined as a value falling within the 95% confidence interval of its respective duplicate). Blanks were consistently clean and duplicates were within the defined range of acceptability.

All samples were analyzed at the Lowell Drinking Water Laboratory using an IDEXX Quantitray system with the Colilert-18 method (SM 9223B). Samples were transported to the laboratory upon completion of each sampling round and were processed and incubated within eight hours of sample collection.

3.1.3 Sampling Locations

Figure 3-1 and Table 3-1 presents the locations where samples were collected. In addition to main-stem locations on the Merrimack, samples were collected from local tributaries to assess bacteria loads from urban stormwater runoff, and from CSO stations on the North and South banks of the river in Lowell.

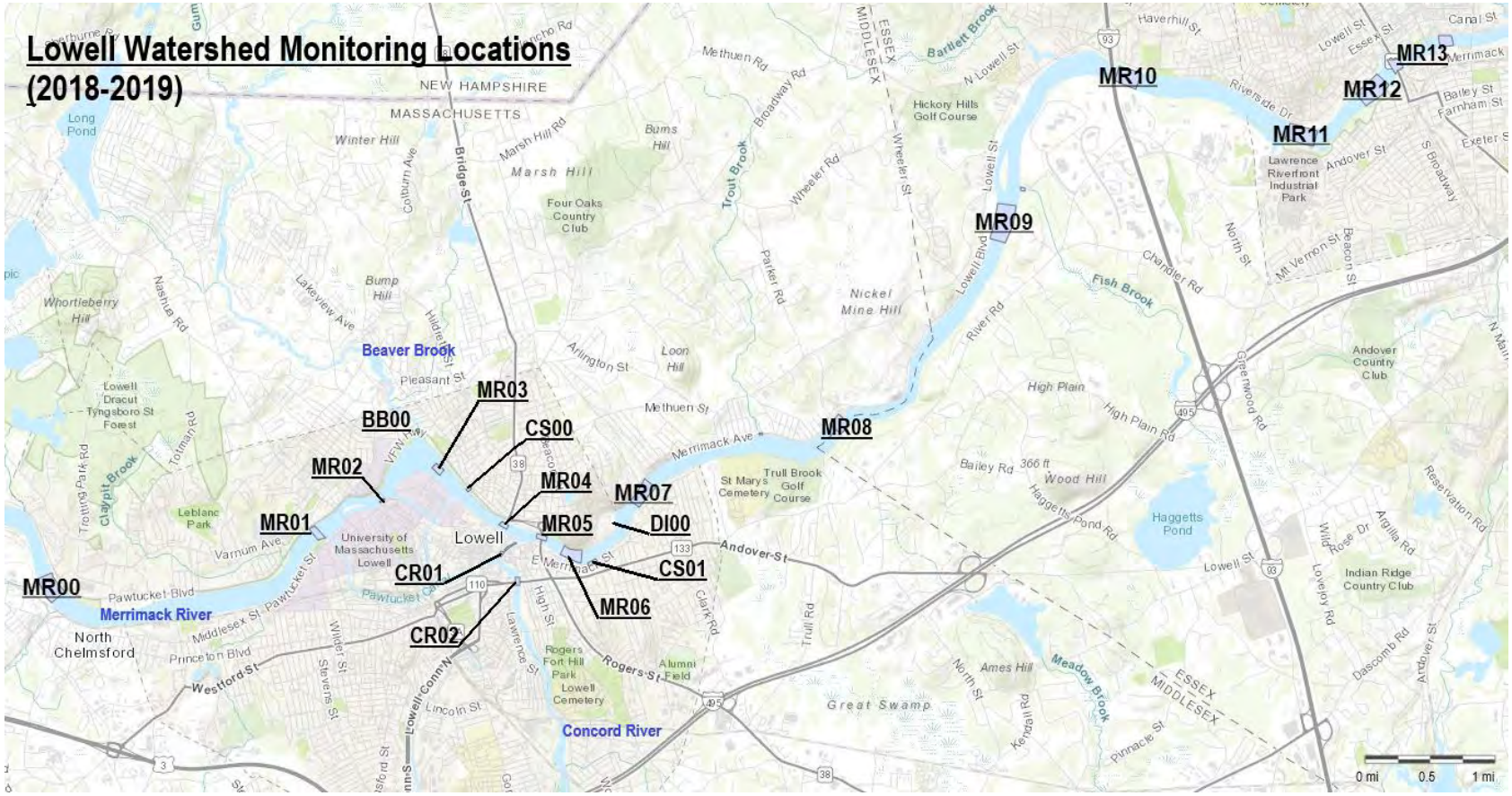


Figure 3-1: Lowell Monitoring Locations

Table 3-1: Lowell Monitoring Location ID and Description

Location ID	Location Description	Location Comments
MR00	Lowell Drinking Water Intake	Main-stem sample at intake during wet-weather, EWI composite by boat during dry-weather
MR01	Upstream of Pawtucket Dam	Not used
MR02	University Avenue Bridge	Main-stem, center channel grab
BB00	Beaver Brook, VFW Bridge	Tributary, center channel grab
MR03	Aiken Street Bridge	Main-stem, center channel grab
CS00	West Street CSO Station	Combined sewer discharge, ISCO auto sampler
MR04	Bridge Street Bridge	Main-stem, center channel grab
CR00	Concord River mouth	Dry weather only, center channel grab
CR01	Concord River, Middlesex Street	Tributary, center channel grab
CR02	Concord River, Church Street	Tributary, center channel grab
MR05	Hunts Falls Bridge	Main-stem, center channel grab
MR06	Hunts Falls	Main-stem, Dry-weather only, EWI composite
CS01	Merrimack Street CSO Station	Combined sewer discharge, ISCO auto sampler
DI00	Duck Island CWF	Wastewater effluent, ISCO auto sampler
MR07	Downstream of Duck Island	Main-stem, center channel grab wet weather, EWI composite dry weather
RB00	Richardson Brook	Tributary, center channel grab from flow over weir
MR08	Tewksbury Water Intake	Main-stem, center-channel grab
MR09	Pine Island near Andover Water Intake	Main-stem, center channel grab wet weather, EWI composite dry weather
FB00	Fish Brook, Andover Water Plant	Tributary, side channel grab upstream of weir
MR10	Methuen Water Intake	Main-stem, center-channel grab
MR11	Greater Lawrence Boating Center	Not used
MR12	Essex Dam	Main-stem, center channel grab wet weather, EWI composite dry weather
MR13	Broadway Bridge	Main-stem, river-right channel grab (near turbine discharge)

3.1.4 Sampling Event Summary (2018)

As shown in Table 3-2, eleven rounds of sampling were conducted during or following wet weather, and therefore followed the wet-weather monitoring (WWM) protocols described above. An additional six sampling events were conducted in 2018 to evaluate dry weather conditions at times when no wet-weather loads were likely to affect water quality, following the dry weather monitoring (DWM) protocols described above. Wet weather events targeted a range of conditions, from no CSO discharges to high-volume CSO discharges, and such monitoring continued until bacteria levels returned to near or below recreational bacteria guidelines.

Table 3-2: Wet and Dry Weather Sampling

Dates	Streamflow (Daily, cfs)	Prior Day Rainfall (inches)	Daily Rainfall (inches)	Sampling Event Type	Prior CSO Discharge	CSO Discharge	Nashua Wet Weather Treatment
2018-06-24	2450	0.03	0.20	WWM	6/18/2018, 2.41 MG	0.00 MG	6/18/2018, 2.25 hrs
2018-06-25	3340	0.20	0.46	WWM		3.65 MG	6/25/2018, 3.75 hrs
2018-06-28	3630	0.05	0.20	WWM	6/25/2018, 3.65 MG	2.14 MG	6/28/2018, 6.25 hrs
2018-06-29	6020	0.20	0.02	WWM	6/28/2018, 2.14 MG	0.00 MG	
2018-06-30	7690	0.02	0.01	WWM		0.00 MG	
2018-07-01	6280	0.01	0.01	WWM		0.00 MG	
2018-07-02	4410	0.01	0.00	WWM		0.00 MG	
2018-07-17	2340	0.00	1.41	WWM	7/14/2018, 0.01 MG	9.53 MG	7/17/2018, 6.75 hrs
2018-07-18	2460	1.41	0.00	WWM	7/17/2018, 9.53 MG	0.00 MG	
2018-07-19	2450	0.00	0.00	WWM		0.00 MG	
2018-07-20	2180	0.00	0.00	WWM		0.00 MG	
2018-07-31	4770	0.01	0.00	DWM	7/26/2018, 10.77 MG	0.00 MG	7/28/2018, 5.25 hrs
2018-08-01	3580	0.00	0.01	DWM		0.00 MG	
2018-08-27	6130	0.00	0.00	DWM	8/22/2018, 2.83 MG	0.00 MG	8/22/2018, 2.00 hrs
2018-08-28	4430	0.00	0.00	DWM		0.00 MG	
2018-08-29	4190	0.00	0.00	DWM		0.00 MG	
2018-09-06	1890	0.00	0.59	DWM*		9.21 MG	

**Sampling on 9/6/2018 was conducted prior to the storm event on that day, following dry-weather protocols.*

Following the wet weather surveys conducted in 2018, it was determined that the magnitude and duration of water quality impacts on the Merrimack River had been sufficiently defined over a reasonable range of conditions likely to impact recreational use of the river. Further monitoring would improve understanding of the variance and distribution of such events, but at relatively little value and at high labor and effort using current methods. Consequently, wet-weather monitoring was deferred in 2019 to evaluate advances in technology supporting automated *in-situ* bacteria monitoring (specifically, Lowell Water purchased a *Fluidion* ALERT system to enable automatic collection and analysis of in-stream bacteria), which will be evaluated in a pilot study in 2020 alongside targeted manual sampling during representative wet-weather events.

3.1.5 Results and Discussion

Results of the bacteria analyses conducted during these sampling events are summarized for the purposes of this discussion in the figures below. Figure 3-2 presents the main-stem sampling locations as a schematic (box) plot of all results at each main-stem location. Results are separated into two categories: dry-weather samples and wet-weather samples, defined as samples collected within 48 hours of rainfall. This figure is a concise presentation of the magnitude and duration of bacterial risks associated with rainfall in the Merrimack River at Lowell, as observed in this study period. The commonly referenced "single-sample maximum" (SSM) value of 235 MPN/100 mL of *E. coli* is plotted for comparison.

One notable, if expected, observation that can be made is that the dry-weather bacteria values in the river are predominantly distributed below the SSM, with the exception of upper quartile results at MR06, which is the location immediately below the confluence of the Merrimack with the Concord River. A number of factors may contribute to this deviation in trends, including the proximity to CSO discharge stations, stormwater outfalls, and increased scour associated with the narrow channel of the river at this location.

Another notable – and perhaps less expected – observation is that bacteria levels in the portion of the Merrimack upstream of Lowell did not rise appreciably during wet weather. While the data does show elevated levels during wet weather compared to dry weather, Figure 3-1 shows that measured bacteria levels were low during and after wet-weather events until location MR04, which is at Bridge Street and is downstream of multiple CSO discharge points and the confluence with Beaver Brook.

This observation is worth discussing in more detail, particularly in the context of the storm of July 17, 2018, which measured 1.41 inches of rainfall in Lowell and corresponded with more than six hours of wet-weather bypass at the Nashua Treatment Facility and nearly ten million gallons of CSO discharge in Lowell. Despite the intensity and volume of this storm and related discharges, it can be seen in the detail plot, Figure 3-3, for the Lowell Water Treatment Plant intake (MR00), that the bacteria measurements conducted did not exceed the single-sample maximum throughout the storm or afterward. A clear rise in the bacteria levels over the course of the storm and a rapid decrease following the storm exists, but the response is significantly muted compared to the instream response observable at locations downstream of Lowell, shown in Figure 3-4, Figure 3-5, and Figure 3-6.

One interpretation of this data might be that the Nashua wet weather screening and disinfection facility has successfully improved water quality in the Merrimack during wet weather events. Future work with

automated monitoring equipment deployed instream will seek to confirm and further document this interpretation.

Shown in Figure 3-7, additional promising observations that can be made from the data include a predominance of dry weather samples below the single-sample maximum guideline in Beaver Brook and the Concord River, as well as further evidence in support of a relatively rapid return to compliance in the main stem of the Merrimack downstream of Lowell following wet-weather events over a range of CSO discharges.

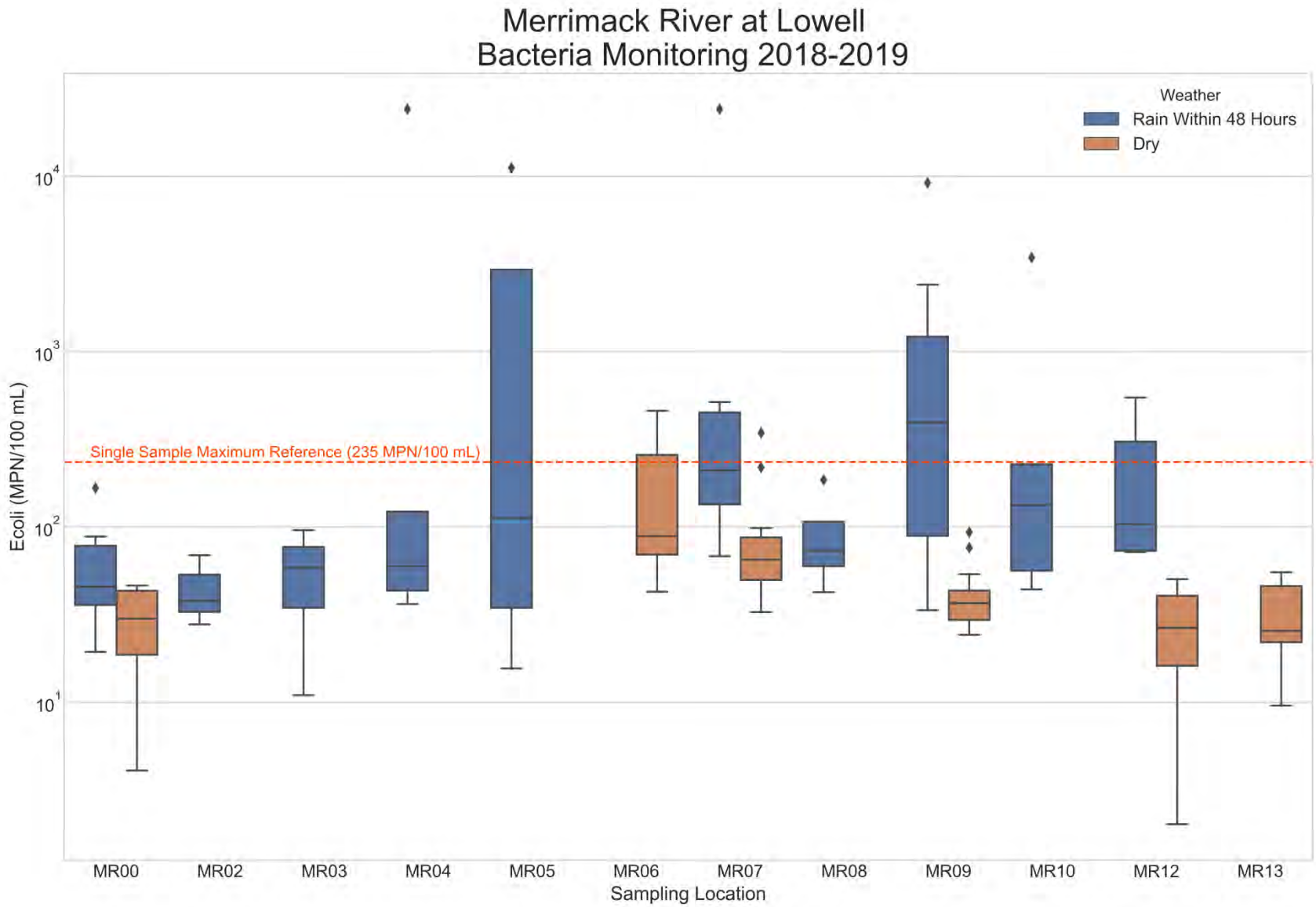


Figure 3-2: Box Plot of Main-Stem Sampling Locations

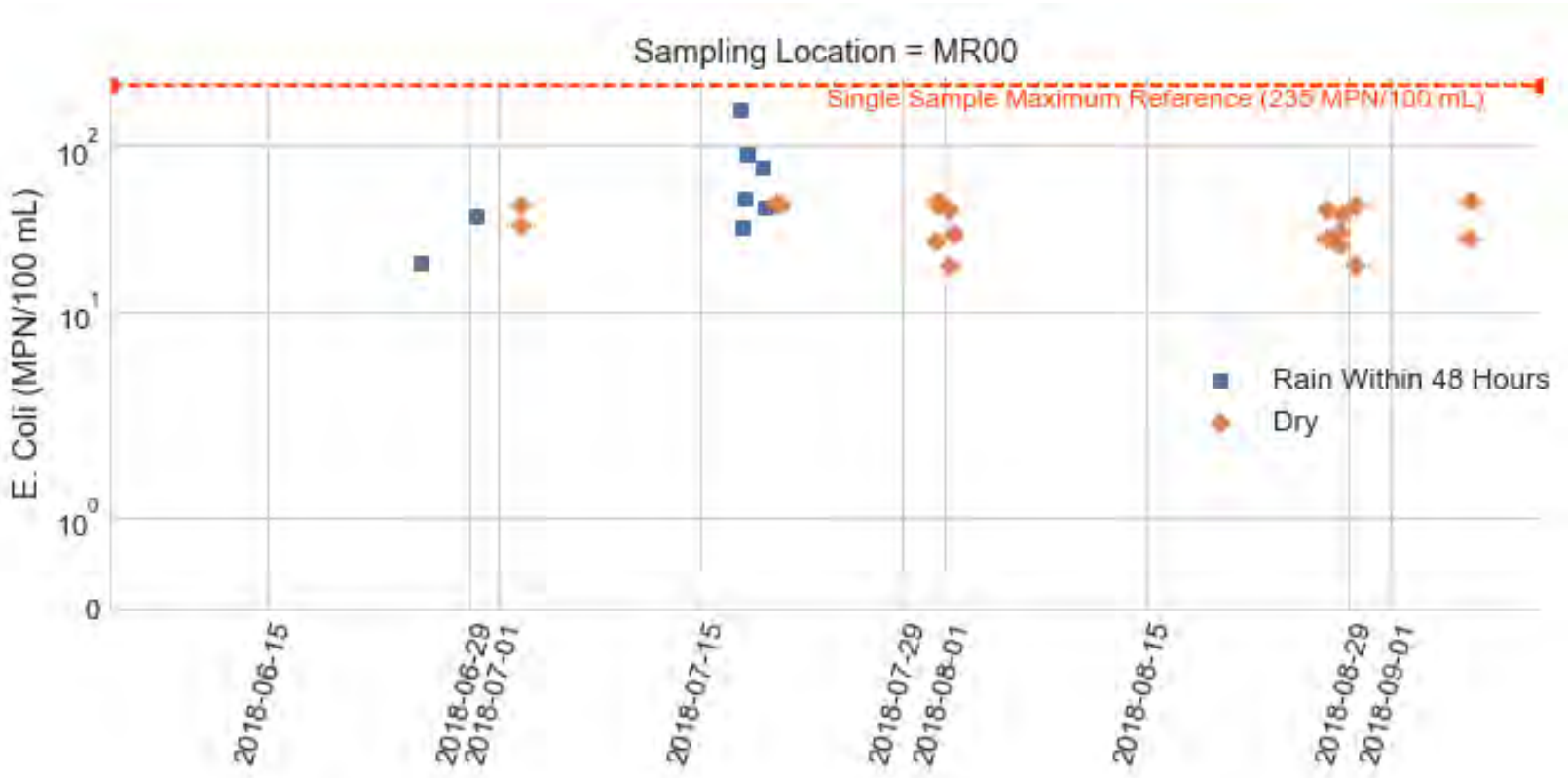


Figure 3-3: Bacteria Observed at MR00

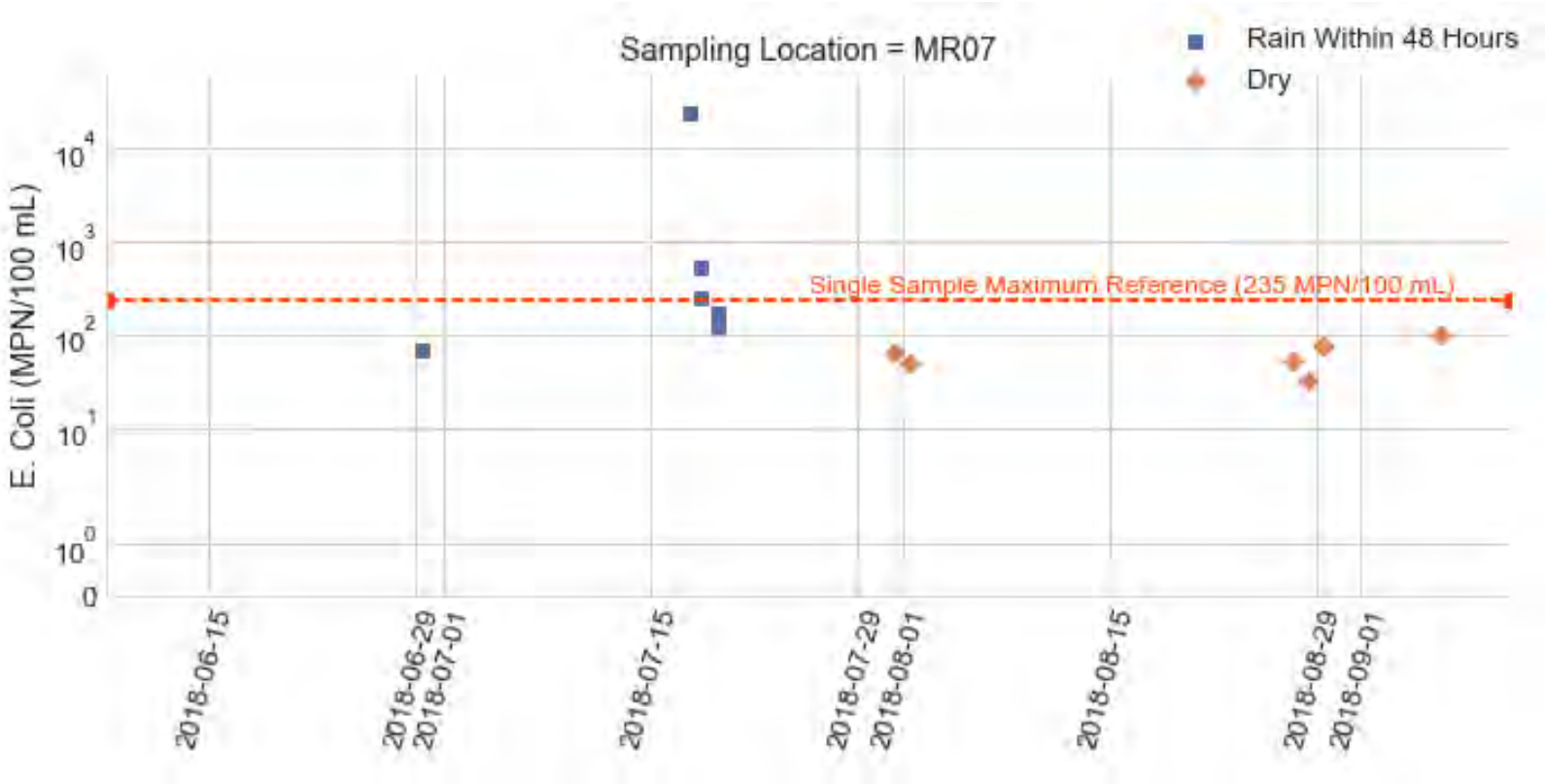


Figure 3-4: Bacteria Overserved at MR07

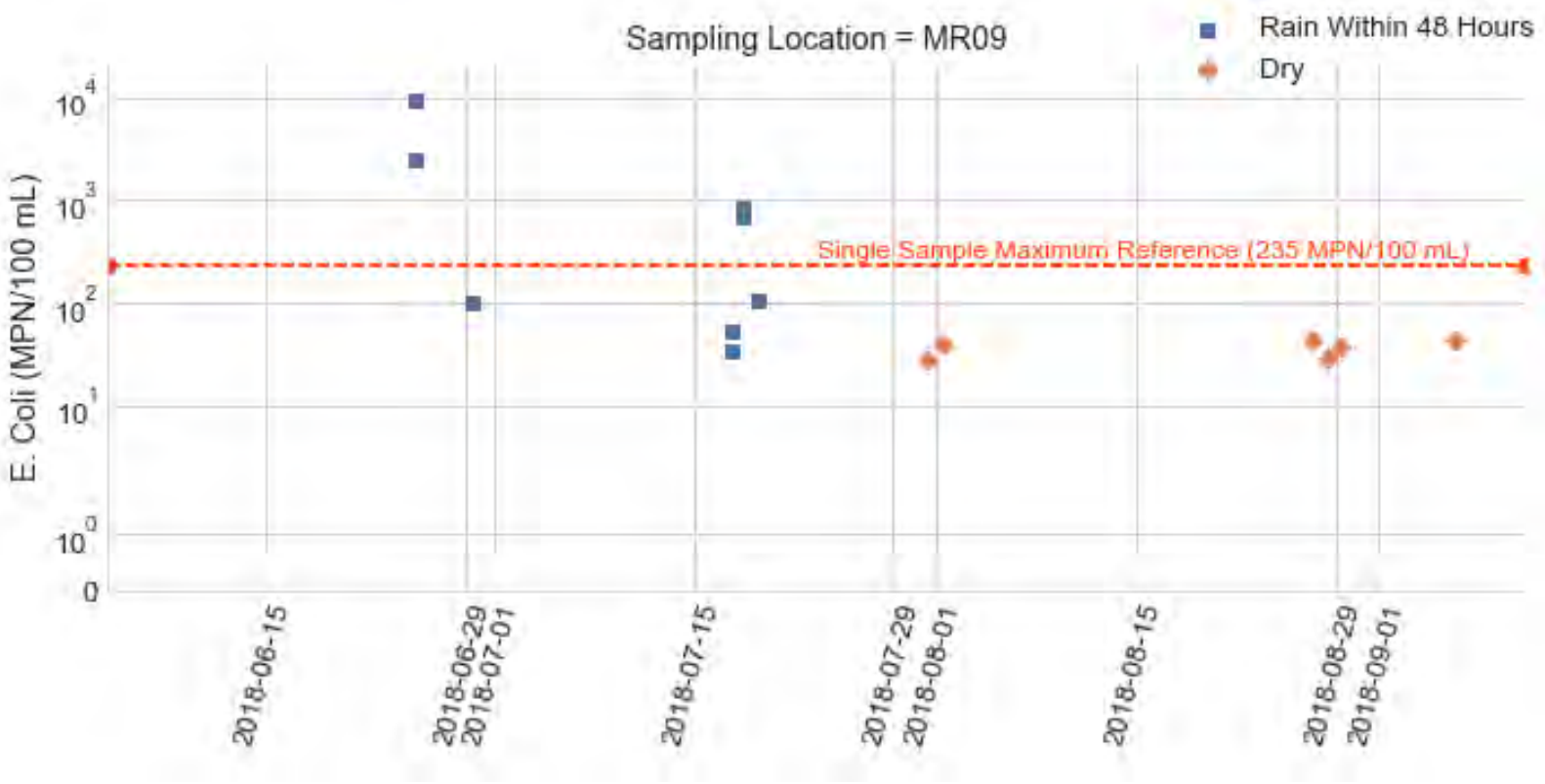


Figure 3-5: Bacteria Observed at MR09

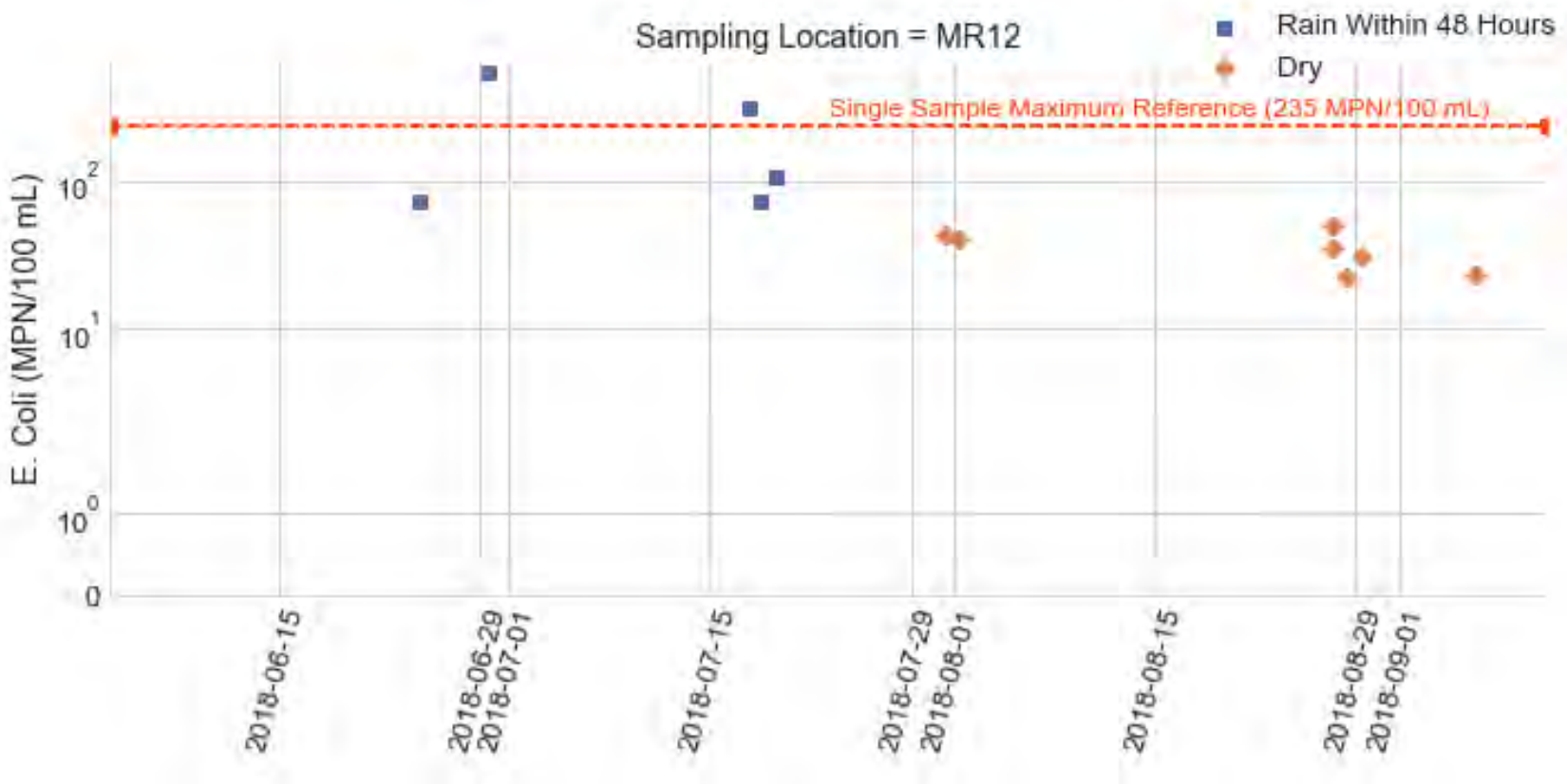


Figure 3-6: Bacteria Observed at MR12

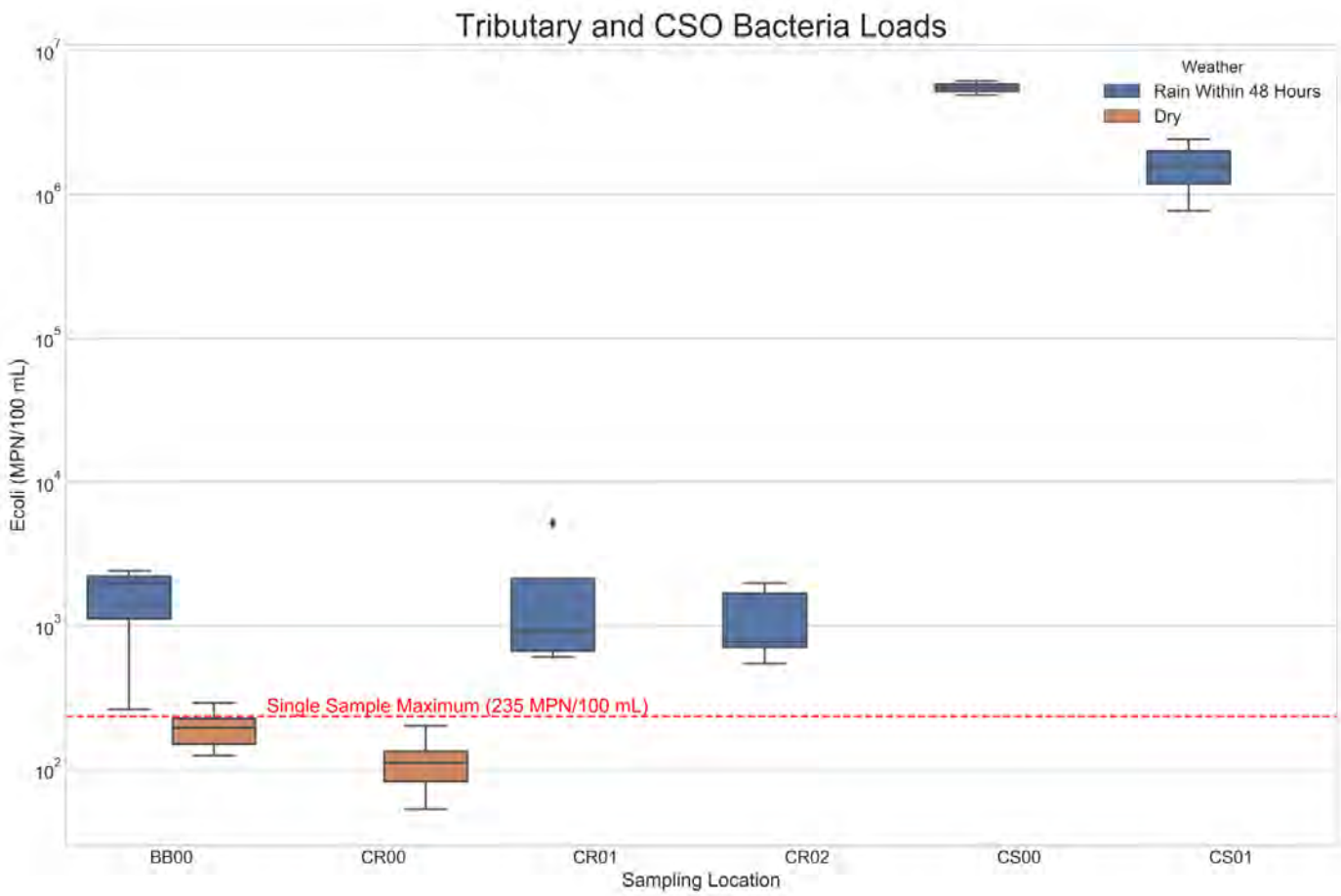


Figure 3-7: Tributary and CSO Bacteria Discharge Loads

3.2 Merrimack River Water Quality (2017 Watershed Assessment Study, Army Corps of Engineers)

It is essential to understand the water quality conditions of the Merrimack River in order to preserve aquatic life and avoid further impacts of pollution on the river. A study was conducted by the Army Corps of Engineers (ACOE) in 2017 (referred to as the Merrimack River Watershed Assessment Study) to assess the water quality of the Merrimack River Watershed in New Hampshire and Massachusetts. It was found that the Merrimack River is an overall healthy system that occasionally exhibits impacts of excess nutrients and bacteria from point and nonpoint sources.

The nutrients that were measured include total phosphorus (TP) and total nitrogen (TN). Nitrate criteria for New Hampshire Class B are 10 mg/L. Total nitrogen levels generally stay below 2.0 mg/L in the Merrimack River but seemed to increase from upstream to downstream. Upstream of the Manchester WWTF, total nitrogen concentrations were below 1.0 mg/L. Between Manchester and the GLSD WWTF, concentrations were generally between 1.0 and 1.5 mg/L. Downstream of Lawrence, the concentrations were generally between 1.5 and 2.0 mg/L until the confluence with the Atlantic Ocean.

The total phosphorus concentration typically increased from upstream to downstream in the Merrimack River. In the Upper Merrimack, the TP ranged from 30 to 40 µg/L. For the Lower Merrimack, wet weather events had TP varying from 52 to 200 µg/L and during dry weather events they varied from 15 to 136 µg/L. The locations of the high TP levels showed to be both point and nonpoint based. Specifically, there are several increases in high concentration downstream of the Manchester WWTF, Nashua WWTF, and Lowell WWTF. There was also higher concentration in nonpoint sources such as the Concord River tributary.

Chlorophyll is important to the photosynthesis process and provides nutrients which become harmful when entering water in very high quantity. It is an indicator of organic productivity and can deplete oxygen supplies. The typical concentration in the Merrimack River was below 16 µg/L. When tested, the concentration of chlorophyll also increased from upstream to downstream. In New Hampshire, the concentration ranged from 4.7 to 17 µg/L indicating a low amount of algal growth. In Massachusetts, it ranged between 6.8 and 57 µg/L. It was found that the Nashua and Concord River, tributaries, had unusually high concentrations of chlorophyll relative to the Merrimack River. Additionally, concentrations increased after the Amoskeag Dam, the Pawtucket Dam, and the Essex Dam and dropped several miles upstream. This correlates with high temperature readings at these locations.

Dissolved oxygen (DO) is essential to aquatic life. In dry weather, dissolved oxygen levels in the Merrimack are consistently above the minimum state standard of 5 mg/L or DO percent saturation standard of 75%. During wet weather they are generally within the required levels as well.

The pH of the Merrimack River is used to assess any changes in the chemical properties of the water which may be caused by pollution. The pH level by the Massachusetts Class B standards require pH to range from 6.5 to 8.3 and no more than 0.5 units outside of this range. Water at these levels are suitable for fishing and swimming. Field readings have found that the Merrimack River ranged between 6.6 and

8.6. The lowest pH reading was found upstream of the Trull Brook Outfall in Tewksbury, MA and the highest was found upstream of the Merrimack WWTF.

Bacteria in the Merrimack River was tested for E. coli, fecal coliform, and enterococci. Bacteria level at most mainstream stations showed that the Merrimack has a low baseline level for bacteria during dry weather and is close to complying with the state water quality criteria of 235 mpn/100 mL. A few stations had isolated exceedances which were found downstream of major WWTFs. Bacteria levels also increased above the state criteria during wet weather events. After a wet weather event in 2015, about 50% of E. coli concentration results were greater than the state criteria. It was found in an earlier study that although the bacteria concentration increases temporarily during CSO discharge, the primary cause for bacterial impairment was not CSO related. Untreated stormwater discharges during wet weather may be the main contributor to bacterial impairment. The highest E. coli concentration and second highest fecal coliform concentration sample was collected at the site upstream of the Mine Falls storm drain in the Nashua River. The highest fecal coliform concentration was found in a tributary called Little River in Haverhill, NH. Lastly, the highest enterococci concentration was at a site upstream of the Merrimack WWTF.

3.3 Combined Sewer System

Lowell owns and operates a combined sewer system which transports wastewater from the City of Lowell (and several neighboring communities) to the Duck Island WWTF for treatment and discharge to the Merrimack River. After the Clean Water Act (CWA) was enacted in 1972, much of Lowell's current collection system was constructed; construction of this system was largely federally funded. Before 1972, the collection system in Lowell (and many other older urban communities in the United States) consisted of dual-purpose piping, sized to collect stormwater runoff and sewage, and convey that directly to the nearest receiving waterbody (the Merrimack River and tributaries) for discharge. Many of these older parts of the system can be found in the central area of Lowell and still exist today as combined sewers.

After the CWA was enacted, Lowell constructed large interceptor pipes which receive flow from the collection system and transport it to the Duck Island WWTF. The interceptor system was constructed with a number of regulators, or hydraulic relief points, which were designed to allow some portion of the combined sewage/stormwater flow to overflow to a receiving waterbody during intense rainfall events when excess flow might otherwise result in sewerage in the streets or backups into homes and businesses. These regulators are each associated with a permitted discharge location and outfall and are often referred to as CSO stations. At present, Lowell has nine permitted CSO stations that may discharge to the Merrimack or Concord River, or to Beaver Brook. Only eight of these stations are functional at this time.

3.3.1 Major Interceptors and Conveyance

Flow in the collection system is primarily conveyed by one of two large diameter sewer interceptor systems; the South Bank (SB) interceptor system or the North Bank (NB) system. There are eleven interceptors within these two systems that lead to a downstream CSO station or treatment facility. The interceptor piping systems are designed to collect the flow from the older combined sewers which previously discharged into the rivers. The majority of the flow for both interceptors is conveyed from west to east to the Duck Island WWTF.

The SB interceptor system consists of seven interceptors all ranging in length, size, and shape. The SB system collects flow from several large neighborhoods, including the Downtown area, and conveys it towards the Duck Island WWTF. Flow is regulated at four CSO stations throughout the SB interceptor, including Warren Station, Tilden Station, Barasford Station, and lastly Merrimack Station.

The NB interceptor collects flow from several large residential neighborhoods, including Pawtucketville and Centralville, and conveys it towards the Duck Island WWTF. Flow is regulated at all five CSO stations along the NB interceptor. Figure 1-1 depicts North and South Bank conveyance.

3.3.1.1 Upper Tilden Interceptor

The Upper Tilden Interceptor begins near the Aiken Street Bridge on the south bank of the Merrimack River and runs east to the Tilden CSO Station where the diameter then changes in size to become the Lower Tilden Interceptor. The CSO Station is responsible for regulating wet weather flow to the Merrimack West Interceptor. The Lower Tilden ends near the intersection of the Concord and Merrimack River. There is a set of three siphons located along the Upper Tilden used to pass flow under the Lawrence Wasteway. The Lower Tilden contains two siphons that convey the flow across the Concord River to the Merrimack West Interceptor. The Upper Tilden Interceptor is 2,765 feet ranging in diameter from 42 to 72 inches. The Lower Tilden Interceptor is 2,930 feet and is 36 inches in diameter. Both interceptors are made of reinforced concrete.

3.3.1.2 Warren Interceptor

The Warren Interceptor runs north along the west bank of the Concord River to the Warren CSO Station. This portion of the system collects the combined wastewater flow from a majority of Lowell's southern and central collection system. It is constructed of brick and runs 2,975 feet long with a diameter ranging from 84 to 90 inches. The Warren CSO station regulates this flow and dry and wet weather flow is conveyed by three siphons across the Concord River to the Merrimack West Interceptor. The excess flows can be discharged to the Concord River as CSO.

3.3.1.3 Marginal/Middlesex Interceptor

The Marginal/Middlesex Interceptor is a trunk sewer located between the Walker Interceptor and Warren Interceptor. The flow is conveyed east to run along Marginal and Middlesex Street. In the upstream portion of the Marginal Interceptor, there is a high-level cross connection that relieves surcharge flow to the Walker Interceptor and CSO Station under extreme storm events. The interceptor consists of 12,200 feet of reinforced concrete and brick piping. The reinforced concrete pipe is 36 inches in diameter and the brick pipe is an egg shape measuring 52 inches by 35 inches.

3.3.1.4 Merrimack West Interceptor

The Merrimack West Interceptor begins at the siphon outlet of the Warren CSO Station and runs north along the east bank of the Concord River. Once this flow meets the intersection of the Concord and Merrimack River, it travels east along the south bank of the Merrimack River to the Merrimack CSO

Station. The interceptor receives flow from the Warren siphon outlet, a siphon outlet at East Merrimack street, and the Lower Tilden Interceptor siphon. It is constructed of reinforced concrete which runs 5,465 feet and ranges in diameter from 48 to 120 inches. The dry weather flow and a portion of wet weather flow is combined with the Merrimack West Interceptor flow to be conveyed across the Merrimack River to the Duck Island WWTF by three siphons at the Merrimack CSO Station. Excess wet weather flows can be discharged to the Merrimack River.

3.3.1.5 Merrimack East Interceptor

The Merrimack East Interceptor starts at the Lowell and Tewksbury border and runs west along the south bank of the Merrimack River. The interceptor collects combined wastewater flow from several sewer tributary areas adjacent to the southeast bank of the Merrimack river, for example the Barasford CSO Station. The reinforced concrete pipe is 5,465 feet long and ranges in diameter from 48 to 120 inches. Dry weather flow and a small amount of wet weather flow then combines with the Merrimack West Interceptor. Using the same siphons at the Merrimack CSO Station as the Merrimack West Interceptors, the flow is conveyed across the Merrimack River to the Duck Island WWTF. The excess wet weather flow can be discharged to the Merrimack River.

3.3.1.6 Barasford Interceptor

The Barasford Interceptor is a trunk sewer and runs from southeast Lowell to the Barasford CSO Station. There are several changes in direction throughout its length as the interceptor makes its way through neighborhoods. There is approximately 10,200 feet of reinforced concrete pipe with diameters from 24 to 60 inches. This pipe is relatively flat which causes surcharging problems at the upstream end of the interceptor. The Barasford CSO Station regulates the dry weather flow and a portion of wet weather flow to be conveyed to the Merrimack East Interceptor. The excess wet weather flow can be diverted to the Merrimack River.

3.3.1.7 Walker Interceptor

The Walker Interceptor runs east from the border of North Chelmsford and Lowell to the south bank of the Merrimack River. The interceptor is a reinforced concrete pipe which runs approximately 9,850 feet and has a diameter which ranges from 30 inches to 48 inches. It serves the southeast area of Lowell along with flow from the North Chelmsford regional connection. This flow is then conveyed to the Beaver Brook Interceptor using three siphons from the Walker CSO Station to transport it under the Merrimack River. Excess wet weather flow can be discharged to the Merrimack River.

3.3.1.8 Beaver Brook Interceptor

From a siphon outlet located at the Walker CSO Station, the Beaver Brook Interceptor runs east along the north bank of the Merrimack River to the Beaver Brook CSO station. The interceptor is approximately 6,800 feet and is made of reinforced concrete, ranging in diameter from 36 to 96 inches. It collects combined wastewater conveyed by the Walker Interceptor in addition to the northwest area of Lowell, north of the Merrimack River. When the flow arrives at the Beaver Brook CSO station, it is conveyed

through three siphons and sent under the Beaver Brook to the West Interceptor. Any excess wet weather flow can be discharged to Beaver Brook.

3.3.1.9 West Interceptor

The West Interceptor runs from the Dracut border, south along Beaver Brook, and then east along the north bank of the Merrimack River, which discharges to the West CSO Station. Sanitary flow is collected from Dracut by this interceptor and combined flow is collected from the Beaver Brook CSO Station. This interceptor is about 5,050 feet long, made of reinforced concrete with a diameter ranging from 48 to 96 inches. Any excess flow can be discharged to the Merrimack River.

3.3.1.10 Read Interceptor

The Read Interceptor begins downstream of West CSO Station and runs east along the north bank of the Merrimack River to a point where the dry weather flow from the Read CSO Station connects to the interceptor system. The interceptor is about 3,280 feet long and 96 inches in diameter. The Read CSO Station is connected to the interceptor by a dry weather pipe with a diameter of 30 inches. This pipe regulates flow from a smaller combined area of Lowell, near Bridge Street.

3.3.1.11 Duck Island Interceptor

The Duck Island Interceptor begins at the point where the Read Interceptor and 30-inch dry weather pipe meet. It runs along the north bank of the Merrimack River to the Duck Island WWTF at approximately 3,475 feet long and 96 inches in diameter. There is one direct connection to the interceptor pipe on Llewellyn Street containing both dry and wet weather flow.

The conveyance pathways of the NB and SB interceptors are depicted in Figure 1-1.

3.3.2 CSO Stations

Flow in Lowell's collection system is regulated at nine permitted CSO diversion stations. During dry weather, flow passes directly through these stations and towards the Duck Island WWTF for treatment and discharge. During wet weather, some flow that is in excess of the interceptor or treatment plant capacity may be discharged at these CSO stations directly to a receiving waterbody. At present, these stations serve as crucial hydraulic relief points and prevent sewer backups into buildings and the street during wet weather. Six CSO stations discharge directly to the Merrimack River, one station discharges to the Concord River (near its confluence with the Merrimack River), and one discharges to the Merrimack River tributary called Beaver Brook. One permitted CSO station, First Station, remains a permitted relief point that could discharge to the Merrimack River; at present, this station is not functional and has not discharged in several years. A description of each CSO station and its functionality follows.

The CSO Stations contain sophisticated equipment to allow the system to run as smoothly as possible. This includes screening equipment to remove larger solids before entering the siphons, pumping equipment for discharge of CSOs if river levels are too high, and large diameter diversion gates and

discharge outfalls. Each CSO Station has multiple gates including at least one diversion gate and a flow control gate. Using Programmable Logic Controllers (PLCs), the operators have real time control of each CSO station in order to monitor flow depths and maintain remote or automatic control of gates and pumps.

Schematic drawings of each CSO Station can be found in Appendix A.

3.3.2.1 Walker CSO Station

The Walker CSO Station is located on Pawtucket Street which runs along the Merrimack River, upstream of the Black Brook and Pawtucket Dam. This is a densely populated area located just North of the UMass Lowell Library, but the station is not limited in space having a large parking lot and convenient walking path along the river. In Figure 3-8, the Walker CSO station is shown in addition to the Pawtucket Dam just downstream. Flow from the Walker Interceptor travels through mechanically cleaned bar screens, into a diversion channel, and continues through a parshall flume where it is sent into the siphons that convey it across the Merrimack River to the Beaver Brook Interceptor. Figure 3-9 is an image of the three siphons, influent channels and sluice gates. Flow to the siphons are controlled by a flow control gate, as seen in Figure 3-10.

During some intense wet weather events, the flow will exceed the overflow weir elevation and enter a wet well containing diversion pumps. These pumps discharge excess combined sewage to the Merrimack River. The discharge pumps have a capacity of 66 MGD and activate automatically based on the wet well level. Gravity diversion is not used in this system because the interceptor is below typical river water level.

Figure 3-8: Google Earth View of Walker CSO Station

Figure 3-9: Siphon Influent Channels and Sluice Gates

Figure 3-10: Flow Control Slide Gate at Walker CSO Station

3.3.2.2 Beaver Brook CSO Station

The Beaver Brook CSO Station is located along the Beaver Brook just after it becomes a tributary of the Merrimack River. This station is also in a densely populated area, located NE of UMass Lowell's North Campus and next to the VFW highway, as shown in Figure 3-11. Flow travels upstream from the Beaver Brook Interceptor into two mechanically cleaned bar racks and a diversion channel segment/chamber. The PLC holds control over the flow through the diversion channel by automatically modulating the flow control gate at the end of the channel. During dry weather, the flow will travel from the diversion channel, past the flow control gate, into the parshall flume, and to the downstream siphons to be sent to the West Interceptor. The flow control gate is pictured in Figure 3-12.

During wet weather events, the influent gates are also controlled by the PLC to achieve inline storage. The influent gates are located upstream of the two bar screen channels and restrict the influent flow coming into the station by storing it in the Beaver Brook Interceptor and avoid overflow to the diversion channel. Wet weather flow is stored in the Beaver Brook Interceptor until the HGL reaches approximately 1 foot below the crown on the pipe. At this point the combined sewage will be diverted either by gravity or via pumping. Two weirs, at different elevations, determine the occurrence of an overflow. The lower weir allows a gravity diversion to Beaver Brook to occur. During some intense wet weather events the gravity diversion gate may be closed allowing flow to overtop the second weir elevation and enter a wet well to be pumped into Beaver Brook.

Figure 3-11: Google Earth View of Beaver Brook CSO Station

Figure 3-12: Flow Control Gate at Beaver Brook CSO Station

3.3.2.3 West CSO Station

The West CSO Station is located along the Merrimack River on the median of the VFW Highway in Centralville. This area of Lowell is densely populated and is located across the Merrimack River from the Tsongas Arena and Tilden CSO Station as seen in Figure 3-13. There is limited access and parking available at this station. Flow from the West Interceptor in addition to flow from Centralville passes through this CSO Station to the Read Interceptor. This station recently underwent extensive rehabilitation.

During wet weather, excess wet weather flow may enter a diversion chamber and discharge to the Merrimack River if the CSO diversion gate is opened. If river levels are too high, then this gate will be closed and overflows are pumped to the Merrimack River.

Before 2018, all flow in the West/North Bank interceptor system was regulated at the West CSO Station. In 2018 a new flow control gate, installed in the North Bank interceptor in the proximity of Read CSO station, was activated. This flow control gate is further downstream of West Station and allows for the ability to store flow in the large (and relatively flat) interceptor between the new flow control gate and West Station. As such, the operation of the new Read inline flow control gate significantly influences the HGL in the North Bank interceptor and West CSO station and plays a crucial role in determining the occurrence of a CSO at this location.

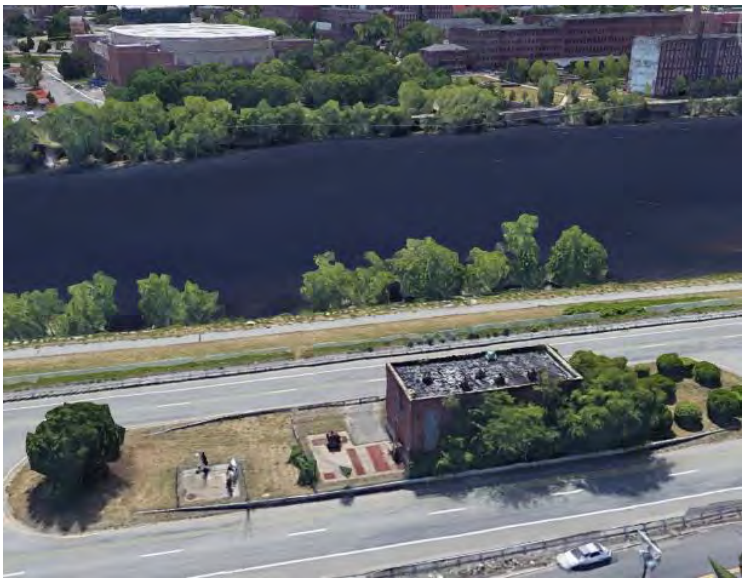


Figure 3-13: Google Earth View of West CSO Station

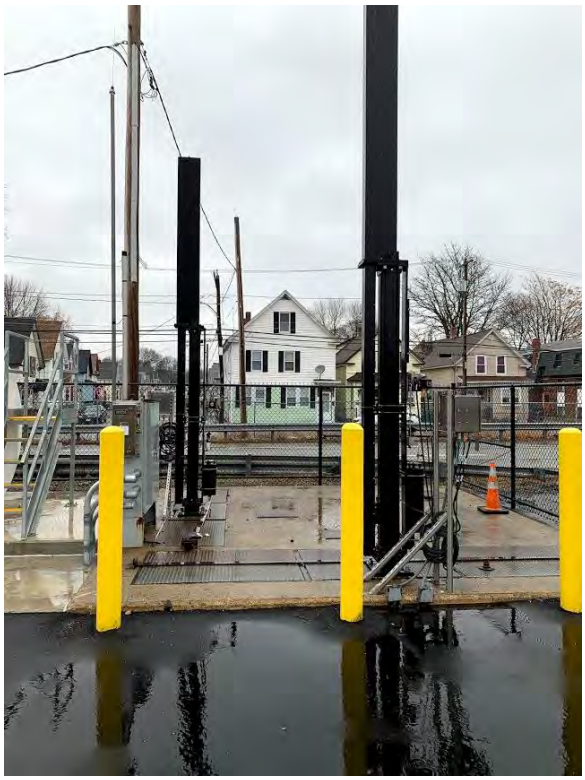


Figure 3-14: Slide Gate Actuator

3.3.2.4 Read CSO Station

The Read CSO Station is located along the Merrimack River near the Hunts Falls Bridge rotary and is a below-ground structure, as seen in Figure 3-15. It is across the VFW Highway from residential buildings. There is no automatic operation of the gates in this system during excessive flow. The dry weather flow travels from the Read Interceptor, through a flow control gate, and into the Duck Island Interceptor.

During intense wet weather, the level of flow may rise above a weir in the outlet chamber and excess flow may discharge as a CSO (via gravity) to the Merrimack River. Data indicates that overflows at this location are uncommon at present.

Figure 3-15: Google Earth View of Read CSO Station

3.3.2.5 First CSO Station

The First CSO Station is located on First Street, directly across from the Duck Island WWTF and includes a building and below ground levels. This station can be seen in Figure 3-16 as the small structure located in between a row of trees. The only access point is off First Street which is low traffic. Figure 3-17 shows First CSO Station in relation to the Duck Island WWTF. At present a diversion sluice gate is sealed shut and discharge of a CSO is not possible.

Figure 3-16: Google Street View of First CSO Station

Figure 3-17: Google Earth View of First CSO Station

3.3.2.6 Tilden CSO Station

The Tilden CSO Station is located near the Tsongas Arena, along the Merrimack River and includes a building and below ground levels. It is set in the back of the parking lot which serves the arena as seen in Figure 3-18. Flow enters through the Upper Tilden Interceptor, passes a flow control gate, into a parshall flume, and exits the facility through the Lower Tilden Interceptor. The flow control gate is operated based on the depth and storage available in the Upper Tilden Interceptor and maximizing flow to the Lower Tilden Interceptor.

During wet weather, excess flow may be discharged via gravity or pumping to the Merrimack River to prevent excessive surcharging and the occurrence of an SSO in the Tilden Interceptor. The pumps and motor located at Tilden CSO Station is shown in Figure 3-19. A gravity diversion gate is modulated in conjunction with the flow control gate to mitigate SSO risk while maximizing safe inline storage and downstream conveyance. If the river level is too high for discharge via gravity, excess wet weather flow may be discharged to the river via pumping.

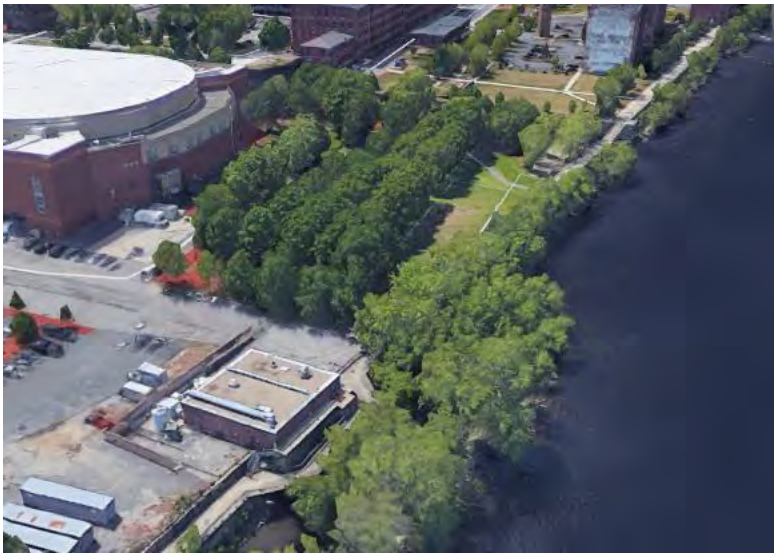


Figure 3-18: Google Earth View of Tilden CSO Station

Figure 3-19: Motor and Pump of Tilden CSO Station

3.3.2.7 Warren CSO Station

The Warren CSO Station is located along the Concord River in a populated downtown area, adjacent to a parking garage. As shown in Figure 3-20, the station is tightly constrained and is located between the parking lot and the Concord River. The station includes a building and below ground levels. Both flows from the Warren Interceptor and the Marginal Interceptor combine at an influent chamber within the Warren CSO Station and proceed into a flow control gate and into three siphons to be sent across the Concord River into the Merrimack West Interceptor. A mechanically cleaned bar screen was recently removed to reduce headloss through the station.

When wet weather occurs, excess flow may enter a gravity diversion chamber. There are two overflow sluice gates that may open to allow overflows in the diversion chamber to discharge to the Concord River, near its confluence with Merrimack River.

Figure 3-20: Google Earth View of Warren CSO Station

3.3.2.8 Barasford CSO Station

The Barasford CSO Station is located below ground adjacent to the Merrimack CSO Station. Flow travels from neighborhoods such as Wentworth Avenue and Douglas Road, and the Belvidere neighborhood. Dry weather flow enters the station from the Barasford Interceptor, travels through a flow control gate, into a parshall flume, and into the Merrimack CSO station for further regulation.

When wet weather occurs, diversion gates are opened based on the downstream HGL. The flow control gate and the diversion gates modulate by opening one as the other closes in order to maximize flow into Merrimack CSO station. Merrimack Station and Barasford Station essentially function as one station and are located directly adjacent to each other, shown in Figure 3-22. A more detailed picture of the Barasford Station is depicted in Figure 3-21.

Figure 3-21: Barasford CSO Station

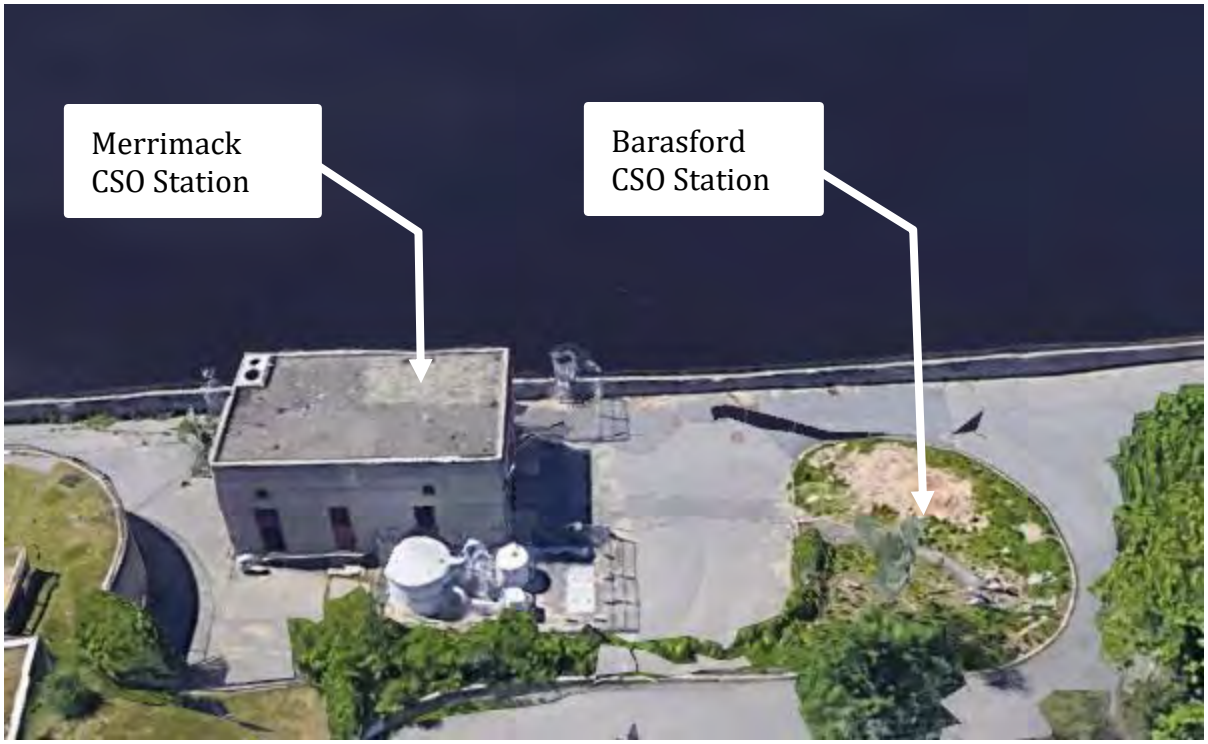


Figure 3-22: Google Earth View of Merrimack CSO Station

3.3.2.9 Merrimack CSO Station

The Merrimack CSO Station is located across the Merrimack River from the Duck Island WWTF on East Merrimack Street. It consists of a building and below ground level located in the neighborhood directly adjacent to the Barasford CSO Station.

Similar to the Read inline flow control gate (and previously the West CSO station) in the North Interceptor system, this CSO station is the last control point for flows entering the WWTF from the South Interceptor system. The flow control strategy at Merrimack Station maximizes conveyance to the Duck Island WWTF and utilizes inline storage capacity to reduce the occurrence of overflows to the Merrimack River. Flow enters the station from the Merrimack East and Merrimack West Interceptors, through a flow control gate, into a mechanically cleaned bar rack, and into siphons beneath the Merrimack River to the Duck Island WWTF.

During wet weather, excess flow can be discharged via gravity or pumping. There are four gravity diversion gates, as shown in Figure 3-23, which open along the river wall and modulate with the flow control gate. Flap gates shown in Figure 3-24 block any flow from the river that could enter the CSO Station. If the river level is too high, it is necessary to pump overflows into the river. Once the levels rise, flow will enter the wet well where it can be pumped into the Merrimack River.

Figure 3-23: Gravity Diversion Gate

Figure 3-24: Flap Gate Covering a Gravity CSO Discharge Pipe at Merrimack CSO Station

3.4 High Flow Management (on-going)

Lowell has developed an interim High Flow Management (HFM) plan. The interim HFM plan is included in Appendix B. The HFM plan describes how the wastewater collection and treatment system should be operated during wet weather when stormwater runoff enters the collection system causing high flows. The goal of Lowell's HFM plan is to ensure safe operation of the wastewater collection and treatment system so as to prevent excessive sewer surcharging and the occurrence of an SSO and damage to the treatment process (and WWTF) by conveying too much flow. The HFM plan also includes strategies to reduce the frequency and volume of CSOs by utilizing inline system storage, actively managing flow control and CSO discharge gates, and maximizing conveyance to the WWTF.

At present, Lowell has bi-weekly staff meetings to discuss HFM during recent wet weather events and to partake in continuous improvement and optimization of the HFM plan. During these meetings, staff review SCADA data regarding the operation of the CSO stations to evaluate opportunities for further system optimization. During these meetings, rainfall data, flow data, level data, CSO discharge estimates, and other available data (e.g., gate position, and WWTF influent flow) are quantitatively compared storm-by-storm.

Lowell intends to develop a formal update to its HFM plan/protocol as part of the implementation of this IP. As projects are implemented (constructed), new strategies will be required to optimize HFM, and ensure that flow to the WWTF is maximized, SSOs are mitigated, and CSOs are consistently minimized. As such, an update the HFM plan will be an important adaptive management strategy,

3.5 Duck Island Wastewater Treatment Facility

The Duck Island Regional WWTF is an activated sludge treatment process serving the City of Lowell and the surrounding towns of Chelmsford, Dracut, Tewksbury, and Tyngsborough to remove total suspended solids (TSS) and biochemical oxygen demand (BOD) prior to discharge into the Merrimack River. The treatment process includes influent screening, primary clarifiers, aeration basins, secondary clarification, chlorine disinfection, as well as solids thickening and dewatering. The site of the Duck Island WWTF is restricted by the Merrimack River and the VFW Highway, making available space extremely limited.

The Duck Island WWTF has a design flow of 32 MGD, and a peak flow of 110 to 115 MGD. High wet weather flows are controlled by bypassing a portion of the primary effluent around the secondary treatment process to the chlorine contact tanks for disinfection prior to discharge. Dry weather flows have consistently been below historical averages due to collection system improvements and water conservation technologies.

3.5.1 Treatment Process

3.5.1.1 Headworks and Primary Influent

From interceptor pipes, the flow is pumped into the facility by large diameter screw pumps. Lowell is permitted to operate up to three screw pumps for a combined influent pumping capacity of 126 MGD. The fourth pump serves as redundancy and added resiliency in the event a pump fails. The screw pumps are shown in Figure 3-25. Influent then flows through two mechanical bar screens to remove large debris that may be problematic for the other treatment processes.

Figure 3-25: Screw Pump at Duck Island WWTF

3.5.1.2 Primary Clarification

Primary clarifiers reduce the velocity of flow to provide settlement of large suspended solids, grease, and other floatables. There are six primary clarifiers at Duck Island WWTF. The primary clarifiers are "squircles", square clarifiers that operate as circular clarifiers with a center feed well, rotating sludge and scum rakes, and a V-notch weir along the perimeter. About 65% of solids are removed through this process. The primary sludge collected by the rotating sludge rake is directed to the gravity thickeners.

3.5.1.3 Aeration Basins

The primary clarifiers are followed by four aeration trains. The aeration trains are divided into aerated and unaerated zones to select for desired bacteria to achieve better settling sludge. Construction is currently underway at the Duck Island WWTF to reconfigure the aeration basins to achieve biological nutrient removal through the use of selectors.

3.5.1.4 Secondary Clarification

The Duck Island WWTF has four squircle secondary clarifiers. Secondary clarifiers allow for the settlement of fine solids and active bacteria. A portion of the active bacteria are recycled back to the aeration basins.

3.5.1.5 Disinfection

Prior to discharge into the Merrimack River, plant effluent is chlorinated to remove any remaining pathogens and bacteria with sodium hypochlorite. After achieving the required contact time, sodium bisulfate is used to dechlorinate flow prior to discharge into the Merrimack River.

3.5.1.6 Solids Handling

The solids handling process includes two covered gravity thickeners, each 55 feet in diameter. The gravity thickeners are used to thicken primary sludge. The wasted solids from the secondary clarifiers are sent to the rotary drum thickeners for thickening. Septage received at the Duck Island WWTF can be sent to the gravity thickeners or straight to dewatering. Dewatering of thickened primary sludge, thickened waste activated sludge (TWAS), and septage is achieved using a centrifuge. The dewatered cake produced by the centrifuge is loaded onto hauling trucks using a series of conveyors and taken offsite for disposal. Liquid streams from the gravity thickeners, rotary drum thickeners, and centrifuge are returned to the head of the plant.

3.6 Pumping Stations

There are ten pumping stations in Lowell's wastewater collection system to assist in the transport of wastewater that is unable to move amongst the system via gravity flow. Lowell's sewer system pumping stations include the following:

- Appleton Mills Pump Station
- Cannington Pump Station
- Chelmsford Pump Station
- Jackson Street Pump Station
- Pawtucket Pump Station
- Princeton Pump Station
- River's Edge Pump Station
- School Street Pump Station
- Trotting Park Pump Station
- Varnum Pump Station

These pumping stations are important assets that are essential in the transportation of wastewater for treatment.

3.7 Drinking Water System

3.7.1 Distribution System Overview

The City of Lowell's water distribution system is comprised of approximately 215 miles of water main with pipe diameters ranging from 4 to 36 inches, approximately 5,300 valves, and 2,300 hydrants. Lowell currently provides water service to 100 percent of the population, approximately 24,352 metered service connections. The existing water mains are constructed of various materials including pre-stressed concrete, unlined and cement lined cast iron, and ductile iron. The diameter of the service tubing ranges from 5/8-inch to 2-inch diameter mains. Approximately 500 of the service connections are suspected to be lead.

The distribution system is supplied by raw water from the Merrimack River. A raw water intake is located in the Merrimack River off Pawtucket Boulevard, which is then gravity fed to the Raw Water Pump Station (RWPS). The raw water is chlorinated and pumped to the 30 million gallon per day (MGD) Water Treatment Facility (WTF) also located off Pawtucket Boulevard. The 2018 average daily finished water consumption for the system was reported to be approximately 11.33 MGD, with approximately 26

percent attributed to residential usage and 53 percent attributed to commercial usage, and approximately two percent attributed to municipal, institutional, non-profit usage. In 2018 the residential water usage was 25 gallons per person per day and the unaccounted-for water was calculated to be 5.8 percent.

The water distribution system includes three service areas, the Low Service Area (LSA), High Service Area (HAS), and the Highlands Service Area (HLSA). The LSA includes the majority of Lowell's water system, and includes areas of Pawtucketville, the Highlands, Downtown, South Lowell and a portion of Centralville. The Water Treatment Facility serves the distribution system through two parallel transmission mains. The transmission mains include a 36-inch diameter main and a 24-inch diameter main. Service elevations in the LSA range from as low as 100 feet at Sheffield Street to as high as 205 feet at 342 Trotting Park Road. Storage for the LSA is currently provided by the Christian Hill 5.5 million gallon (MG) and 5.0 MG storage tanks which maintain an overflow operating gradient of 267 feet. The Christian Hill Water Storage Tanks are located at the intersection of Richards Street and Christian Street.

The HSA is comprised of 42 miles of water main generally on the east side of Lowell including Belvidere and most of the higher elevations of Centralville. The HSA is served by booster pump stations. Service elevations in the HSA range from as low as 66 feet at River Road to as high as 270 feet at Belmont Street @ Hovey Street. Storage for the HSA is currently provided by the Tenth Street 1.5 MG storage tank located at the intersection of 10th Street and Pleasant Street, which maintains an overflow operating gradient of 343 feet.

The HLSA is the smallest service area located within the LSA bordered by Westford Street, Stevens Street, Westchester Street and Pine Street at Westview Road. The HSLA is served by the Wedge Street Booster Pump Station. Service elevations in the HLSA range from as low as 106 feet at Ostrander Avenue to as high as 194 feet at Oakland Street. Storage for the HLSA is currently provided by the Wedge Street 1.0 MG storage tank located at the intersection of Wedge Street and Campbell Street, which maintains an overflow operating gradient of 305 feet MSL.

Lowell is also divided by the Merrimack River, therefore there are a number of river crossings to service the area south of the River. There are a total of twelve water mains crossing the River, many of them are out of service. Table 3-3 summarizes the river crossings with their size, material, location, and status.

Table 3-3: Merrimack River Water Main Crossings

Location	Diameter (inches)	Material	Installation Year	Service Area	Status
Pawtucket Boulevard – Sub-aqueous	24	Steel	1960s	Low	Active
O'Donnell Bridge (1) – Below Bridge Deck	16	Cast Iron	1900's	Low	Out of Service
O'Donnell Bridge (2) – Below Bridge Deck	20	Cast Iron	1900's	Low	Active
Textile Bridge (1) – Bridge Deck	16	Ductile Iron	2004	Low	Active
Textile Bridge (2) – Below Bridge Deck	12	Cast Iron	1980's	Low	Active
Aiken Street – Sub-aqueous	24	Cast Iron	1890's	Low	Abandoned
Bridge Street Bridge – Alongside	20	Cast Iron	1940's	Low	Active
Hunts Fall Bridge (1) – Below Bridge Deck	24	Steel	1955	Low	Active
Hunts Fall Bridge (2) – Below Bridge Deck	24	Steel	1955	High	Out of Service
East Hunts Fall Bridge (1) – Sub-aqueous	30	Cast Iron	1873	Low	Active
East Hunts Fall Bridge (2) – Sub-aqueous	24	Cast Iron	1880's	Low	Out of Service
East Hunts Fall Bridge (3) – Sub-aqueous	12	Cast Iron	1880's	High	Active

3.7.2 Water Supply Source

The Lowell water system is served solely by the Merrimack River. The raw water intake and RWPS were constructed on the north bank of the river in the western end of Lowell, close to the Tyngsborough town line. Raw water from the Merrimack River enters a wet well at the RWPS by gravity and is then pumped to the WTF through 3,300 linear feet of 36-inch diameter pre-stressed concrete transmission main. Fluctuating river flow due to stormwater run-off and seasonal impacts results in significant variations in raw water quality. During the late summer and early fall, the river experiences low flow conditions which can result in the release of organic material. During the winter, the build-up of ice has prevented pumping operations in the past as well as the build-up of leaves in the Fall. Ammonia concentrations and turbidity after rain storms may impact the treatment processes.

3.7.3 Water Treatment Facility

The water treatment facility (WTF) treatment train consists of coagulation, flocculation, sedimentation and filtration. It was built in 1961 with a capacity of approximately 10.5 MGD. In 1981 the capacity was increased to 30 MGD. In 2002, treatment upgrades were completed and in 2006 additional upgrades to the pumping equipment, chemical feed equipment, flow metering equipment and the building infrastructure were completed. The water treatment process at the plant consists of rapid mixing using inline static mixers, coagulation using polyaluminum chloride (or alternatively using aluminum sulfate and sodium hydroxide), flocculation using two-stage propeller type flocculators, sedimentation, dual media and sand filtration using automatic-backwashing traveling bridge filters, granular activated carbon adsorption, fluoridation using hydrofluosilicic acid, post-chlorination to maintain a distribution system residual using sodium hypochlorite, pH adjustment and corrosion control using sodium hydroxide, sodium bicarbonate and zinc orthophosphate.

3.7.4 Water Storage Facilities

3.7.4.1 Christian Hill Reservoir #1 and #2

The Christian Hill Reservior #1 and #2 serve the Low Service Area and are located at the intersection of Richards Street and Christian Street. Christian Hill Tank #1 is a 5.0 million gallon (MG) cast-in-place concrete water storage tank constructed in the 1920's and the Christian Hill Tank #2 is a 5.5 MG pre-stressed concrete water storage tank constructed in 1997. The overflow elevation of the tanks is 267 feet with the base of Christian Tank #1 at elevation 242 feet MSL and the base of the Christian Hill #2 tank at elevation 235 feet MSL.

3.7.4.2 Wedge Street Tank

The Wedge Street Water Storage Tank is connected to the Highland Service Area and is located at the intersection of Wedge Street and Campbell Street. The Wedge Street Water Storage Tank is a 1.0 MG elevated spheroidal water storage tank constructed in 2006. The water storage tank was constructed to create a new service area in order to minimize pressure fluctuations in the Highlands area by increasing the overflow elevation to 305 feet MSL.

3.7.4.3 Tenth Street Standpipe

The Tenth Street Water Storage Tank is connected to the High Service Area and is located at the intersection of Tenth Street and Pleasant Street. The Tenth Street Water Storage Tank is a 1.5 MG riveted steel water storage tank constructed in 1911. The water storage tank was constructed to create a new service area in order to minimize pressure fluctuations in the Highlands area by increasing the overflow elevation to 343 feet MSL. The water storage tank during certain demand conditions is hydraulically locked.

3.7.5 Pump Stations

3.7.5.1 Raw Water Pump Station

The Raw Water Pump Station located adjacent to the Merrimack River Raw Water Intake was constructed in 1961 with a capacity of approximately 21 MGD and was increased in 1981 to a capacity of 37 MGD. The pump station contains four vertical turbine pumps equipped with variable frequency drives. Pump station upgrades occurred in 2005, replacing the pumps, variable frequency drives and electrical equipment. Chemical addition includes sodium hypochlorite for pre-chlorination for combining ammonia to form chloramines and chlorine dioxide for disinfection. Chlorine dioxide after injection is monitored as well as pH, turbidity, temperature and particle counts.

3.7.5.2 Stackpole Street Booster Pump Station

The Stackpole Street Booster Pump Station located off Stackpole Street was constructed in 1947 and rehabilitated in 1963, 1979, and 1995. The pump station is equipped with two 1,600 gallon per minute (gpm) horizontal split case pumps, a 500 gpm horizontal split case pump, and an emergency generator. The pump station is operated based on discharge pressures. Discharge pressures are maintained at about 150 psi by a small jockey pump. The Stackpole Booster Pump Station provides water to the high service area with flows ranging from 2.2 to 4.0 MGD.

3.7.5.3 Wedge Street Booster Pump Station

The Wedge Street Booster Pump Station located on Wedge Street and was constructed in 2006. The pump station serves the Highland Service Area, the smallest service area located within the LSA bordered by Westford Street, Stevens Street, Westchester Street and Pine Street at Westview Road. The pump station is equipped with two 350 gpm pumps.

3.7.5.4 Newbridge Booster Pump Station

The Newbridge Booster Pump Station is located on Aegean Lane in the Newbridge subdivision in Pawtucketville and was constructed in 1999. The pump station is equipped with three 175 gpm pumps and one 750 gpm pump.

3.7.5.5 Trotting Park Booster Pump Station

The Trotting Park Booster Pump Station is located Trotting Park Road, and was constructed in 1999. The pump station is equipped with two 100 gpm pumps and one 600 gpm pump.

3.7.5.6 Beacon Booster Pump Station

The Beacon Pump Station is located on Beacon Street. The pump station has a total maximum aggregate pumping capacity of 1,400 gpm.

3.7.6 Interconnections

The water system has metered interconnections with the Town of Tyngsborough, four with the Town of Chelmsford, three interconnections with the Town of Dracut, and four interconnections with the Town of Tewksbury. The Tyngsborough interconnection is located on Varnum Avenue. The Chelmsford interconnections are served through the North Chelmsford Water District located on Technology Drive and through the East Chelmsford Water District located on Bigelow Street, Carlisle Street and Gorham Street. The Dracut interconnections are located on Hildreth Street, Bridge Street, and through the Kenwood Water District on Methuen Street. The Tewksbury interconnections are located on Woburn Street, Rogers Street, Dead Horse Lane, and Andover Street (inactive).

3.8 Drinking Water Infrastructure Needs

Lowell has developed a list of critical drinking water system needs. These improvements are critical to improve redundancy, reduce unaccounted for water, and protect public health.

3.8.1 Redundant 24-inch Diameter Water Main

Lowell plans to increase the reliability of the water distribution system by constructing a new 24-inch diameter water main as a redundant finished water transmission main from the water treatment facility. There is currently a lack of redundancy leaving the treatment facility. A water main break on this transmission main would not only eliminate supply to Lowell's customers but would also be difficult to repair and could result in costly consequences. The project would involve construction of 4,000 linear feet of 24-inch diameter water main.

3.8.2 Water Treatment Plant Upgrades

Lowell has identified that an upgrade at the Water Treatment Facility to replace aging equipment, increase security and increase resiliency is necessary to ensure the effective and reliable treatment of raw water from the Merrimack River that is polished into finished water for Lowell's customers.

3.8.3 New Finished Water Storage Tank

There is a need for finished water in the eastern quadrant of Lowell. Due to the long distance from the water treatment facility and the absence of any active water storage tanks in this area, supply to customers in this area could be jeopardized if a transmission main break were to occur. This water storage tank is also an important consideration for maintaining fire suppression capability in this area if a water main break were to occur.

3.8.4 Distribution System Improvements (Control valves, etc.)

As described above, the distribution south of the Merrimack River is served by a series of water mains installed under the river. The transmission mains crossing the Merrimack River are vulnerable to leaks

and breaks. Vulnerability in these mains create the potential for inadequate water supply for residential and commercial users, as well as for fire safety in the event of a break.

3.8.5 Lead Service Replacement

As an effort to improve public health, Lowell plans to undertake a lead service replacement program. Lowell has identified approximately 500 water service pipes with suspected lead material installed decades ago. The lead pipes will be replaced with new pipes that are made of modern materials in order to prevent the leaching of lead into Lowell's drinking water.

3.8.6 Water Meter Replacements

Lowell conducted a meter replacement program from 1990-1991. Commercial and industrial meters were not replaced as part of this program. There are approximately 1,100 larger commercial and industrial meters. Lowell plans to implement a large meter replacement program.

3.8.7 Backflow/Meter Survey

Lowell plans to continue to inspect backflow prevention devices and has identified the need to institute a formal backflow/meter survey program.

4. Sewer System Modeling and Characterization

In order to evaluate the benefits of LTCP alternatives, Lowell developed and calibrated a hydrologic/hydraulic SWMM collection system model, which was utilized in the 2014 LTCP Update.

In an effort to improve confidence in the model's predictive ability and update it to represent current conditions, a temporary flow/rainfall monitoring program and model update (including additional calibration/validation) was undertaken. As a result of this effort, the model is capable of simulating the current conditions of the sewer system (within reasonable predictive limits). The model was utilized to assess the performance of various CSO control measures and strategies.

4.1 Temporary Flow and Rainfall Monitoring Program

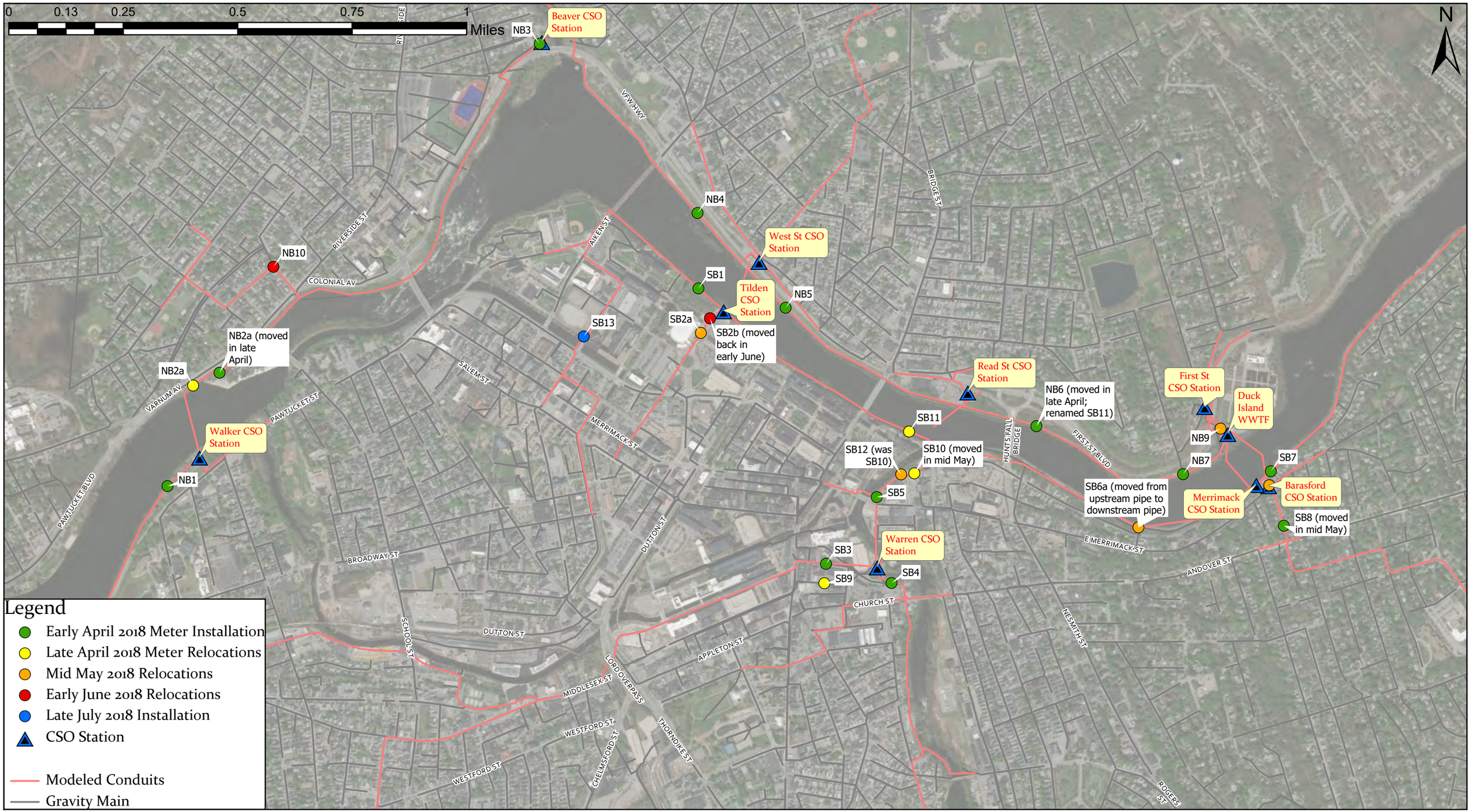
4.1.1 Overview of Program and Meter Locations

Temporary flow monitoring was performed from April through August 2018 at a total of 26 individual locations. Figure 4-1 illustrates the locations of meters throughout the monitoring period, and Appendix C contains the installation site sheets for each location.

The flow monitoring program that occurred as a part of this program was developed with several goals:

1. Recalibrate the existing SWMM model to enable it to accurately predict CSO discharges
2. Increase system understanding
3. Provide additional insight into the effectiveness of system controls (e.g. the movement of inline flow control gates for inline storage) and identify opportunities for improvement
4. Characterize conditions in upstream portions of the system where alternatives such as sewer separation or green infrastructure might be possible

To accomplish this goal, bi-weekly meetings occurred throughout the duration of the five-month program to relocate and optimize the placement of temporary flow meters. QA/QC of meter data was provided throughout the monitoring period in real time so that irregularities and anomalous flow meter readings were identified in the field.



Hazen

Lowell Water
Integrated Plan
Flow Meter Location Map

LOWELL WATER
Community ~ Health ~ Environment

Figure 4-1

4.1.2 Rain Data and Storm Events

Observed rainfall for the monitoring period was characterized at four locations, as shown in Figure 4-1 and as summarized in Table 4-1 through Table 4-4. All rain gauges used during the monitoring period are owned and maintained by Lowell Water. Some gauges were temporarily unusable due to maintenance activities. As such, the period of record may differ between the rain gauges. The data also indicate significant spatial variability between rain gauges as depths and peak intensities differed for a given storm between gauges. This is not an unusual finding given the distance between rain gauges and potential for rainfall intensity to vary significantly over short distances.

Table 4-1: Observed Rainfall Events at Duck Island WWTF Gauge

Rain Start	Duration (hrs)	Total Depth (in)	Peak Intensity (in/5min)	Peak Intensity (in/hr)
4/16/2018 4:10	15.7	1.62	0.07	0.29
4/25/2018 17:15	5.2	0.25	0.02	0.10
4/26/2018 6:55	0.7	0.15	0.05	0.15
4/27/2018 15:20	2.4	0.24	0.03	0.14
4/29/2018 9:15	5.6	0.14	0.02	0.06
5/6/2018 9:05	13.8	0.56	0.02	0.15
5/15/2018	2.8	0.42	0.05	0.24
5/27/2018 0:45	0.8	0.18	0.07	0.19
6/4/2018 9:20	1.2	0.15	0.02	0.12
6/5/2018 13:50	0.2	0.14	0.08	0.14
6/18/2018 18:30	2.2	0.17	0.033	0.13
6/24/2018 23:15	2.7	0.48	0.05	0.28
6/28/2018 0:05	3.2	0.19	0.03	0.09
7/17/2018 13:05	8.4	0.96	0.07	0.39
7/22/2018 7:30	2.4	.010	0.01	0.06
7/22/2018 21:40	5.8	0.11	0.03	0.05
7/26/2018 3:00	3.2	0.44	0.05	0.26
7/26/2018 15:05	0.3	0.43	0.20	0.43
8/2/2018 18:40	0.6	0.52	0.15	0.52
8/4/2018 10:35	1.1	0.17	0.02	0.16
8/7/2018 20:00	0.2	0.11	0.06	0.12
8/11/2018 13:00	3.1	1.01	0.09	0.59
8/12/2018 5:45	6.5	0.45	0.06	0.24
8/13/2018 21:30	1.2	0.10	0.02	0.09
8/14/2018 13:50	5.1	0.43	0.14	0.36
8/17/2018 16:10	8.7	0.58	0.18	0.48
8/18/2018 13:00	0.9	0.20	0.04	0.20

Table 4-2: Observed Rainfall Events at Warren Gauge

Rain Start	Duration (hrs)	Total Depth (in)	Peak Intensity (in/5min)	Peak Intensity (in/hr)
4/3/2018 17:55	13.0	0.29	0.01	0.09
4/12/2018 20:10	0.8	0.11	0.02	0.11
4/16/2018 4:55	15.1	2.30	0.09	0.41
4/25/2018 17:10	6.7	0.39	0.02	0.16
4/26/2018 7:00	0.7	0.21	0.06	0.21
4/27/2018 15:15	2.5	0.31	0.03	0.17
4/29/2018 9:15	5.6	0.19	0.03	0.07
5/6/2018 9:05	14.3	0.60	0.03	0.16
5/15/2018 16:15	2.9	0.49	0.07	0.25
5/19/2018 13:55	3.6	0.13	0.02	0.06
5/27/2018 0:45	1.1	0.15	0.03	0.13
6/4/2018 9:20	1.1	0.16	0.02	0.14
6/5/2018 13:50	0.2	0.15	0.10	0.15
7/14/2018 21:45	2.1	0.18	0.01	0.10
7/17/2018 13:05	10.8	1.42	0.04	0.40
8/9/2018 16:55	0.2	0.31	0.18	0.31
8/11/2018 12:50	23.5	2.56	0.14	0.97
8/13/2018 22:10	0.8	0.13	0.03	0.13
8/14/2018 13:55	5.2	0.58	0.18	0.47
8/17/2018 16:10	9.7	0.95	0.23	0.67
8/18/2018 13:00	0.9	0.26	0.03	0.26

Table 4-3: Observed Rainfall Events at River's Edge Gauge

Rain Start	Duration (hrs)	Total Depth (in)	Peak Intensity (in/5min)	Peak Intensity (in/hr)
4/30/2018 23:55	0.2	0.12	0.07	0.12
5/6/2018 12:05	2.2	0.12	0.02	0.06
5/6/2018 20:55	6.4	0.45	0.09	0.17
5/15/2018 16:25	2.7	0.60	0.09	0.33
5/16/2018 3:15	0.1	0.14	0.14	0.14
5/19/2018 14:20	13.0	0.27	0.05	0.06
5/20/2018 14:10	1.0	0.16	0.05	0.16
6/4/2018 9:00	1.8	0.30	0.04	0.21
6/18/2018 18:30	2.5	0.56	0.15	0.52
6/19/2018 3:15	0.1	0.13	0.13	0.13
6/25/2018 0:15	3.7	0.67	0.08	0.41
6/28/2018 0:10	17.7	1.32	0.09	0.41
6/29/2018 3:15	0.1	0.31	0.31	0.31
7/3/2018 16:00	1.3	0.34	0.20	0.33
7/14/2018 21:55	1.0	0.10	0.02	0.10
7/17/2018 13:20	9.1	1.41	0.22	0.55
7/22/2018 7:25	5.6	0.25	0.02	0.08
7/22/2018 21:20	12.6	0.20	0.05	0.08
7/26/2018 2:30	4.2	0.72	0.08	0.41
7/26/2018 15:05	0.3	0.21	0.09	0.21
8/2/2018 18:55	1.0	0.11	0.04	0.11
8/4/2018 10:30	1.3	0.35	0.04	0.29
8/11/2018 12:55	8.9	1.26	0.10	0.58
8/12/2018 5:20	7.2	0.40	0.08	0.21
8/13/2018 22:05	0.8	0.12	0.02	0.12
8/14/2018 13:45	5.5	0.65	0.16	0.53
8/17/2018 16:05	11.1	1.40	0.28	1.03
8/18/2018 13:05	4.3	0.27	0.07	0.25

Table 4-4: Observed Rainfall Events at WTF Gauge

Rain Start	Duration (hrs)	Total Depth (in)	Peak Intensity (in/5min)	Peak Intensity (in/hr)
5/15/2018 16:15	3.0	0.54	0.16	0.25
5/19/2018 14:00	15.5	0.30	0.03	0.07
5/27/2018 0:30	1.7	0.14	0.05	0.10
6/4/2018 9:15	4.3	0.14	0.04	0.10
6/18/2018 18:15	2.3	0.26	0.11	0.24
6/24/2018 16:30	11.8	0.92	0.20	0.55
6/27/2018 22:45	15.3	1.06	0.07	0.22
7/3/2018 16:00	1.3	0.11	0.04	0.08
7/6/2018 11:15	0.8	0.10	0.05	0.10
7/17/2018 12:45	9.3	1.66	0.31	0.74
7/22/2018 8:30	4.0	0.22	0.03	0.08
7/22/2018 20:45	13.7	0.26	0.04	0.12
7/26/2018 2:15	4.7	0.56	0.10	0.25
7/26/2018 14:45	0.8	0.65	0.51	0.65
8/2/2018 18:45	1.3	0.27	0.18	0.25
8/4/2018 10:15	1.7	0.31	0.09	0.26
8/7/2018 19:45	1.3	0.14	0.10	0.14
8/8/2018 19:45	8.0	0.11	0.02	0.06
8/11/2018 12:45	10.0	1.73	0.28	0.73
8/12/2018 11:00	1.7	0.29	0.14	0.27
8/13/2018 22:00	1.0	0.10	0.03	0.10
8/14/2018 13:45	4.8	1.07	0.40	0.51
8/17/2018 16:00	10.0	1.12	0.49	0.66
8/18/2018 12:45	4.5	0.36	0.16	0.32

The rain events that occurred during the monitoring period were varied and representative of a wide range of different wet weather conditions. Based on NOAA Atlas 14 Precipitation Frequency Estimates, most storm events had an average recurrence interval of less than 1 year. Regardless, the storm events observed included storms with different rainfall distributions, including first, second, and third quartile storm events. The largest storm event during the monitoring period occurred on April 16, 2018. This event resulted in a total rainfall depth of 2.47 inches and exceeded the NOAA Atlas 14 1-year return period thresholds for 12 and 24-hour storms, as shown in Figure 4-2 below.

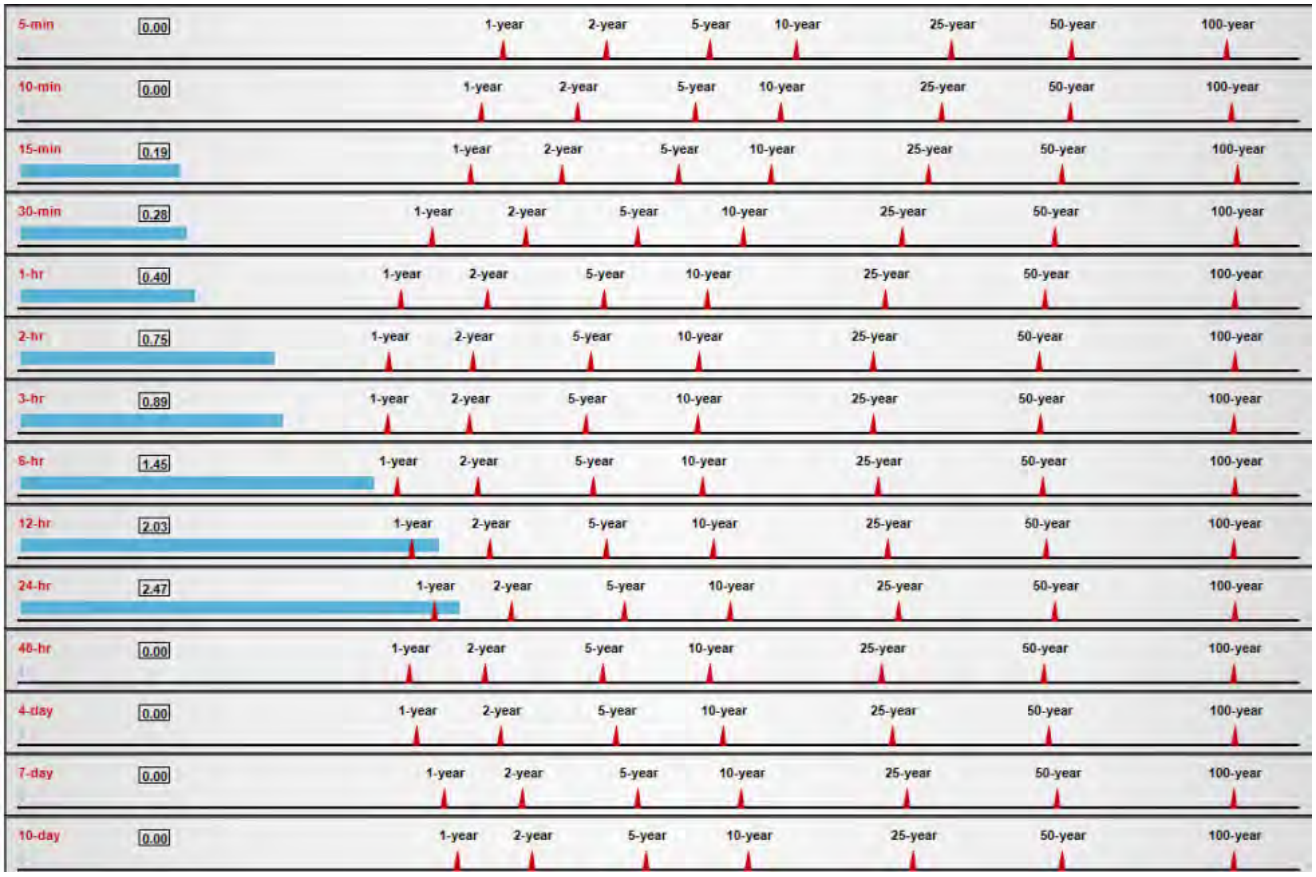


Figure 4-2: April 16, 2018 Storm Event Recurrence Interval Thresholds

4.1.3 Flow Data Summary

Flow data collected during the temporary monitoring period were generally of high quality and sufficient for the goals of the monitoring program. For the purpose of this report some key findings are highlighted below.

The metering program was actively managed over its entire duration, and bi-weekly meetings between Lowell, its consultant, and the flow metering subcontractor occurred to verify the quality of meter data and determine if meters should be relocated. As such, much of the data received QC in real-time, and meters were periodically relocated to maximize the usefulness of the metering program relative to the IP and its goals.

Figure 4-3 is a scattergraph of flow data collected at meter SB11. This type of chart, which includes velocity on the Y-axis and depth on the X-axis, was produced at all meter locations at various points throughout the monitoring period. These scattergraphs are useful tools for verifying the quality of meter data and determining the presence of other hydraulic conditions that might impact data analysis.

As can be seen in Figure 4-3 below, the first region of the chart shows a repeatable pattern and correlation between velocity and depth. This type of pattern is indicative of high-quality meter data and open channel

flow that can be described according to Manning's Equation. The second region of the chart, which indicates increasing depth without increasing (or decreasing) velocity is indicative of a backwater condition. This could be caused by several factors including flow above the pipe's capacity, a downstream bottleneck, or a closed flow control gate.

In the context of meter SB11, this information was used to help increase system understanding. The backwater condition present at meter SB11 indicated that the downstream pipe was already above capacity and is not capable of conveying additional flow to the WWTF (via Merrimack station). Since meter SB11 was downstream of Tilden Station, this information indicates that increased conveyance through the station would not be an effective CSO control strategy, since the downstream interceptor does not have additional conveyance capacity. As such, CSO control strategies that focus on removal of stormwater inflow, such as sewer separation and green infrastructure, were prioritized for analysis in the Tilden sewershed. These types of analyses were conducted at all meter locations and used to help guide the development of the CSO control alternatives analysis.

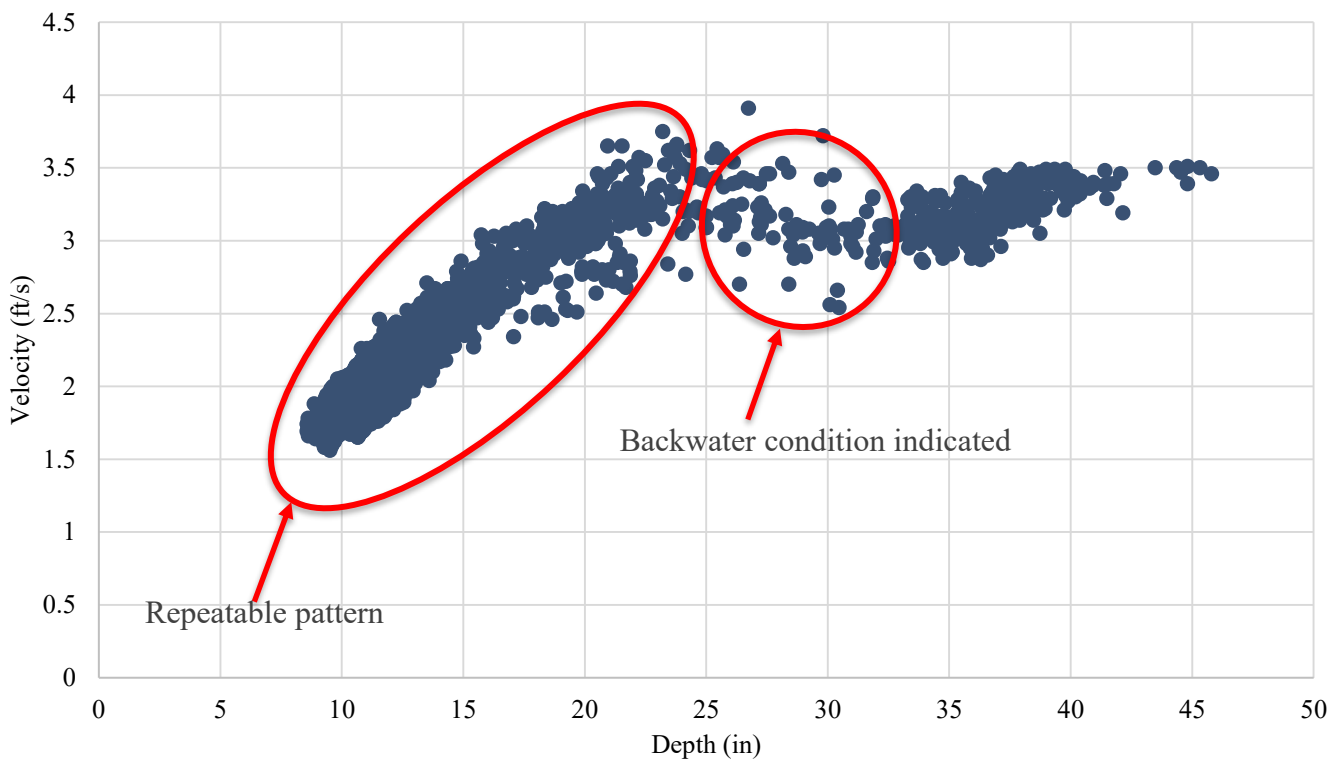


Figure 4-3: Scattergraph of Flow Data Collected at Meter SB11

The temporary flow meters were also useful for helping to validate Lowell's CSO volume estimates. By strategically placing flow meters around CSO stations so they measure inflows and outflows, it was possible to perform flow balances around several stations. For example, at Tilden Station, meters SB1 and SB2a measured flows coming into the station, and meter SB11 measured flow downstream of the station. As such, if the volume of flow entering the station exceeds the volume measured downstream, that volume can be accounted for by an overflow at that station. Figure 4-4 depicts such an overflow. During dry weather, flow difference should be zero, indicating no lost flow. The positive flow indicated in Figure

4-4 depicts more flow entering the station than was measured downstream. This excess volume was discharged as a CSO.

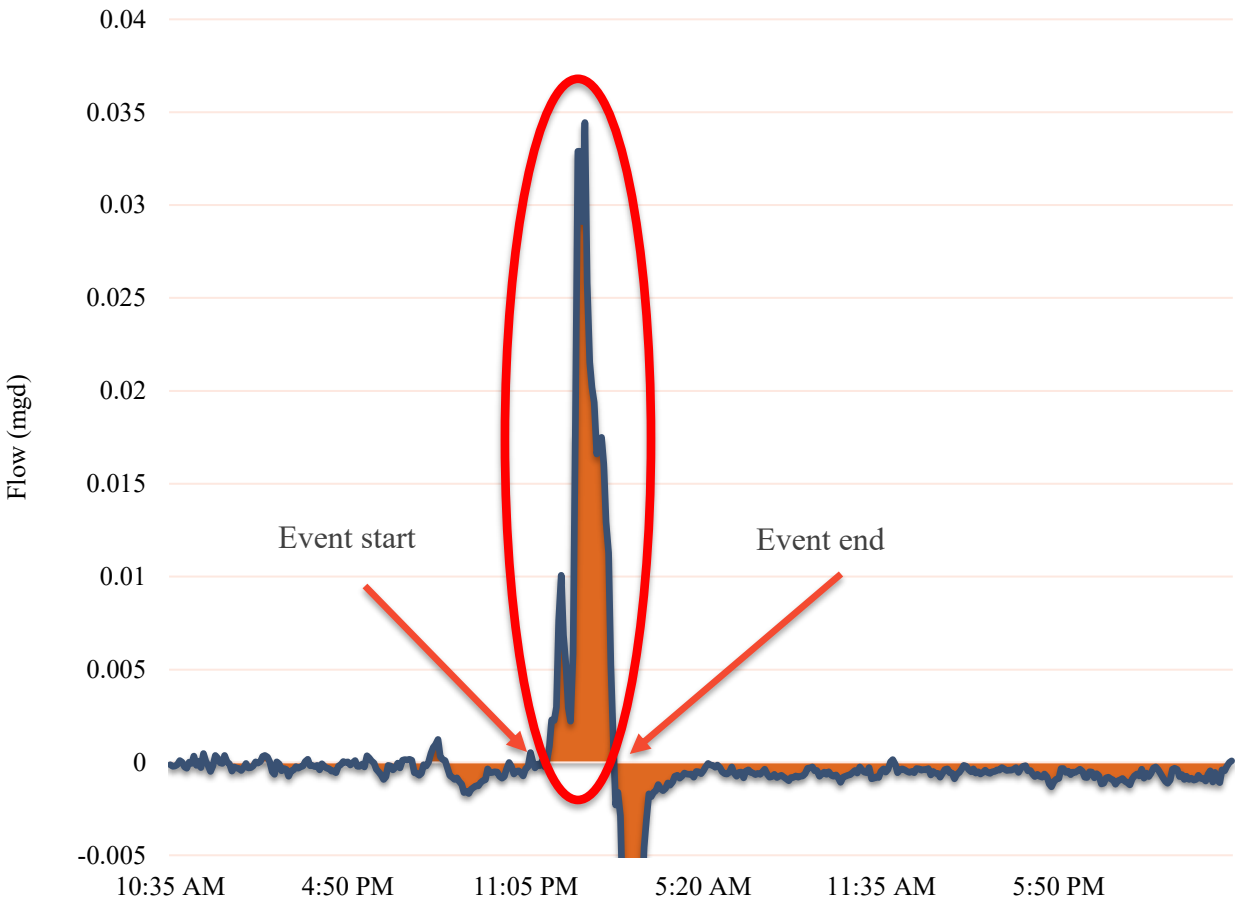


Figure 4-4: Flow Balance around Tilden Station Depicting a CSO Event

The types of analyses described above (and more) were performed throughout the temporary metering program. This hands-on approach to the metering meant that the data collected were not only used for model calibration, but also for improving system understanding and guiding the development of the CSO control alternatives analysis.

4.1.4 Level Monitoring (On-Going)

In addition to temporary flow monitoring using area-velocity flow meters, Lowell conducted level monitoring and continues to do so on an on-going basis. Level monitoring helps Lowell to gather data about system behavior and inform wet weather operation. One of Lowell's high flow management (HFM) strategies is to store wet weather flow in large sewer interceptors and trunk lines. Lowell uses level monitoring to help ensure storage is safe, and any risk of an SSO occurring due to excess surcharge is

minimized. For example, it was discovered at Tilden station during the monitoring period that wet weather flow was being stored within one foot of the rim of a low-lying manhole upstream of the station. This information was useful as it indicates that no more storage capacity is available within that pipe and that the risk of an SSO occurring was too high per Lowell's safe storage policy. As such, operational changes were made at this station to reduce the amount of flow stored during wet weather in this pipe.

Lowell owns several level monitors and will continue to use these devices on an on-going basis to further optimize the system, identify opportunities for additional inline storage, and ensure all inline storage is consistent with Lowell's safe storage policy.

4.2 Model Background

A hydrologic/hydraulic model of a sewer or drainage system is a mathematical representation of an actual physical collection system. Lowell has performed previous modeling studies, using SWMM-based, GIS-capable modeling software. Lowell's original CSS model was developed in 2002 as part of its Phase I LTCP using SWMM 4, and then later expanded and updated to use SWMM as part of Lowell's Phase II LTCP efforts. In addition to pipes with a diameter of 42 inches or larger, the model includes sufficient detail to accurately characterize how flow is "loaded" into (enters) the collection system and is conveyed to CSO stations. Since the model's purpose has been to analyze possible CSO control measures, it also includes significant detail that describes the piping network around CSO stations.

In the development of this IP, PCSWMM was utilized as the model platform. PCSWWM is developed and maintained by Computational Hydraulics International (CHI). PCSWMM is a fully dynamic hydrologic/hydraulic modeling program, based on the EPA-SWMM framework, and is fully interactive with GIS.

The PCSWMM model includes a network that is subdivided into three primary features: subcatchments, conduits (includes sewer pipes, pump stations, weirs, gates, or any other appurtenances), and nodes (includes manholes, outfalls, wet wells, storage tanks, and any other point along a piped network where physical characteristics change). The model network for any modeling project typically consists of a subset of the actual sewer system, and this subset is often determined by a variety of factors including project needs, regulatory requirements and availability/reliability of data.

The modeling program uses information about the collection system together with a set of equations which are then solved by the program to simulate specific conditions of I/I, rainfall, sewer flow, and determine resulting flows and levels within the piping network. As such, the model can be used to predict the magnitude and frequency of CSOs at the permitted and active overflows in Lowell's sewer system.

As part of IP development, the model was recalibrated using data collected during the flow/rainfall monitoring program described above. The model was also improved to more accurately represent the geometry of the sewer system and reflect how Lowell Water currently manages the system.

4.3 Model Improvements/Updates and Calibration

4.3.1 Model Updates & Improvements

4.3.1.1 System Controls and Updates

Lowell Water actively manages its sewer system using flow control gates and by opening and closing gates (diversion gates) at CSO stations to manage discharges. SWMM is capable of simulating the movement of these gates, and other system controls, through the use of Real Time Controls (RTCs). RTCs govern how certain model elements (orifices and weirs) that represent gates respond to different flows and levels in the system.

Lowell Water has a complex strategy for operating its sewer system that is part of its High Flow Management (HFM) program. Gate positions throughout the sewer system are controlled by the SCADA system. This section contains descriptions of how Lowell manages the gates and other control structures throughout the sewer system. This section also contains a description of some updates and improvements that were made throughout the model (separate from model recalibration).

4.3.1.1.1 Walker CSO Station

No model updates were made at this station. CSO discharges at Walker Station are pumped to the Merrimack River. The pumps at Walker Station are represented in the model with a SWMM Type 4 pump, which is a variable speed in-line pump where flow varies continuously with inlet node (wet well) depth. The pump is set to activate when the depth reaches 8.1 feet and shut down when the depth drops to 4.8 feet. The flow control gate at this station remains set to 80% open. Figure 4-5 shows Walker CSO station as it is configured in the model. The pump curve this SWMM Type 4 pump operates on is shown in Figure 4-6.

Figure 4-5: Modeled Schematic of Walker Street CSO Station

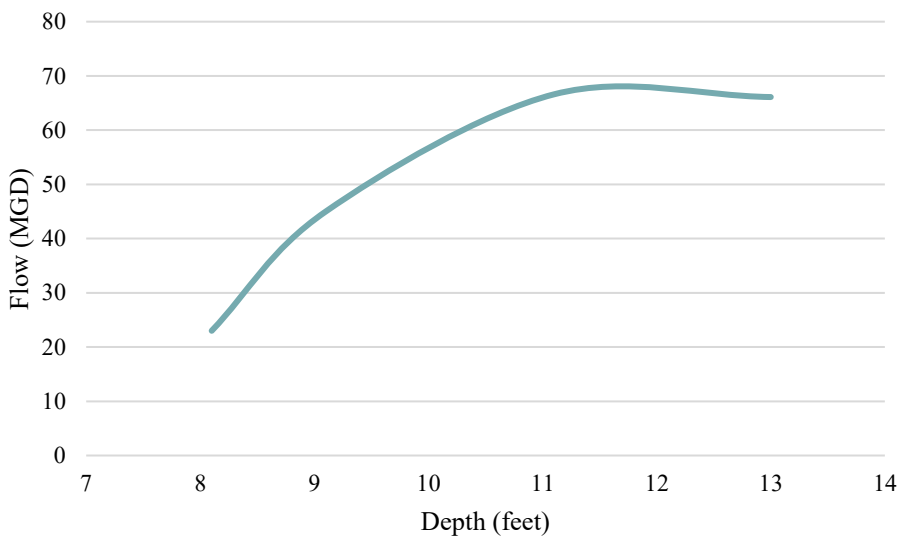


Figure 4-6: Walker CSO Station Pump Curve

4.3.1.1.2 Beaver Brook CSO Station

No model updates were made at this station. An influent bar rack (represented with an orifice) at the station has a default position of 50% open. During wet weather, the bar rack is modulated to induce inline storage upstream of the station by maintaining a depth of 8 feet at an upstream node. During dry weather, a flow control gate (orifice) that regulates flow out of the station is set to 49% open. During wet weather the flow control gate is modulated to maintain a depth of 3.0 feet in the downstream flume channel. Overflows can occur via gravity or pumping. When the depth in the station exceeds 4.75 feet, flow can

overtop a weir and discharge to the Merrimack River via one of three gravity discharges. If the depth in the station exceeds 5.95 feet, flow can overtop a weir into a wet well for a discharge pump. The pump activates when the depth in the wet well reaches 8 feet and shuts down when the depth drops to 5 feet. The pump is a SWMM Type 4 pump in the model. Figure 4-7 depicts how Beaver Brook station is modeled in schematic view. The pump curve this SWMM Type 4 pump operates on is shown in Figure 4-8.

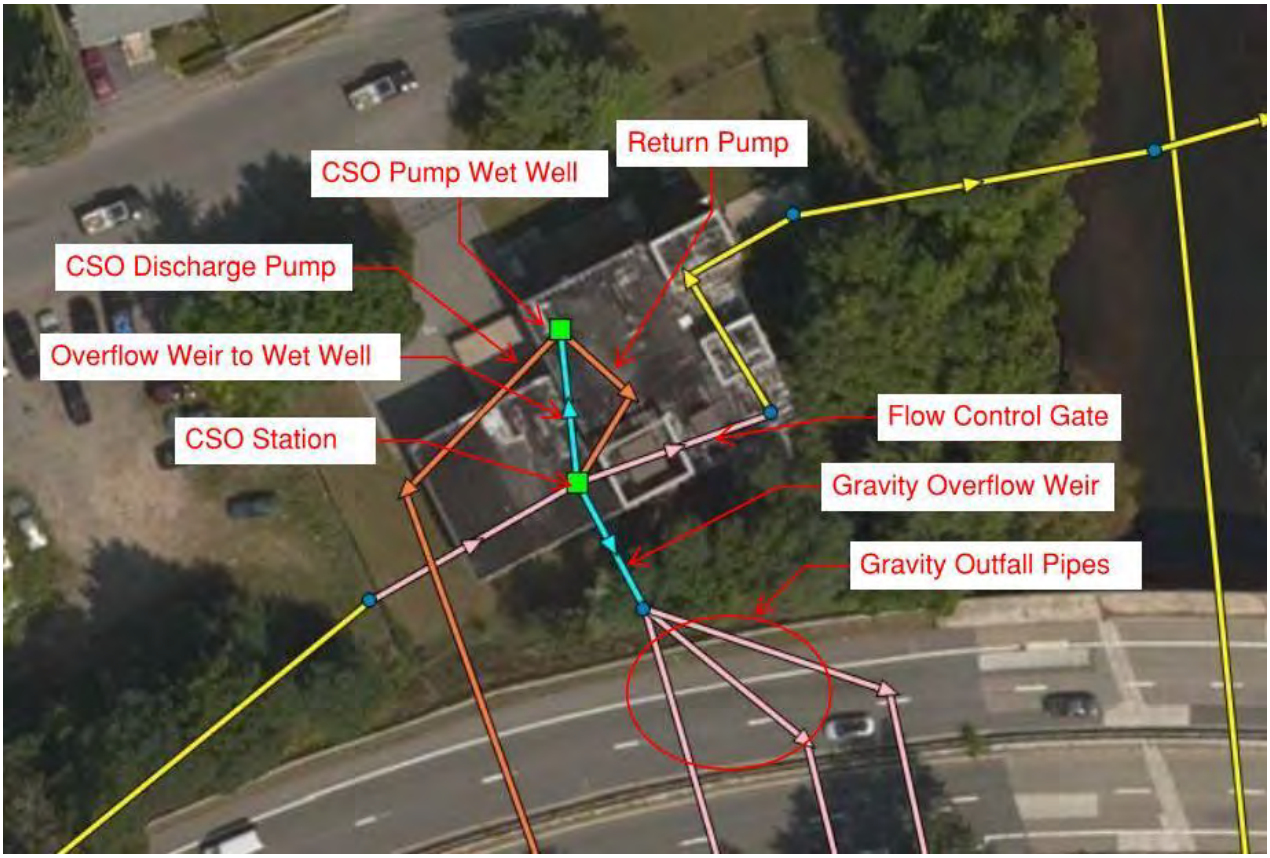


Figure 4-7: Modeled Schematic of Beaver Brook CSO Station

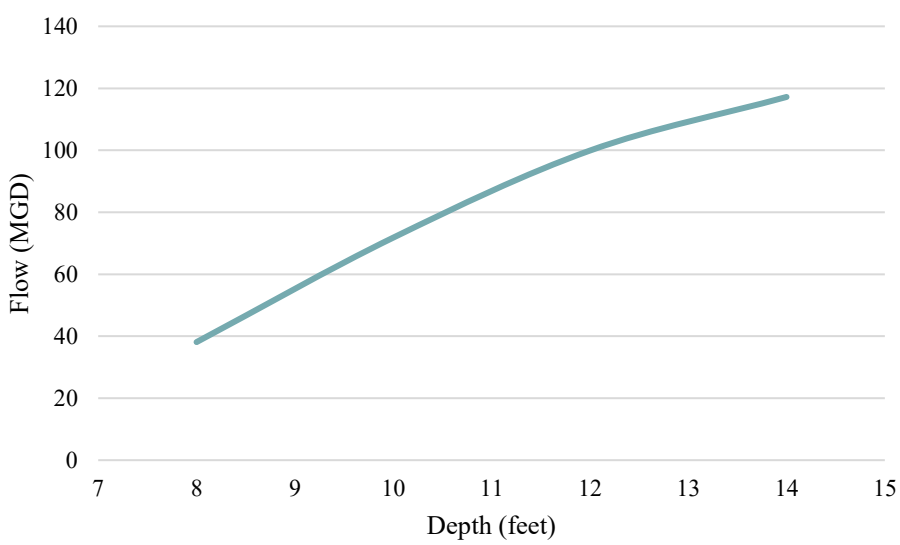


Figure 4-8: Beaver Brook CSO Station Pump Curve

4.3.1.1.3 West CSO Station

Several updates were made at West Station to more accurately represent the current geometry and control strategy at this station. Since the model was last updated, this station was rehabilitated. In addition, an inline flow control gate was installed in the North Bank interceptor downstream of West Station to induce storage. As such, the flow control strategy at this station has been changed. At present, the flow control gate (orifice) is at West Station and remains open during dry and wet weather. The occurrence of an overflow at West Station is determined by the level in the station and position of a gravity diversion gate (orifice). When the level in the station reaches 7.5 feet the gravity diversion gate opens and modulates to maintain a depth of 7.5 feet. When the level in the station drops back to 6.0 feet the gate closes. Figure 4-9 depicts how West CSO station is modeled in schematic view.

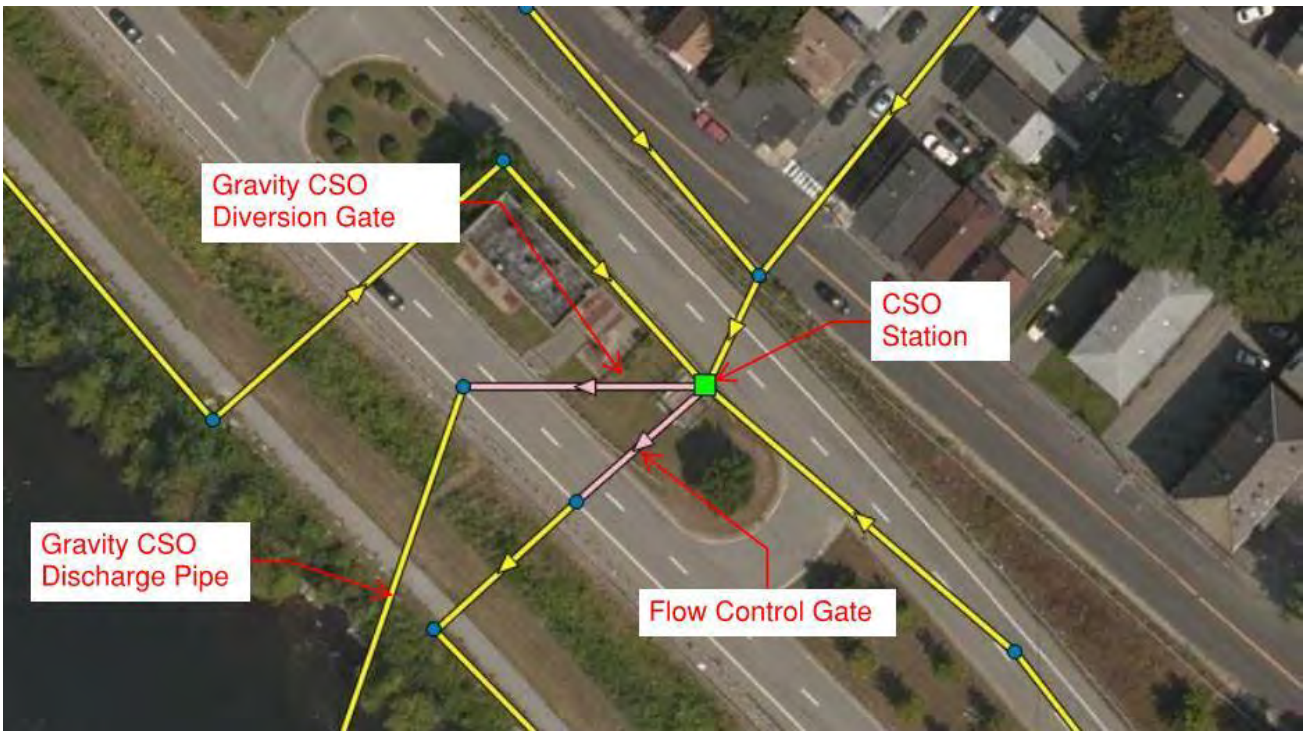


Figure 4-9: Modeled Schematic of West Street CSO Station

4.3.1.1.4 Read Inline Flow Control Gate

In 2018, a flow control gate was installed in the North Bank interceptor in the vicinity of Read Station. The purpose of this gate is to induce inline storage in the 8-foot interceptor between West and Read Stations. During dry weather the Read Inline Gate remains set at 6% open. During wet weather, the Read Inline Gate is modulated to induce storage in the interceptor but avoid the occurrence of a CSO at West Station. As such, when the level at West Station approaches the diversion level, the Read Inline Gate is modulated to maintain the level at West Station such that it remains at 6.5 feet (1 foot below the level that would trigger the gravity diversion gate to open).

In addition, during wet weather both the Read and Merrimack flow control gates are modulated together to ensure that excessive flow is not conveyed to the WWTF. In reality, SCADA control of these gates is based on level in the influent chamber of the WWTF. However, for the purposes of the model, RTCs were developed to modulate the gates based on flow at the WWTF. The WWTF is capable of sustaining a peak flow of 115 MGD for a short period and sustaining 110 MGD for a longer period. As such, once flow at the WWTF exceeds 95 MGD, the Read and Merrimack gates are modulated together to maintain a flow of 105 MGD. This target flow means that flow at the WWTF may briefly spike to 115 MGD but be maintained between 105-110 MGD during wet weather. This control has a higher priority than maintaining the level at West Station, meaning that Read Gate will close sufficiently to avoid allowing too much flow to be conveyed to the WWTF; this may cause overflow at West Station.

In the model, the Read gate is configured to have a maximum opening area that is 20% of the actual gate size (8 feet), based on actual operating information indicating that the gate does not open beyond 20%. Since the gate remains at least 2% open, the model also includes an orifice that corresponds to 2% of the gate size. This "minimum" orifice is not actively controlled. Figure 4-10 depicts the Read Inline flow control gate in the model.

Figure 4-10: Modeled Schematic of Read Inline Flow Control Gate

4.3.1.1.5 Read CSO Station

The Read CSO station has a flow control which is left fully open during dry and wet weather. An overflow can occur when the level in the station exceeds 9.81 feet and overtops a static weir to enter a gravity discharge. No updates were made at this location. Figure 4-11 depicts the Read Street CSO station in the model.

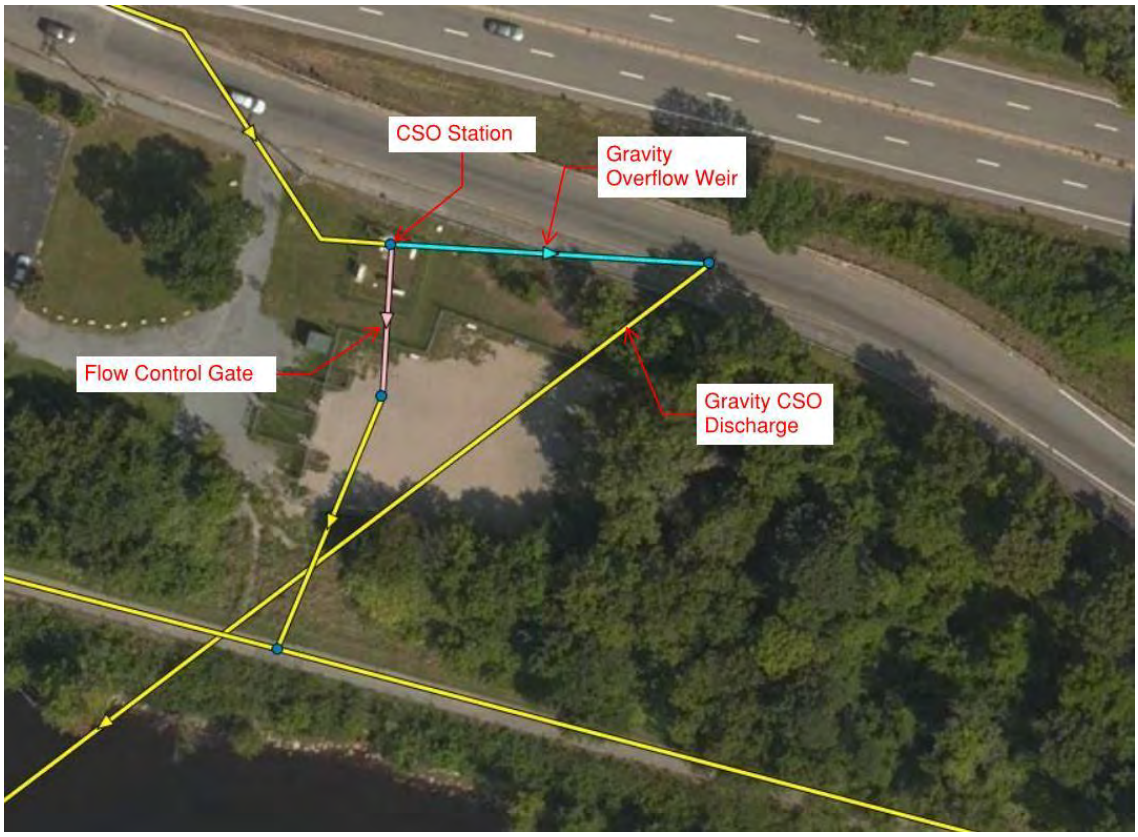


Figure 4-11: Modeled Schematic of Read Street CSO Station

4.3.1.1.6 Tilden CSO Station

The Tilden CSO station may discharge via gravity or pumping. This station regulates flow from a 6-foot and 3-foot pipe to prevent excessive surcharging of the downstream interceptor, which only has a diameter of 3 feet. In the model, a flow control gate is modulated during wet weather to maintain a depth of 2.5 feet at the effluent weir. When the level in the station rises above 5 feet, the gravity discharge gate (modeled as an orifice) is modulated to maintain a depth of 4.5 feet. If the depth in the station rises above 6.5 feet, and the river level is sufficiently high (determined by the head value at a specific node in the model), then the gate to the discharge pump is opened and modulated to maintain a depth of 4.5 feet. A SWMM Type 4 pump is used to represent the discharge pump. Figure 4-12 depicts the Tilden Street CSO station in the model. The pump curve this SWMM Type 4 pump operates on is shown in Figure 4-13.

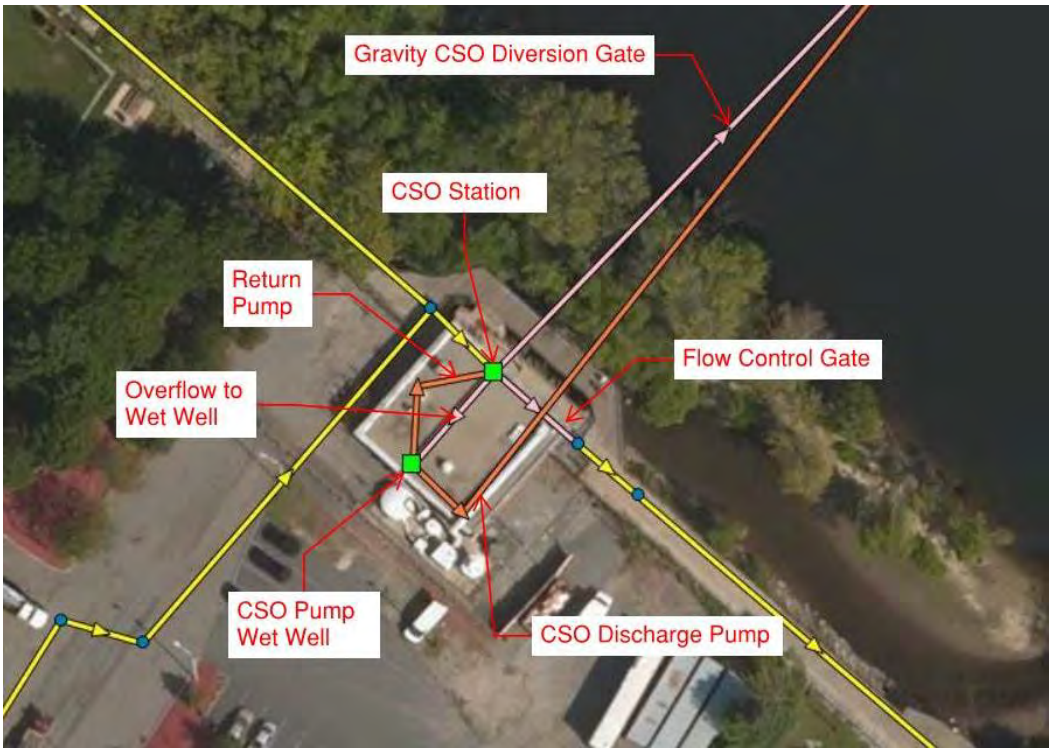


Figure 4-12: Modeled Schematic of Tilden Street CSO Station

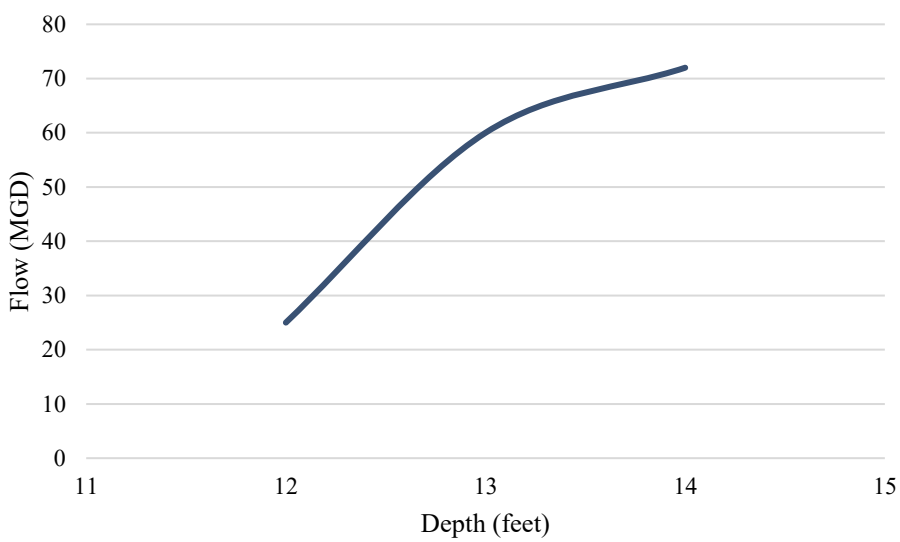


Figure 4-13: Tilden CSO Station Pump Curve

4.3.1.1.7 Warren CSO Station

Warren CSO station may discharge CSOs via gravity to the Concord River or pass under the river through three 2.5-foot siphons towards the Merrimack East interceptor. In the model, the flow control gate is left

fully open during dry weather and is modulated to maintain a depth of 6 feet in the siphon channel during dry weather. The station also includes two gravity diversion gates which are simulated as weirs in the model. When the level in the station rises above 7.5 feet, the weirs are modulated to maintain a depth of 6.5 feet in the model.

Several improvements were made at Warren Station in the model:

1. The invert at Warren Station was incorrect in the previous version of the model. Figure 4-14 shows a profile of a tributary sewer interceptor and Warren Station with previous (incorrect) invert and the updated corrected invert.

2. The previous RTCs reflected an older control strategy at the station where the gravity diversion gates opened when the depth reached 7.0 feet. At present, the gates do not open until the depth reaches 7.5 feet. The RTCs were updated to reflect this operational change.

Figure 4-14: Previous vs. Corrected Invert at Warren CSO Station

During the development of this IP, and after the conclusion of the temporary metering program, a bar rack was removed from the station. This bar rack imposed headloss through the station such that the flow

control gates were rarely used. The effect of removing this bar rack has not yet been quantified, but the existing model utilizes a triple barrel siphon conduit with a high manning's n (roughness) coefficient of 0.04. This results in significant headloss through the siphon and restricts flow through the station. During IP implementation, the impact of the bar rack will be quantified, and this coefficient will be re-evaluated. As part of this effort, CSO discharge measurements will be obtained to update the characterization of CSO performance at this station. Figure 4-15 depicts the Warren Street CSO station in the model.

Figure 4-15: Model Schematic of Warren Street CSO Station

4.3.1.1.8 Barasford Street CSO Station

Barasford CSO station is a small station that is directly tributary to Merrimack Street station. During dry weather a flow control gate remains open at 98%. If the level downstream of the station (towards Merrimack CSO station) rises above 9.4 feet, the flow control gate closes to only 1% open. When the depth in the station rises above 4.5 feet the gravity diversion gate may open. The gravity diversion gate closes when the depth in the station drops back below 3 feet. Figure 4-16 depicts the Barasford CSO station in the model.

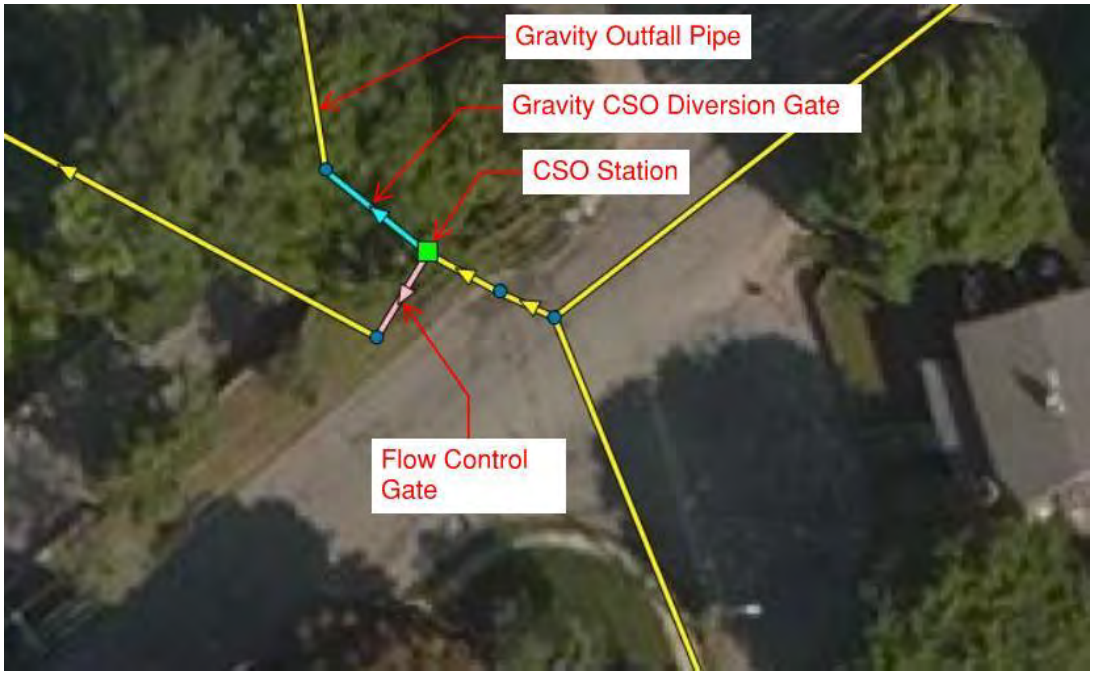


Figure 4-16: Model Schematic of Barasford Street CSO Station

4.3.1.1.9 Merrimack CSO Station

The CSO station at Merrimack Station is a large station that regulates flow from the South Bank interceptor system before it is conveyed through three (2.5', 3', 4' diameter) siphons to the Duck Island WWTF. The station utilizes a flow control gate to restrict flow through the siphons to prevent overwhelming the WWTF with excessive wet weather flow. During dry weather flow, this gate is set to 76% open. During wet weather, the gate is modulated to maintain a depth of 8.2 feet in the station, which allows for some inline storage in the interceptors tributary to the station. In reality, this flow control gate is modulated in conjunction with the Read Inline flow control gate to maintain a set depth in the influent pumping chamber at the WWTF. To replicate this control strategy in the model, a control was developed to allow the gate to modulate to maintain a depth of 8.2 feet during wet weather, when the WWTF flow is below 95 MGD. If WWTF flow rises above 95 MGD, then the behaviors of the flow control gate at Merrimack Station and the Read Inline flow control gate are governed by an RTC which modulates both of these structures together to target 105 MGD at the WWTF. This strategy consistently delivers 105-110 MGD to the WWTF and allows brief spikes to 115 MGD while the gates are moving. City staff has stated that Duck Island can sustain 115 MGD for short periods.

These controls were updated from the previous version of the model, which controlled the Merrimack and West flow control gates together to maintain flow at the WWTF. These previous controls also had different set points and did not reflect how Lowell currently manages its system. In addition, the configuration of the siphons in the model was updated. In the previous version of the model, the three different diameter siphons were represented as one equivalent size siphon. If all siphons were the same size and had the same invert, this would be a reasonable representation. However, the siphons actually have different diameters and inverts. Further, the siphon channels all have different weir elevations such

that the smallest siphon is used first, before excess flow may spill into the larger siphons during wet weather. The model was updated to reflect this configuration as shown in Figure 4-17 .

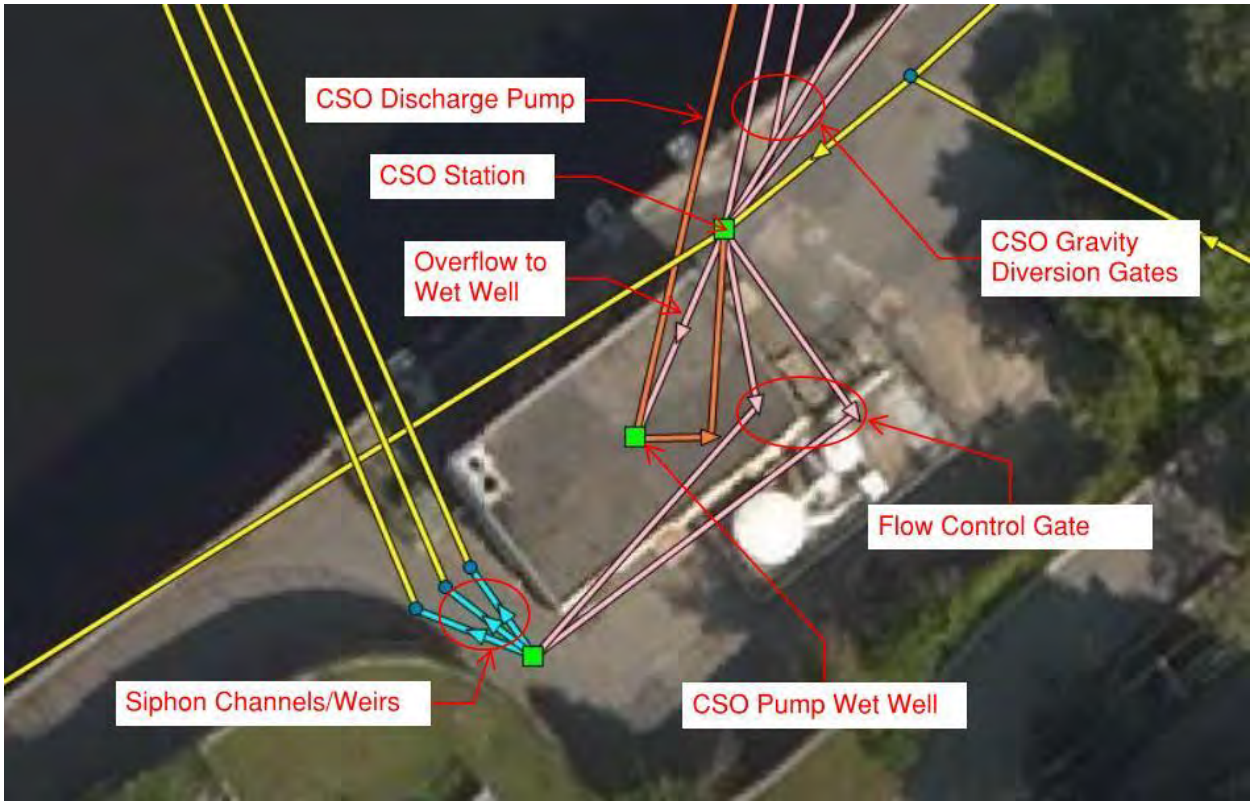


Figure 4-17: Modeled Schematic of Merrimack CSO Station

The model also includes two flow control gates to represent the maximum and minimum opening of the flow control gate that is currently possible. If the level in the station rises to above 9.2 feet, then all four gravity diversion gates open and modulate to maintain a depth of 9.2 feet in the station. Once the level in the station drops to below 8.5 feet the gravity diversion gates close. If the level in the station rises above 7 feet, excess flow may spill into a wet well from which excess flow can be pumped to the Merrimack River. The pump is activated when the depth in the wet well reaches 15.2 feet. The pump curve this SWMM Type 4 pump operates on is shown in Figure 4-18.

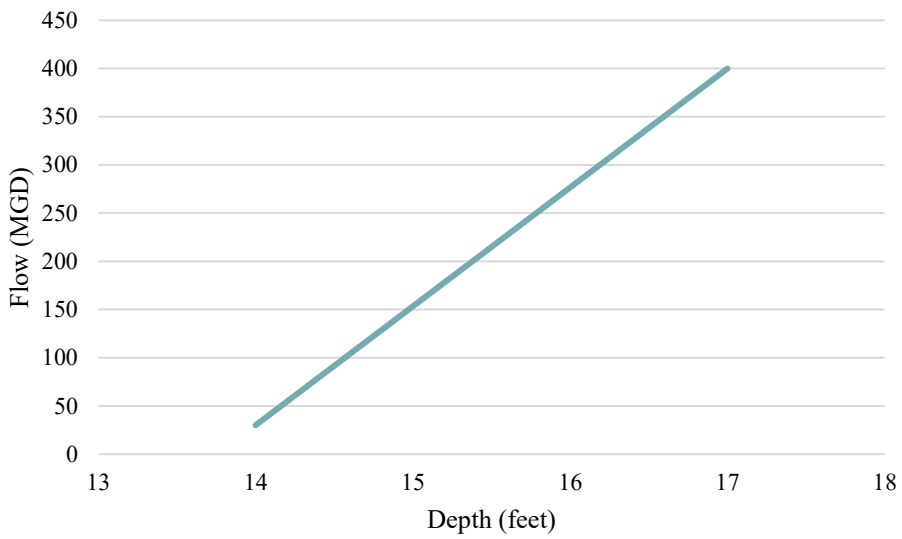


Figure 4-18: Merrimack CSO Station Pump Curve

4.3.2 Confirmation of Modeled Diversion Station Operation

Lowell and its consultant met several times during the process of updating and recalibrating the model. The purpose of these meetings was to analyze the model's RTCs and verify that they were reasonably configured to represent the control strategies utilized by Lowell's SCADA system (and other PLCs). Several of the updates described above were made through consultation between Lowell and its consultant. Throughout this process, charts were produced depicting the model predicted operation of various CSO stations, such as those shown in Figure 4-19, which depicts the operation of Merrimack Street CSO station during an intense wet weather event.

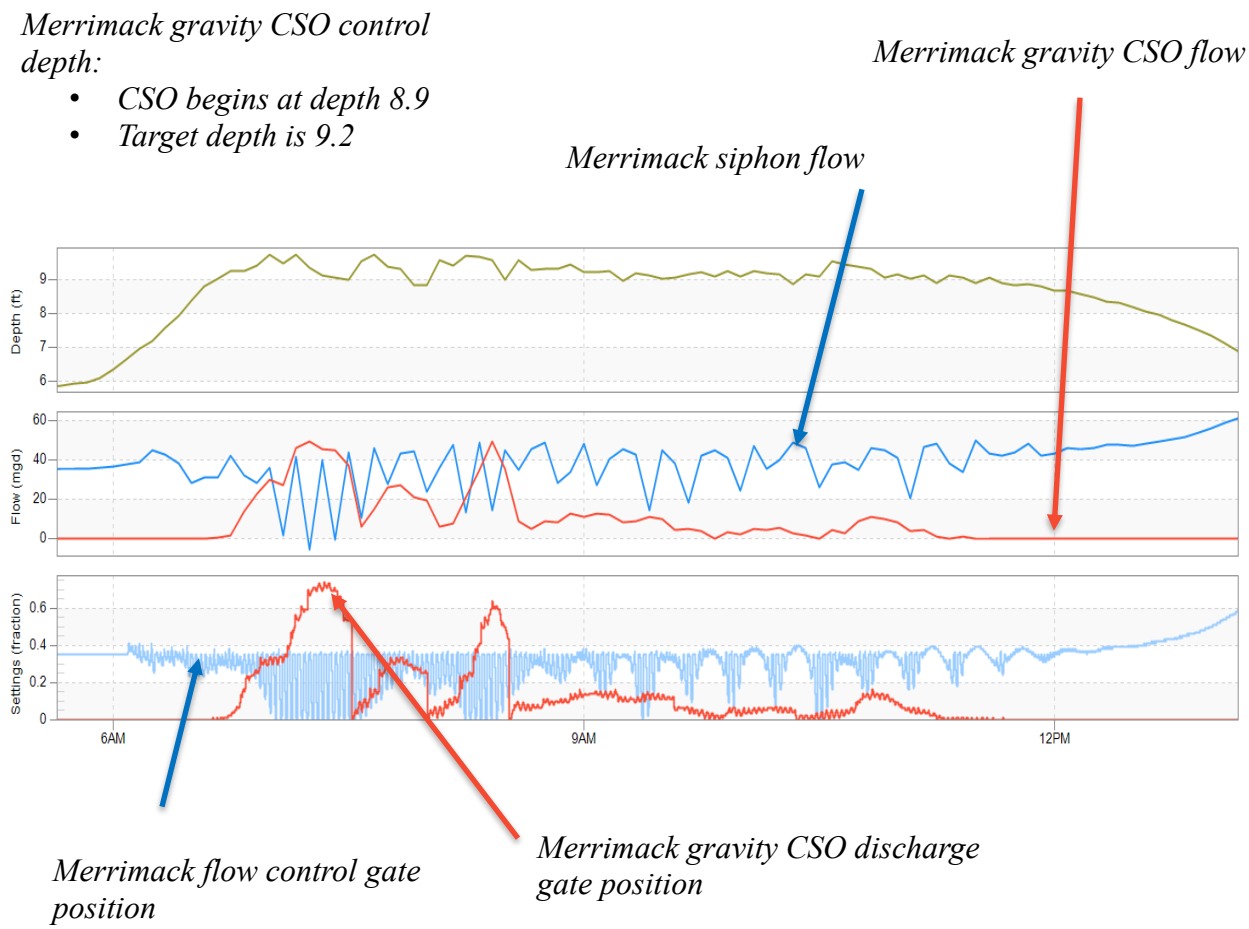


Figure 4-19: Modeled Operation of Merrimack CSO Station During Wet Weather

By examining the operation of complicated and crucial CSO stations, and structures like the Read Inline flow control gate, Lowell and its consultant were able to significantly improve the accuracy of the model's representation of Lowell's actual flow and gate control strategies. Lowell also regularly produces similar charts depicting the operation of its assets during wet weather. These charts are analyzed by City staff at bi-weekly HFM meetings to identify opportunities for improved wet weather operations. By comparing model predicted gate operation to actual gate operation (as shown in HFM charts, such as the example from Merrimack Street shown in Figure 4-18), Lowell and its consultant were able to further validate the modeled operation of crucial CSO stations. Although this collaborative process is not a typical part of model recalibration, it has resulted in a more robust model that is capable of accurately representing existing conditions that is also a useful tool for analyzing future changes.

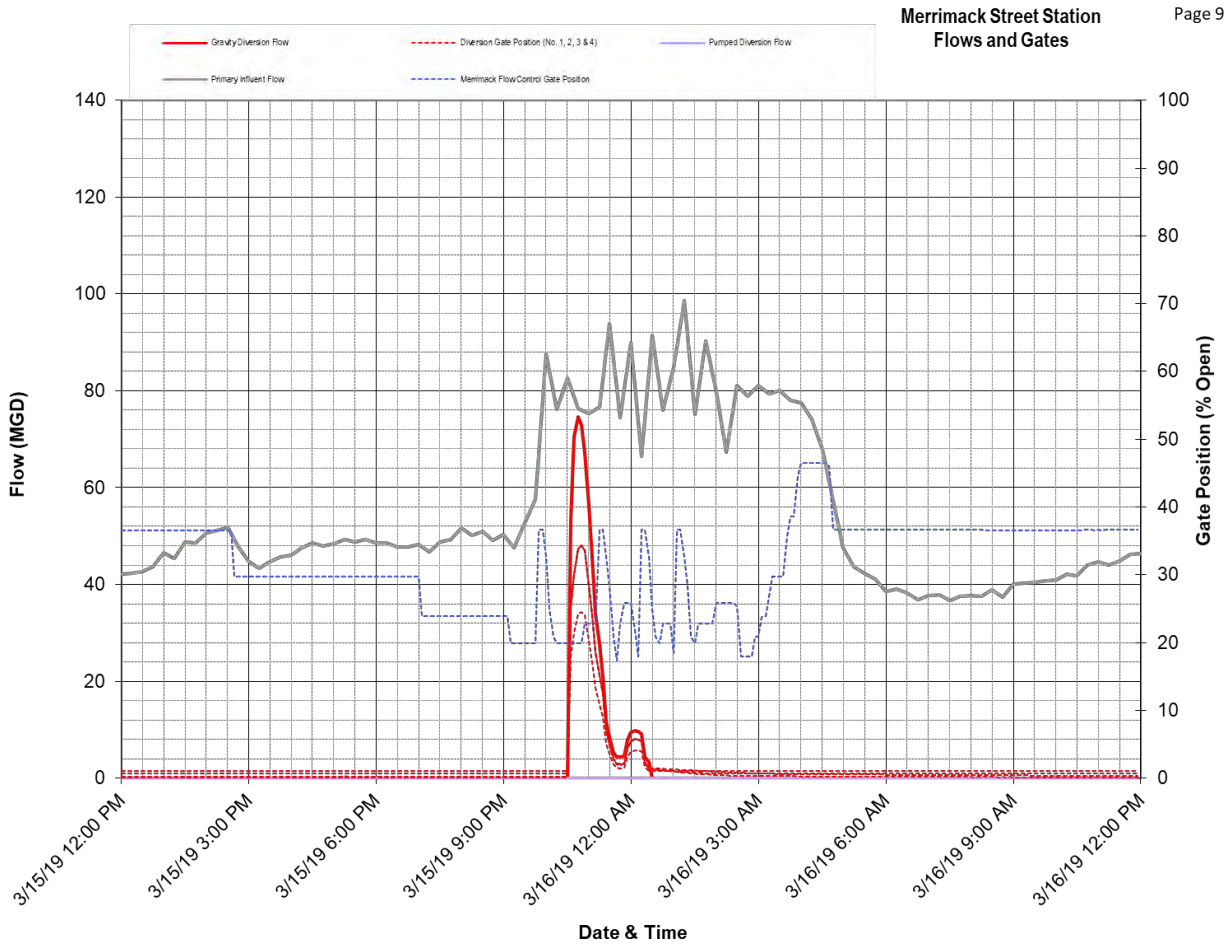


Figure 4-20: City of Lowell HFM Chart at Merrimack CSO Station During a Storm Event

*note that this is a different storm event than the one depicted in Figure 4-19 above

As changes are implemented in Lowell's sewer system and new CSO control projects are constructed, the model should be revalidated, and recalibrated if necessary, to ensure that its predictive capabilities remain sufficiently robust to support further implementation of the IP. Lowell's adaptive management strategy requires that this model be maintained as a useful predictive tool to support the final design of the CSO control projects identified in this IP.

4.4 Model Recalibration

In order to ensure that the model can accurately simulate storm events, the model was adjusted so that it produces results that closely matches the conditions observed during the monitoring period. This process is called model calibration, which is the process of adjusting data describing the mathematical model of the system until model-predictions are in reasonable agreement with observed data over a wide range of environmental conditions. Validation of the calibrated model is then performed by comparing model results to a different set of observations without making adjustment.

The processes of calibration and validation were completed by quantitative analyses of model predictions and comparison to observed measurements for selected storms that occurred during the flow monitoring period. This includes comparisons of volumes, peak flows and depths. Additionally, visual examination of plots of model results compared to observed data for the entire flow monitoring period was also conducted to evaluate hydrograph shape and timing. This process ensured that the model was robust and could be used to simulate CSO control alternatives.

4.4.1 Calibration Methodology

Based on generally accepted practice, model accuracy and robustness are achieved by setting the model calibration parameters (within an acceptable range) such that the model's predicted response matches that of an observed or measured response (e.g., monitored field conditions). The following paragraphs summarize the model calibration criteria as described in the industry standard guideline document, "Wastewater Planning Users Group (WaPUG) Code of Practice for the Hydraulic Modelling of Wastewater Systems, November 2002."

Generally, the comparison of predicted and observed responses were quantified in a statistical framework and visually through observed versus model-predicted plots for each location in the model (i.e., meter locations) where the respective data is compared.

<u>Dry Weather Flow Calibration</u>

- Modeled peak flows should be within 10 percent of the observed peak flows
- Modeled 24-hour volumes should be within 10 percent of the observed volumes

<u>Wet Weather Flow Calibration</u>

- Modeled peak flows should be within +25 percent and -15 percent of the observed peak flows
- Modeled storm event volumes should be within +20 percent and -10 percent of the observed volumes
- Modeled depths of flow in surcharged sewers should be within +1.6 feet and -0.33 feet

<u>General</u>

- Matching as closely as possible the ratio of the time to peak for the modeled and observed events indicating that the shapes of the modeled and observed hydrographs are similar

4.4.2 Dry Weather Calibration

To achieve dry weather calibration, the diurnal pattern and average daily sanitary flow at each meter location was adjusted according to the criteria described above. The model was calibrated to accurately simulate dry weather conditions for the periods during which each meter was installed. It is important to note that some meters were not installed for the entire monitoring period, so not all meters were calibrated to the same dry weather periods. The model was also calibrated to billing meter data that was collected by

Lowell Water at four locations. Figure 4-21 is a chart showing dry weather volumetric model calibration. Figure 4-22 is a chart showing peak flow dry weather model calibration. Note that each point represents an individual meter location, and the purple lines represent the calibration criteria described above.

The model is generally calibrated well to dry weather conditions observed during the monitoring period. In some cases, the model slightly under predicts peak dry weather flow. Although it is possible to adjust parameters within the model to better match peak values in some cases, appropriate engineering judgment must be exercised to ensure model parameters are within reasonable limits and that the model accurately predicts volume at each meter location. In some cases, unknown conditions within the pipe (such as sediment depth) may lead to inflated peak depth and flow measurements. Since these conditions typically are not precisely measured and tend to vary over time, they are not reflected in the model. As such, it is reasonable to conclude that the model's dry weather calibration achieves an appropriate balance between matching the metered data and ensuring model parameters remain within reasonable limits.

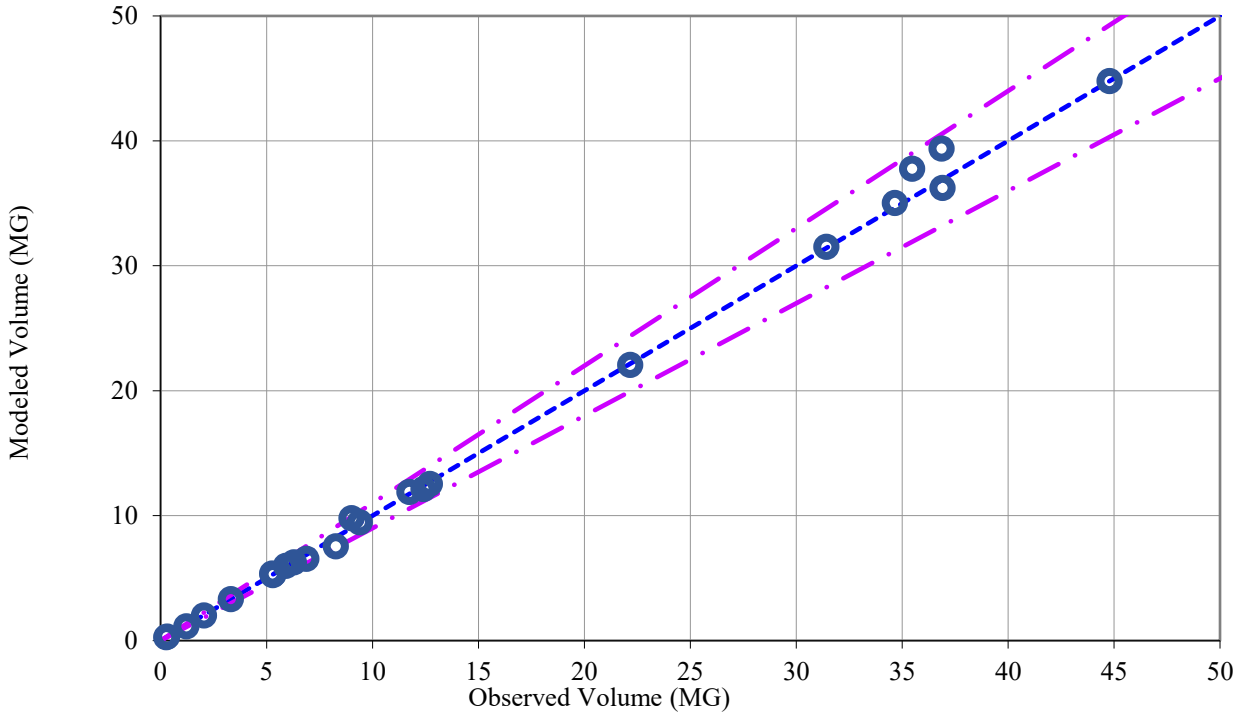


Figure 4-21: Volumetric Dry Weather Model Calibration

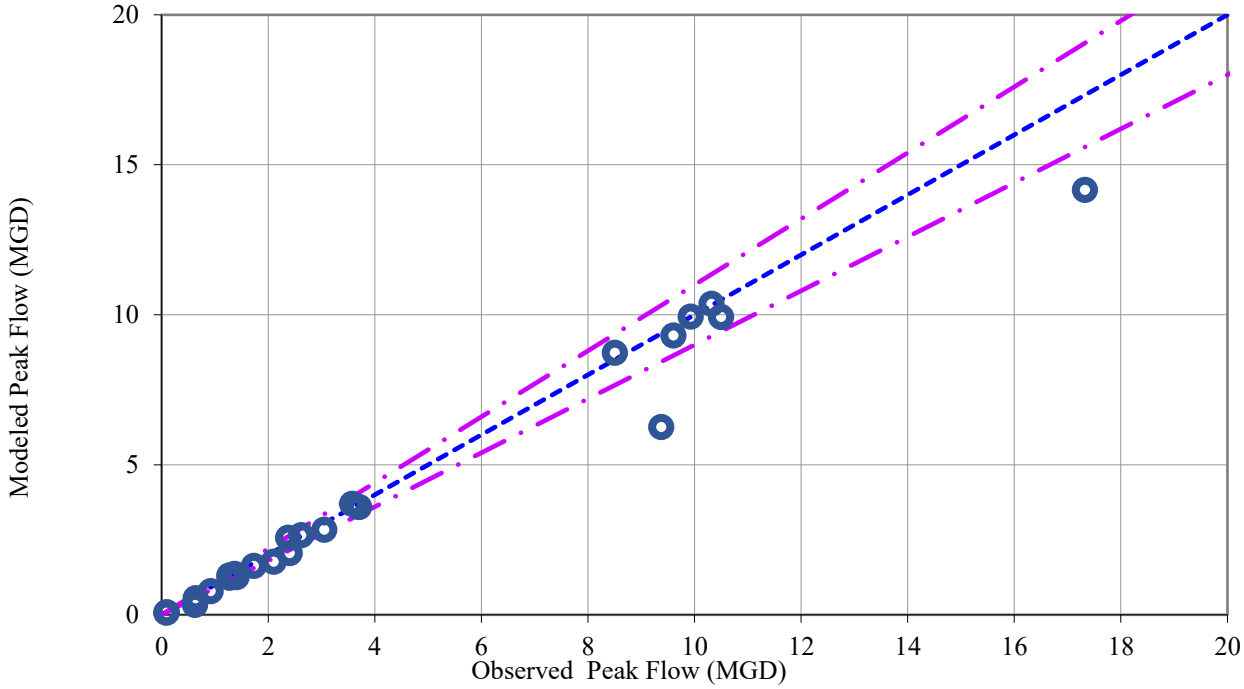


Figure 4-22: Peak Flow Dry Weather Model Calibration

4.4.3 Wet Weather Calibration and Validation

To achieve wet weather calibration, a series of storms were selected to calibrate the model against at each meter location. The storms which were selected for calibration are shown in Table 4-5 below. Note that the storms described using red text were used for validation, and those shown in black text were used for model calibration. The storm characteristics described within this table are based on data collected at the Warren rain gauge. Data from all rain gauges was used to create different representative rain profiles for all subcatchments in the model to ensure the most spatially accurate representation of rainfall as possible.

Table 4-5: Calibration and Validation Storm Events (Warren Rain Gauge)

Storm Event	Rain Start	Rain End	Duration (Hour)	Peak Intensity (Inch/5 min)	Total Depth (Inch)
1	5/15/2018 16:15	5/15/2018 19:30	3.3	0.16	0.60
2	5/19/2018 13:55	5/20/2018 15:45	25.8	0.05	0.38
3	5/27/2018 0:30	5/27/2018 2:15	1.7	0.07	0.18
4	6/4/2018 9:00	6/4/2018 13:30	4.5	0.04	0.30
5	6/5/2018 13:45	6/5/2018 14:10	0.4	0.10	0.15
6	6/18/2018 18:15	6/18/2018 21:00	2.7	0.15	0.56
7	6/21/2018 14:20	6/21/2018 14:35	0.2	0.01	0.04
8	6/23/2018 11:25	6/23/2018 11:35	0.2	0.02	0.04
9	6/24/2018 16:10	6/25/2018 4:15	12.1	0.20	0.91
10	6/27/2018 22:45	6/28/2018 17:55	19.2	0.09	1.22
11	7/3/2018 15:50	7/3/2018 17:20	1.5	0.20	0.35
12	7/6/2018 11:15	7/6/2018 12:00	0.8	0.05	0.10
13	7/14/2018 21:45	7/14/2018 22:55	1.2	0.03	0.10
14	7/17/2018 12:45	7/17/2018 22:25	9.7	0.31	1.66
15	7/22/2018 7:25	7/22/2018 13:00	5.6	0.03	0.25
16	7/22/2018 20:45	7/23/2018 10:30	13.7	0.05	0.26
17	7/23/2018 9:45	7/23/2018 9:55	0.2	0.05	0.07
18	7/26/2018 2:15	7/26/2018 7:00	4.7	0.10	0.72
19	7/26/2018 14:45	7/26/2018 15:30	0.8	0.51	0.65
20	7/28/2018 22:30	7/28/2018 22:45	0.2	0.02	0.02
21	8/2/2018 18:40	8/2/2018 20:15	1.6	0.18	0.52
22	8/3/2018 20:00	8/3/2018 20:15	0.2	0.03	0.03
23	8/4/2018 10:15	8/4/2018 12:00	1.7	0.09	0.35
24	8/7/2018 19:45	8/7/2018 20:15	0.5	0.10	0.14
25	8/8/2018 19:45	8/8/2018 20:00	0.3	0.01	0.02
26	8/9/2018 2:45	8/9/2018 17:10	14.4	0.18	0.31
27	8/11/2018 12:45	8/12/2018 12:20	23.6	0.28	2.56
28	8/12/2018 5:20	8/13/2018 2:25	21.1	0.14	0.45
29	8/13/2018 21:30	8/13/2018 23:00	1.5	0.03	0.12
30	8/14/2018 13:45	8/14/2018 19:20	5.6	0.40	1.07
31	8/17/2018 16:00	8/18/2018 3:10	11.2	0.49	1.40

It is important to note that some meters were relocated, added, or removed throughout the monitoring period. As such, not all events in Table 4-5 were applicable for each meter location.

The model uses hydrologic units called subcatchments to distribute and load wet weather flow into the sewer system. The wet weather behavior of each subcatchment is governed by a series of parameters that define its characteristics. By adjusting these parameters, it is possible to calibrate wet weather behavior by controlling how responsive (time to peak flow) each subcatchment is to wet weather and adjust what percentage of rainfall becomes flow that enters the sewer system. Some of the parameters which were adjusted to achieve calibration include subcatchment area, width, imperviousness, and flow length.

In general, satisfactory calibration was achieved at most meter locations in the model. In some cases, the model underpredicted peak flow and volume at several locations in the South Bank interceptor for some storm events. Although it might be possible to adjust some of these parameters to achieve better calibration, engineering judgement must be exercised when calibrating the model. Parameters should remain within boundaries that are reasonably descriptive of physical conditions. In reality, it is likely that the model under predicts peak flow and volume at some South Bank locations due to the spatial variability of rainfall. Significant variability was observed between rain gauges, and when data from the gauge that recorded the most intense rainfall were applied to subcatchments on the South Bank (as a sensitivity test), model calibration was improved.

Calibration plots for each meter location can be found in Appendix D.

4.5 2018 Annual CSO discharges (modeled vs. calculated)

After the model was calibrated and validated, the model was used to simulate the calendar year of 2018, with rainfall data collected by Lowell from its rain gauges. The purpose of this simulation was to compare model predicted overflow volumes at each CSO station with City calculated (estimated) volumes. Lowell uses mathematical equations to estimate CSO discharges at each CSO station based on the SCADA recorded level and diversion gate position. As such, these estimates generally represent overflow volumes at each location, but are not precise measurements and cannot be used directly for model calibration.

In 2019 Lowell removed a restrictive bar screen at Warren Street CSO station. Prior to removal of the bar rack, the flow control gate at Warren Street CSO station was almost never used to restrict flow through the siphons because the bar screen created sufficient headloss to limit flow. The impact of the bar rack removal has not yet been quantified, although it is probable the increased conveyance through the siphon will reduce CSO volumes at Warren Street, possibly such that overflow volumes more closely resemble the original calculation. As part of the adaptive management strategy that is a central element of this IP, flow and level monitoring will be undertaken at Warren Street (and other CSO stations) to precisely quantify CSO discharges and validate the benefit of improvements.

Figure 4-23 depicts model predicted CSO volumes vs. the reported (estimated) values for 2018.

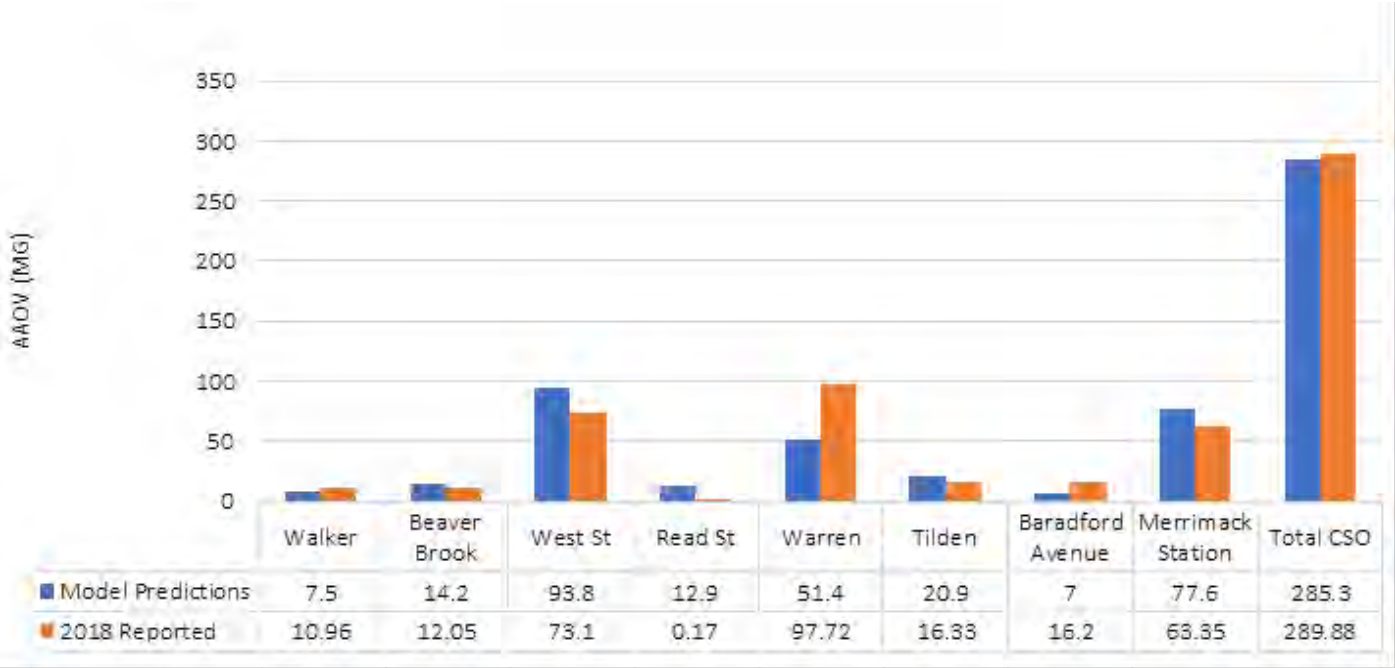


Figure 4-23: Model Predicted vs. Reported CSO Volumes (2018)

As shown in Figure 4-23, model predicted overflow volumes generally closely correspond with Lowell reported values. As previously discussed, further efforts during IP implementation will be undertaken to more accurately characterize CSO discharge estimates at all CSO stations.

Based on the comparison between predicted and reported overflow volumes, and the fact that the model has been properly calibrated according to industry standard criteria, it can be concluded the model is an effective tool for characterizing the effectiveness of different CSO control alternatives.

5. CSO Control Alternatives Analysis

This section describes available CSO abatement technologies and assesses their applicability to achieve Lowell's CSO control objectives. Many alternative strategies are available to control pollutants discharged from CSOs ranging from O&M improvements to complete separation of the combined sewer system into separate sanitary and stormwater systems. This assessment analyzes technologies presented in the EPA CSO Guidance for Long-Term Control Plans for the purpose of selecting appropriate technologies for further evaluation and comparison later in this document.

5.1 Nine Minimum Controls and Best Management Practices

In 1998, the City of Lowell submitted a report on Nine Minimum Control (NMC) measures to the EPA. These NMC measures form the foundation of Lowell's CSO control strategy and are summarized in Table 5-1. Although the focus of this document is primarily an analysis of additional CSO control measures, Table 5-1 also indicates where additional and updated CSO control measures would result in an update to an existing minimum control.

Table 5-1: NMC Measures

Minimum Control	Status
Prohibit CSO Discharges During Dry Weather	CSO discharges do not occur during dry weather. No updates or changes are recommended to current operations and maintenance practices.
Control of Solids and Floatable Materials	Lowell currently implements a regular street sweeping program. Lowell also performs catch basin cleaning and sewer system cleaning as part of its CCTV inspection program. Catch basin modifications have also been performed to reduce floatables in the receiving water. Lowell will continue to evaluate opportunities for solids and floatables control at CSO stations (e.g., screening).
Pollution Prevention Programs	In addition to catch basin cleaning, street sweeping, and other measures, Lowell is developing a public information website that will include information about CSOs and how they can be prevented. Litter and hazardous dumping ordinances have been implemented. Lowell continues to implement initiatives to increase public awareness and education, in concert with its Stormwater Program.
Public Notification	Lowell has implemented a program to notify downstream river users and stakeholders when CSO discharges are occurring. Lowell continues to update this notification program according to DEP and EPA guidance and regulations.
Monitoring to Characterize CSO Impacts and Efficacy of CSO Controls	Lowell has developed empirical methods for estimating CSO discharges at each station. Lowell is in the process of developing a monitoring program to validate CSO measurement procedures for each station. In addition, Lowell has implemented a comprehensive program to monitor and assess water quality in the Merrimack River. The *Clean Stream Initiative* includes the collection of hundreds of grab samples during dry and wet weather conditions, continuous monitoring, and data analysis according to a QAPP developed in collaboration with MassDEP. The data collected as part of the Clean Stream Initiative will allow for accurate characterization of water quality and the impact of CSO discharges using a calibrated dynamic hydrologic and hydraulic model.
Proper Operation and Maintenance Programs	Lowell implements and continuously updates a comprehensive O&M program. As an example, Lowell Water staff meet regularly (bi-weekly) to discuss high flow management operating procedures and analyze operations during previous wet weather and CSO events. These meetings provide for continuous collaboration between collections and treatment staff and result in the identification and implementation of improvements to collection and treatment plant operating protocols. Lowell will continue its current practice of proactively improving and updating its operations and maintenance activities.
Maximum Use of Collection System for Storage	Since the initial NMC report, Lowell has developed operating procedures and strategies to aggressively maximize in-line system storage. The SCADA system and remote level monitoring are used to achieve real time control of flow control gates and maximize in-line storage upstream of CSO stations. Through modulation of these flow control gates, Lowell is able to fully utilize existing system capacity and maintain the depth of flow to within 1 foot of the crown in large interceptors. Lowell also utilizes level monitoring equipment to determine if other trunk lines further upstream in the collection system can be used for in-line storage. Maximizing the use of existing capacity in the collection system has been an effective CSO control strategy. Lowell Water will continue to update this practice as the foundation of the forthcoming LTCP update, as detailed further in this analysis.

Review and Modification of Industrial Pretreatment Program	Lowell currently has the ability to control metals and other pollutants originating from industrial processes. No updates to this program are recommended.
Maximizing Flow to the Treatment Plant	Lowell Water staff meet regularly to determine strategies for high flow management and maximizing peak wet weather flow to the treatment plant. This strategy has been effective and an integral element of Lowell's efforts to reduce CSO discharges. In addition, capital projects that will alleviate conveyance bottlenecks and deliver more wet weather flow to the treatment facility are analyzed in further detail in this analysis and will be a primary focus of the LTCP update.

5.2 Available CSO Control Technologies

Lowell currently follows a comprehensive program of operations and maintenance activities designed to minimize receiving water impacts from CSOs. This includes implementation of the NMCs described above, sewer inspection and sewer cleaning, sewer system rehabilitation, and progressive CSO station maintenance.

CSO abatement technologies were divided into Operations and Maintenance Projects versus Capital Projects, and then further broken down into five general categories:

1. Best Management Practices (BMPs)
2. Collection System Controls
3. Green Infrastructure (GI)
4. Storage Technologies
5. Treatment Technologies.

Although BMPs were already discussed and incorporated into the Nine Minimum Control Measures Report (April 1998), these control measures are necessary for effective collection system operations and maximization of wet weather flow to the WWTF. Considering their impact on the control of CSO discharges, an overview of these controls is presented herein as part of the Integrated Plan evaluation process. Some of the BMPs are watershed/drainage basin type controls that are complemented by general public housekeeping efforts (i.e., litter control, hazardous waste collection, illegal dumping ordinances, etc.). Accordingly, a public information program regarding CSOs and the Long-Term Control Plan in Lowell is beneficial to the successful implementation of BMPs. Draft educational materials to inform the public about CSOs, receiving water impacts, and public involvement were included in the NMC report. BMPs also include lower cost upgrades to facilities or adjustments to operations and maintenance to improve collection system performance and maximize system capture of wet weather flow. These controls also include improvements to reduce infiltration and inflow.

Collection system controls including construction of parallel sewers, upgrades and/or modifications to regulators, or additional control structures can help to eliminate bottlenecks and maximize available

storage capacity within the existing sewer system. Relocation of CSO outfalls to less sensitive waterways or diversion of peak flows to adjacent sewersheds to improve CSO capture can also be performed. Sewer separation to remove stormwater inflow from the sewer system is also an effective control measure.

Green Infrastructure (GI) practices focus on diversion of stormwater from the collection system to facilities intended for retention, detention or infiltration of rainfall runoff into the ground. The diversion of runoff can reduce peak flow conditions in the sewer system during wet weather resulting in a reduction of CSO activations and overflow volume. Additionally, GI provides public benefit and education by increasing visibility of stormwater control measures.

Storage of wet weather flow is a common technology used for control of CSO discharges. Peak wet weather flow in excess of the system's capacity can be captured for pump back to the collection system for treatment at the WWTF following a storm event. Storage facilities can be provided for capture of CSO by utilizing inline storage capacity within the existing sewer system or offline in tanks, shafts or tunnels. Surface storage using GI can also be used to capture stormwater before it enters the collection system.

Treatment technologies can be installed remotely at CSO outfalls, regionalized or provided to enhance existing WWTF wet weather treatment capacity. In accordance with USEPA CSO Policy, CSO treatment must be equivalent to primary clarification and disinfection. While a wide range of treatment technologies are available for CSO control, the selection of the technology will be driven by the characterization of CSO discharges and the level of treatment necessary to achieve water quality standards in the receiving waters.

Each CSO control technology is described below and evaluated in general terms of effectiveness and feasibility in Lowell. Technologies that are infeasible for implementation in Lowell, or that offer no benefit to the CSO mitigation program were eliminated from further consideration. The remaining technologies are identified as NMC/BMP type controls or CSO LTCP alternatives in the narrative. Technologies identified as NMC measures may have already been addressed in the NMC report. Technologies that should be considered for Lowell's long term CSO mitigation program are evaluated further in later sections of this report.

Table 5-2 lists the CSO abatement technologies considered for this report and identifies the results of the technology evaluation/screening. The technologies have been evaluated and have been grouped accordingly:

- Technology Not Widely Applicable or Appropriate - These technologies will not work effectively in Lowell or will not reduce the water quality impacts associated with CSOs.
- Continue Current Practice - These technologies are typical best management practices and were, for the most part, addressed in the NMC Report. These technologies will help to optimize system operations and minimize CSO discharges and impacts to the receiving water bodies.
- Update/Initiate Practices - These technologies should be considered by Lowell to improve existing operations and minimize CSOs.

- LTCP Technology - These technologies are feasible control measures that will reduce and/or eliminate Lowell's CSO discharges and impacts.

5.2.1 Description and Analysis

5.2.1.1 Best Management Practices (BMPs)

BMPs help to reduce pollutant concentrations at sources in the tributary basins and improve stormwater runoff quality before it enters the combined sewer system. Most of these measures capture or control pollutants at their source before the pollutant is transported by rainfall runoff and introduced to the collection system. The advantage of many of these technologies is that they can also have beneficial environmental effects in separated stormwater collection areas. BMPs also include operation and maintenance practices including procedures for managing the collection system and remote monitoring and controls. Maintenance practices include catch basin and sewer cleaning, as well as repairs to regulators, backwater gates, pump stations and other collection infrastructure to effectively convey wastewater flows to the WWTF and to control rainfall derived infiltration and inflow.

5.2.1.1.1 Air Pollution Reduction

Particulate matter in the atmosphere ultimately settles and becomes a source of stormwater runoff contamination. The particles consist of both natural sources (fugitive dust from soils and pollen) and manmade processes (grinding and pulverizing processes, combustion, construction dust, etc.). This source of pollution is not significant compared to other sources and therefore does not warrant further evaluation.

5.2.1.1.2 Solid Waste Management

Improper disposal of litter, including leaves, grass clippings, waste paper, wrappings, cigarettes, metal, glass, and paper containers on city streets, in parks and along vacant properties often results in these items entering the collection system and potentially being discharged to the receiving water. The floatable nature of these items can cause visible pollution.

This technology was discussed in the NMC report and the Notice of Intent for the MS4 Stormwater General Permit. Lowell has ordinances in place to control litter and manage solid waste. In addition, Lowell implements an educational program marking catch basins with signage to inform the public that the catch basin leads to a surface water. The signage is intended to minimize litter in the street and/or inadvertent disposal of waste in catch basins. Generally, in urban areas, it is not expected that further enhancements to existing solid waste management programs will completely control floatables. Accordingly, recommendations to update current procedures and policies are not warranted in Lowell.

5.2.1.1.3 Fats, Oil, and Grease (FOG) Control Programs

Fats, oil, and grease (FOG) are often improperly disposed of by pouring these items down the sink. FOG builds up in sewers over time and often causes blockages or reduction in the capacity of the pipe to convey flow. EPA's August 2004 "Report to Congress on Impacts and Control of CSOs and SSOs",

reports that 47 percent of sewer blockages can be attributed to grease buildup. These blockages account for nearly half of all SSOs. The best way to prevent these blockages is to keep FOG from entering the sewer system.

Lowell's FOG program is administered by the Board of Health. Restaurants are required to have and regularly maintain grease traps to remove the FOG. Grease traps slow the flow of wastewater and allow FOG to cool and float to the top, where it can be removed at the source, so it does not get conveyed to the sewer system.

While FOG control is prudent practice, and there are continual efforts to update and improve the current program, it will not be considered for further evaluation as a CSO control measure.

5.2.1.1.4 Street Sweeping

Street sweeping is a common practice in urban areas to improve the aesthetic environment by removing litter and debris that collects along street gutters. This practice can also improve the water quality of surface runoff by reducing the quantity of solids and floatables entering the combined sewer system.

5.2.1.1.5 Fertilizer/Pesticide Control

The use of fertilizers and pesticides can increase the pollutant levels, primarily nutrients, in stormwater runoff. While controlling municipal chemical application and storage practices can help reduce this pollutant loading, effective control of private use is difficult. Through its NPDES Stormwater program, Lowell implements a public education program aimed at curtailing private fertilizer/pesticide use. Modifications to current fertilizer/pesticide control practices will not be considered for further study as an LTCP technology.

5.2.1.1.6 Snow Removal and Deicing Practices

Salting roadways during the winter to reduce icing can increase surface runoff pollutant loads, particularly chloride concentrations. Improper storage of salt can also contribute to high chloride concentrations, especially if the salt is not covered or protected from rain. Generally, salt is mixed with sand to reduce skidding on roadways. The sand can accumulate in catch basins and eventually enter the combined sewer system contributing to the solids loading in CSO discharges.

Lowell uses a synthetic salt mixture, which minimizes the use of salt and uses no sand for deicing roads. Modifications to current deicing practices will not be considered for further study as an LTCP technology.

5.2.1.1.7 Soil Erosion Control

Construction sites contribute to sediment in surface runoff. Lowell currently enforces standards established by the state for construction site drainage permits under the Massachusetts stormwater management policy and Lowell's NPDES Stormwater General Permit. Continued enforcement of these guidelines can maintain reduced suspended solids loadings to the receiving waters. Although soil erosion

is not a significant source of CSO related pollution in Lowell, erosion and sediment control practices should continue to be enforced at all construction sites. Additional controls and/or modification to current practices will not be considered for the development of the LTCP.

5.2.1.1.8 Commercial/Industrial Runoff Control

Pollutant levels in wastewater and stormwater can be reduced through the control of runoff from commercial and industrial establishments in the drainage area. Of particular concern are gas stations and other petrochemical establishments. Oil traps or permanent oil collection systems can be used to reduce the quantity of pollutants entering the system. Illegal dumping policies are enforced regularly by Lowell agencies such as the Highway, Police, Parks, Health, and Fire Departments. Modification of current practices or the incorporation of additional controls will not be considered for the development of the LTCP.

5.2.1.1.9 Animal Waste Removal

Animal excrement is a source of stormwater pollution, especially nitrogen and pathogenic organisms (E. Coli is an indicator). Proper disposal of the animal waste could help reduce the bacteria and nutrient concentrations in CSO discharges by eliminating one source of pollutants. It is expected that Lowell's current solid waste disposal, littering ordinances, and street sweeping programs are adequate to address this potential problem. In addition, Lowell has a public education program about pet waste as part of its NPDES Stormwater program. Because the impact of this pollution source is limited, and future regulations could address this problem if it becomes significant, this technology will not be considered further for CSO abatement.

5.2.1.1.10 Catch Basin Modifications

Modifications to existing catch basins can be made to reduce peak stormwater inflows to the combined sewer system. Catch basins within a drainage area can be retrofitted with devices, such as vortex valves, that will delay surface water runoff entering the sewer system. These devices, however, can cause the catch basin and adjacent street area to flood. During winter months, street flooding can result in ice patches with further complications associated with accumulation of snow. Accordingly, the selection of the appropriate size vortex valve is important to limit the extent of street flooding.

Similar to the use of vortex valves, catch basins can also be modified with devices, such as hoods or baffles that help to capture floatables within the catch basin until the sump is cleaned. These devices can effectively remove floatables and coarse solids that may enter the combined system and be discharged to the receiving water. Lowell installed hoods in the new catch basins constructed under the sewer separation program. However, since installing these catch basin modifications will not eliminate or significantly reduce the need for downstream CSO controls, this technology will not be considered further as an LTCP alternative.

5.2.1.1.11 Catch Basin Cleaning

Catch basins collect and convey surface runoff to the sewer or drainage system. The basins are designed with a sump below the outlet pipe to capture sand, grit, and solids. Catch basins require periodic cleaning to remove the solids and floatables captured in the sump. These structures can be cleaned using a bucket or vacuum. Properly maintained catch basins can help to reduce the quantity of solids that enter the combined sewer system.

Lowell engages an outside contractor to perform catch basin cleaning throughout Lowell. This practice will be continued but will not be considered further for control of CSOs in the LTCP.

5.2.1.1.12 Sewer Cleaning/Flushing

Deposition of solids is a common problem in combined sewer systems. These systems are designed to handle peak wet weather flow; therefore, their hydraulic capacity greatly exceeds typical dry weather flow rates. Consequently, dry weather flow velocities are usually much lower than the design (full pipe) velocity and may cause solids to settle in the pipelines during periods of low flow. During large storms, these solids are re-suspended resulting in high pollutant concentrations during the initial period of a storm.

To avoid this “first flush" phenomenon (the re-suspension of settled solids due to storm flow), sewers may be cleaned by either mechanical means (rodding or draglines) or by flushing. Either technique will flush the solids through the system during dry weather, when system capacity is available to convey flow to the WWTF. This will reduce solids discharged from CSOs to receiving waters during storm events. In severe cases of solids deposition, storm flows may not re-suspend the settled materials causing solids to accumulate and decrease the hydraulic capacity of the pipe.

Sewer cleaning is a regular utility program as part of the NMC and CMOM. Past inspections of the interceptor system indicated minimal sediment deposition problems. Lowell performs sewer cleaning, concurrently with CCTV inspection, to minimize the effects of deposition in problem sewers and within the interceptor system where problems are encountered. Accordingly, it is recommended that Lowell continue with its current practices and cleaning intervals.

5.2.1.1.13 Existing System Management

System management techniques can improve receiving water quality by reducing CSO discharge volumes and capturing first flush pollutant loads. Regular maintenance of CSO regulators and the collection system is essential to maximizing flow to the WWTF and minimizing the frequency of CSO discharges.

Lowell’s system management procedures are incorporated into its NMC and CMOM programs. Lowell regularly inspects its CSO diversion stations and collection system. A comprehensive set of depth monitors has been installed throughout the collection system to help identify obstructions and monitor in-line storage. Based on the results of the collections system modeling and field sampling programs, the first flush is typically captured and treated at the WWTF. Accordingly, the current program identifies and expeditiously addresses problem areas in the system as they arise. Lowell continually assesses its day-to-day operations and makes appropriate adjustments and updates to further optimize the effectiveness of its

collections system management procedures. Lowell continues to update its practices related to system management, to evaluate further opportunities for additional in-line storage and system optimization.

5.2.1.1.14 Regulator Modifications

Modifications to the operation of regulators can help to reduce CSO discharges by reducing the frequency of activation. Regulators can be modified to pass more flow through to the interceptor or to take advantage of upstream pipeline storage. Lowell has installed a very sophisticated control system to actively modulate gates at most of its CSO diversion stations to optimize the use of the collection system to store and convey wet weather flow to the Duck Island WWTF. Lowell is continually evaluating opportunities to improve the effectiveness of its real time control system in reducing CSO discharges and maximizing flow to the WWTF. Evaluations will be performed to ascertain whether potential modifications to regulators will convey additional flow to the WWTF and reduce CSO discharges.

5.2.1.1.15 Regulating Devices and Backwater Gates

This technology utilizes control valves and devices to optimize system operations through the control of flow into and within the collection system. Regulating devices include vortex valves, inflatable dams, and motorized or hydraulically operated sluice gates or control valves, which are used to restrict the conveyance of flow downstream and utilize available storage within existing upstream sewers. Backwater gates, such as tide gates, flap gates, or elastomeric gates, are used to restrict the receiving water from entering the collection system.

Several of the CSO outfalls have flap gates and tideflex valves that are inspected by Lowell and there have been no reported problems with river water entering the interceptor system. In addition, all other CSO diversion gates are controlled locally and remotely by PLCs or WWTF operators. No diversion gate is opened if there is a possibility that the river could flow into the collection system. Accordingly, Lowell has fully implemented this technology and no further consideration in the LTCP is necessary. The practice will be continued.

5.2.1.1.16 Remote Monitoring and Control/Flow Diversion

Diverting flow from one drainage basin having limited hydraulic capacity to a drainage basin having excess capacity can reduce the volume and frequency of CSO discharge. Existing pipeline capacity may be used to convey flow or as in-line storage. Lowell has implemented a sophisticated CSO diversion control system using a data gathering system to monitor rainfall, pumping rates, treatment rates and regulator positions; a central computer processing center to provide real time control; and an instrumentation and control system to remotely regulate pumps, gates, valves and regulators. Lowell continually reviews the effectiveness of this program and looks for way to improve wet weather capture and maximize flow to the WWTF. Lowell is also currently implementing the Clean Stream Initiative. To date, hundreds of grab samples from the Merrimack River have been collected during dry and wet weather. This data, along with data from continuous in-stream probes, can be used to determine river water quality during dry and wet weather conditions. Additional updates will be considered as the IP is developed and implemented.

5.2.1.1.17 Rainfall Derived Infiltration/Inflow Control

To maximize the collection system's capacity, it is necessary to remove the extraneous flows (to the extent possible) caused by rainfall derived infiltration and inflow (RDII). Infiltration is groundwater that enters the system through broken or cracked pipes, defective joints, depressed manholes, and manhole walls. Replacing or lining defective pipes and manholes can reduce infiltration.

Inflow results from direct connections to the system from roof leaders, cellar and yard drains, sump pumps, commercial and industrial drains, and malfunctioning tide gates. Since combined sewers are intended to carry both wastewater and stormwater, inflow cannot be entirely eliminated, but can be reduced or delayed to attenuate peak flows. Control of these inflow sources can be addressed by the technologies discussed herein.

During recent sewer separation projects, Lowell inspected sewers and completed replacement or rehabilitation of the pipes (to reduce extraneous flow). In addition, Lowell conducts a CCTV inspection program, which identifies additional sewer rehabilitation and replacement needs and periodically issues construction contracts to implement recommended collection system repairs.

Infiltration rates during wet weather conditions generally represent only a small portion of the total amount of RDII and stormwater runoff that cause CSOs. Thus, it is not typically cost effective to address the infiltration portion of the drainage basin flow for CSO reduction alone, because it is insignificant compared to incremental costs of stormwater source controls or larger downstream CSO controls. Accordingly, while this strategy will not be considered further as an alternative in the LTCP, Lowell will continue to update its existing sewer rehabilitation program with a focus on inflow sources.

5.2.1.2 Collection System Controls

Collection system controls and modifications are intended to reduce CSO discharges from the collection system by improving collection system capacity, diverting stormwater from the combined sewer, or relocation of CSO discharges. These controls include polymer injection (to increase pipe capacity), sewer separation, and flow diversion.

5.2.1.2.1 Polymer Injection

Injecting polymers into a collection system can decrease pipe friction and thereby increase the pipe's hydraulic capacity. A literature search was performed on the use of polymer injection in other combined sewer systems. The EPA performed most of the available studies between 1969 and 1977. According to one source, the addition of a polymer into gravity sewer lines could increase pipe flow to the treatment facility and reduce CSOs. Polymer slurry injections into gravity sewer lines have decreased hydraulic friction and increased pipeline capacities up to 144 percent.

Polymer injection requires the construction of facilities to store and inject the polymer into the pipelines. Instrumentation to monitor flow and regulate polymer dosage is also required. In addition, there are other problems that can occur with the use of polymers including polymer coagulation and settling, molecular

breakdown of the polymer that reduces its effectiveness, limited storage life, and high cost. Based on these issues, this technology is not considered further.

5.2.1.2.2 Relocation of CSO Outfalls & Flow Tipping/Conveyance

Relocation of CSO outfalls from sensitive to less sensitive discharge locations is similar to other technologies in that regulator modification and flow diversion may be involved. This solution may also involve routing overflows through a new pipe to a new discharge point, or just raising regulator weirs to force more flow downstream. It may also involve consolidation of CSO discharges to minimize the number of CSO control facilities and aid in their siting. This strategy may also involve tipping or rerouting of flows to increase conveyance capacity. For example, it may be possible to reroute flow from the South Bank Interceptor to the North Bank Interceptor. This strategy will be examined using the collection system model and considered further.

5.2.1.2.3 Sewer Separation

Lowell has separated portions of the combined sewer system through the implementation of several large projects over the last several years. These projects were performed to address localized surcharge and flooding problems. Further recommendations for sewer separation of additional portions of the system will be developed in the review of LTCP options in later sections of this report.

It is important to note that unlike storage and treatment alternatives, which reduce the frequency of CSO discharges, sewer separation eliminates or reduces CSOs by diverting stormwater from the collection system. The EPA CSO abatement policies require that combined sewer system separation be evaluated as a step in CSO facilities planning. Although separation eliminates CSOs, it may not, in all cases, be the most appropriate alternative in terms of addressing site-specific water quality objectives. By removing stormwater from the sanitary flow, the CSOs are essentially converted into stormwater outlets, which are now subject to effluent regulations under the NPDES stormwater program. Accordingly, pollutant loadings to receiving waters caused by the sanitary component of CSOs are eliminated; however, impacts caused by stormwater borne pollutants may not be. In consideration of the foregoing, the long-term advantages of sewer separation will be carefully considered as a potential LTCP technology.

5.2.1.3 Green Infrastructure

Green infrastructure captures stormwater sources before they are introduced to the collection system, thereby reducing the wet weather flow tributary to the CSO regulator. Green infrastructure typically includes the use of porous pavement, detention ponds, area drain and roof leader disconnection, the use of pervious areas for infiltration, and catch basin modifications using flow impedance devices.

5.2.1.3.1 Porous Pavement

The quantity of runoff that enters a combined sewer system may be reduced or attenuated through the installation of porous pavement.

Lowell installed porous pavement and porous concrete in two locations at the Duck Island WWTF as a demonstration project. So far, the porous areas have performed well. Accordingly, porous pavement may be considered as a potential (limited) strategy to help reduce CSO discharges, but it is not likely to be a widely applied technology. This strategy would be incorporated into the IP as part of a targeted green infrastructure strategy.

5.2.1.3.2 Flow Detention/Retention

Detention ponds in upstream areas of the tributary basin can be used to temporarily store stormwater runoff, attenuate flow peaks and minimize potential downstream treatment capacities. After the storms, collected water would be drained back into the system and conveyed to the WWTF for treatment.

The majority of the combined sewer system is densely developed, which restricts the capability to implement this technology as a systemwide strategy. There are several smaller areas (i.e., comprised of one or two streets) where a separate storm drain enters and recombines with the existing combined sewer system. However, these areas are too few and too small to consider for cost effective flow detention (as compared to downstream CSO facilities). In addition, there are several brooks and streams that enter the collection system where flow detention of the collected stormwater could be a benefit in Lowell but the areas adjacent to these brooks and streams are fully developed. Additional studies are needed to identify whether flow detention would be effective locally.

Lowell installed a flow retention pond at the Duck Island WWTF as a demonstration project which is performing well. Accordingly, detention ponds may be considered as a potential strategy (limited to select drainage areas) to help reduce stormwater inflow and CSO discharges, but it is not likely to be a solution that is applied systemwide. This strategy would be incorporated as part of a targeted green infrastructure strategy.

Flow detention/retention is also considered for larger development in Lowell by the Engineering Department during subdivision reviews. In accordance with state stormwater policies, developers must attenuate the flow from their property. This will help to reduce stormwater runoff over time. Flow detention/retention is a current practice that Lowell will continue to utilize where determined to be cost-effective in relation to other stormwater inflow and CSO control practices.

5.2.1.3.3 Area Drain and Roof Leader Disconnection/Rain Barrels

In urban areas, such as Lowell, leaders from gutters or roofs and area drains are often connected to the combined sewer system. Direct connection to the sewer system avoids excessive surface runoff across properties to the catch basins or drainage system. However, these direct inflow connections increase the peak flow rates during storm events by decreasing the time of concentration within the drainage basin.

During its sewer separation programs, Lowell has actively investigated potential yard drain and roof leader connections to the sewer system as possible inflow sources that could be eliminated. This effort has elevated the effectiveness of the sewer separation program.

However, as a systemwide solution to CSO reduction, this technology may not be cost effective when compared with the incremental costs required for downstream CSO controls. Therefore, disconnection of these inflow sources as an alternative to CSO treatment/storage technologies will not be considered further. However, Lowell will continue to evaluate the removal of inflow sources whenever opportunities arise, especially for large properties with substantial runoff, as an ongoing management measure.

5.2.1.3.4 Utilization of Pervious Areas for Infiltration

This technology in effect combines some of the aspects of the previous two strategies by attempting to maximize the use of pervious areas for infiltration of stormwater. Various types of facilities include green infrastructure practices, such as grassed swales, infiltration basins and subsurface leaching facilities. Generally, this type of control is more appropriate for new development or redevelopment where some significant area of well drained, pervious soils exist. Where possible, flow detention ponds could be constructed with pervious soils to take advantage of available infiltration rates.

This strategy is primarily applied to new larger developments in the city. However, as a systemwide solution to CSO reduction, this technology may not be cost effective when compared with the incremental costs required for downstream CSO controls. In addition, the city is densely developed with no large areas readily available for implementing detention facilities. Infiltration technologies may be considered as a potential (limited) strategy to help reduce CSO discharges, but it is not likely to be the only solution. This strategy would be incorporated into the plan as part of a green infrastructure strategy within the IP.

5.2.1.3.5 Surface Storage

Storing stormwater runoff prior to entering the collection system can be accomplished through roof storage, playground storage, in natural ponds, or in manmade basins or lagoons. Roof storage can be effective in locations with buildings having flat roofs. However, stored water can seep into the buildings and/or damage the structural integrity of the building. Roof storage is most attractive for new construction in warm climates where snow and ice will not collect on flat roofs. As a demonstration project, Lowell Water installed a green roof on top of the Duck Island WWTP Administration Building, which partially stores rainwater. There is also a cistern attached to the surplus roof drainage to provide some additional secondary capture of flow. However, a systemwide program to implement roof storage would not be practical as it would require application on privately owned properties.

Playground and recreational areas can be used to detain rainfall for a limited time to reduce peak flow in the system. Space availability, public acceptance and potential hazardous conditions are drawbacks associated with this approach. In addition, use of these facilities to store runoff may interfere with their intended use and increase maintenance requirements. Depending on existing land use and the natural topography, temporary stormwater detention may be implemented for runoff attenuation. Storm flow retention in areas having porous soils allow some or all of the detained flow to infiltrate into the soil instead of entering the combined sewer system.

5.2.1.4 Storage

Storage of CSO flows can be performed either at a local site adjacent to a regulator or other control device or downstream at a central site that consolidates the need for several facilities. Storage facilities are typically used to store CSO discharges for eventual treatment at the WWTF after the storm. However, storage facilities can also be designed to provide some sedimentation treatment capacity for flows exceeding the storage volume of the tank.

Storage technologies represent more costly structural modifications to a combined sewer system. These modifications are rarely undertaken without a complete assessment of the CSO discharges and interceptor system and the preparation of a systemwide facilities plan. These technologies are presented briefly below and include inline storage and off-line storage.

5.2.1.4.1 Inline Storage

The use of inline storage is considered a cost-effective method of reducing combined sewer overflows by utilizing available pipeline storage volume. The storage volume helps to both dampen peak flows and detain combined wastewater for later treatment at the WWTF. Control gates or other devices, such as weirs, can be used to create or optimize inline storage during a rainfall event.

Lowell utilizes a sophisticated control system to maximize the use of inline storage within the interceptor system. A project was recently completed to install a flow control gate in the Read Interceptor to take advantage of inline storage capacity. Other opportunities will be evaluated in the system where “safe” storage is available.

5.2.1.4.2 Offline Storage

Offline storage and pump back to the interceptor system is one of the most widely used and effective methods for CSO mitigation. Similar to inline storage, offline storage facilities temporarily store wet weather overflow volumes until the flow can eventually be conveyed and treated at the WWTF. Types of storage facilities include underground tanks, abandoned pipelines, or deep tunnels. Offline storage is usually located at overflow points or near dry weather or wet weather treatment facilities. These facilities can be relatively simple in design and operation and can effectively reduce the frequency of overflows.

Storage facilities can also be designed to remove settleable solids, with periodic cleaning by flushing, mechanical chain and flight scrapers, or other means. In effect, some primary treatment (sedimentation) takes place due to quiescent conditions. The settled solids can be handled by:

- Collecting and pumping to the interceptor as a concentrated slurry to be handled at the WWTF during the wet weather event.
- Collecting, storing and pumping to the interceptor as a concentrated slurry to be handled at the WWTF after the event.

- Collecting and dewatering at the storage site then transported to the sludge processing facilities.
- Re-suspended in the stored mixed flow during the pump back period for transportation to and handling at the WWTF.

Excessively long detention times can result in the settled solids causing offensive odors. Accordingly, prompt solids removal is necessary along with proper odor control equipment.

In general, open space in densely developed urban areas such as Lowell is limited to parks, recreational areas and parking lots.

5.2.1.5 Treatment Technologies

Technologies that could be used to treat CSOs prior to discharge, based on the USEPA's guidance manual, are presented and discussed below. Wastewater treatment facility improvements focus on upgrades to the existing facilities. The other treatment technologies would be applied at the existing site in a new treatment train or at upstream (satellite) treatment sites.

5.2.1.5.1 Wastewater Treatment Facility Improvements

Increasing the capacity of the WWTF to handle higher peak wet weather flows can help to reduce the frequency and volume of untreated CSO discharges upstream in the collection system, primarily for longer duration low intensity storms. This approach maintains wet weather treatment facilities at a common site, which could reduce overall operations and maintenance costs. However, the effectiveness of this approach is limited for high intensity storms, where peak flows typically exceed the capacity of the WWTF. To address these storms, storage facilities are required to capture and store peak flow in excess of the WWTP capacity for conveyance and treatment once capacity becomes available.

Lowell has completed preliminary evaluations of the WWTF dry and wet weather capacities and the capabilities to increase the rated wet weather treatment capacity. The limitations to increasing flow are the screw pumps, primary clarifiers, secondary bypass pipe, disinfection contact chamber, and the effluent diffuser (and finished water pumps). Capacity improvements to these unit processes will be evaluated, in addition to the introduction of polymers at the primary and secondary clarifiers to improve settling and allow for higher hydraulic loading rates.

Construction of an alternative wet weather treatment train, potentially with its own influent pumping station and high rate treatment process, will also be evaluated. However, this potential solution may be impractical considering the limited site availability at Duck Island, which may have to be reserved for future WWTF facilities to address increasingly stringent effluent requirements. Additionally, conveyance of flows from the collection system to the WWTF must be considered for this alternative to be effective in terms of CSO control.

In an effort to continue to optimize peak flow treatment, additional real-time control monitoring will be considered, including secondary effluent TSS monitoring. These real-time monitoring enhancements will enable additional flow treatment while achieving permit limits.

5.2.1.5.2 Screening

Screens are effective in removing large solids and floatables from the wastewater flow. The size of the screen openings determines the level of treatment achieved and also the volume of screenings that may be collected. Screens are usually paired with an additional wet weather treatment process such as disinfection or high rate treatment.

Screens for wastewater treatment are available in various types and sizes ranging from bar racks to coarse/fine screens or microstrainers. Screens can be installed at either inline or at offline facilities. Inline facilities must be closely monitored and cleaned to prevent loss of hydraulic capacity, which could cause sewer backups and flooding. While microstrainers can achieve primary treatment levels by removing 60 percent of the suspended solids, coarser screening must be performed ahead of the microstrainer to remove larger objects that could cause blinding.

Bar screens are almost always installed at the entrance to storage and treatment facilities for removal of large objects, trash and debris, and to protect treatment and pumping equipment. Often two sets of screens in series are used. The first set usually consists of coarse screens with 1 1/2” bar spacing. Finer screens with 1/2” to 1" spacing are located just downstream. A double screen setup also has less tendency to blind than a single fine screen.

Bar screens may be installed vertically or horizontally. Stormwater-type bar screens can be used beneficially in some CSO conditions as the screenings could be removed by cleaning combs and deposited back into the flow stream to avoid satellite screen collection issues.

Screening is a viable treatment alternative to help meet CSO control strategies and will be considered in conjunction with disinfection to meet water quality/treatment objectives.

5.2.1.5.3 Sedimentation

Gravity sedimentation of suspended solids can achieve 20 to 40 percent removal of BOD and 50-70 percent removal of TSS in wet weather flow. It is an additional process that can provide better removal of solids to meet water quality objectives. The major disadvantage of sedimentation is that the land requirements are relatively high. Because the availability of land is usually limited in urban areas, siting of CSO abatement facilities that include sedimentation basins is an important issue.

While sedimentation is a reliable, cost-effective technology at the WWTF, it is not as cost-effective in the collection system as a remotely operated CSO control alternative. It will not be considered further as an explicit LTCP alternative.

5.2.1.5.4 Enhanced High-Rate Clarification

High-rate clarification is a newer technology, which can be operated intermittently during storm events. It is a physical-chemical process where coagulant and polymer are added to wastewater to improve settling in small basins. The coagulant aggregates the suspended solids in the flow into a floc. The resulting floc particles adsorb onto either very fine sand added to the wastewater, or recirculated solids with the aid of a polymer. The fine sand (or recirculated solids) acts as ballast and increases the settling rate of the adsorbed floc. Hence, the process is also known as "ballasted flocculation."

A typical ballasted flocculation system consists of addition of ferric chloride, polymer, and "microsand" (sand approximately 100-microns in diameter) to wastewater. The wastewater and additives are rapidly mixed, then slowly stirred in a maturation tank before settling in a clarifier. The sludge from settling is passed through a hydrocyclone, where the microsand is removed from the sludge and recycled. Several suppliers provide enhanced high-rate clarification systems including: Kruger's Actiflo process, which uses microsand as ballast and Degremont Technologies DensaDeg process, which uses recirculated solids as ballast.

Whichever process is selected, BOD and TSS removal rates associated with high-rate clarification have been shown to be roughly double those of traditional clarification (gravity settling) with a smaller basin. Area requirements for the process are about one-tenth of traditional clarification area requirements (5 to 15-percent of the space required for conventional primary treatment). For this same process, BOD removal is between 65 and 80 percent and TSS removal is between 70 and 95 percent; thus, the pollutant removals are closer to secondary treatment standards.

Another form of this process utilizes secondary solids, as a "bio-ballasted floc" process to improve BOD removal via biological reduction. This approach works best when the high rate clarification process is located at a WWTF site. The high rate clarification process is also beneficial because it can handle high hydraulic loading rates and treat rapidly varying flows (typically observed with "first flushes" and varying precipitation in combined sewer systems).

Storage of chemicals may be of concern at a satellite location, away from the WWTF. Other disadvantages of this technology include the increased operational cost relative to biological treatment and conventional clarification due to the cost of chemicals, ballasted media, sludge disposal and the limited ability to remove soluble pollutants. However, many of the technologies reviewed have limited ability in removing soluble pollutants.

Screening is required prior to the ballasted flocculation treatment component and disinfection is required after. UV disinfection can be utilized with ballasted flocculation treatment because of the high level of suspended solids removal.

In summary, enhanced high-rate clarification provides considerably higher treatment capacities than conventional primary treatment, with significantly higher BOD and TSS removals. In consideration of the siting and operation and maintenance issues associated with application of this technology at remote locations, enhanced high-rate clarification is only considered a viable alternative for enhancing wet weather treatment capacity at the Duck Island WWTF and will be evaluated in conjunction with other

WWTF improvement alternatives. Space constraints, pumping needs, and the need for a new outfall are all complexities that will affect whether this alternative is feasible.

5.2.1.5.5 Chemical Flocculation

Chemical flocculation is a high-rate treatment process utilizing metal salts and polymers to aggregate particles in CSO flow. Depending on their density, the aggregate of particles, or floc, will either sink to the bottom or float to the top where it can be removed. A concentrated sludge is produced, requiring no additional thickening. Chemical flocculation can remove 40 to 80 percent BOD and 60 to 90 percent TSS.

Similar to ballasted flocculation, chemical flocculation can handle high hydraulic loading rates and treat rapidly varied flow. Chemical flocculation is limited in its ability to remove soluble pollutants. There is a potential increase in sludge production due to the addition of treatment chemicals and an increased operational cost due to the cost of chemicals. Since ballasted flocculation achieves similar results to chemical flocculation but the hydraulic capacity for chemical flocculation is much less (20,000 gpd/sq. ft for chemical versus 90,000 gpd/sq. ft. for ballasted flocculation); chemical flocculation will not be further considered.

5.2.1.5.6 Dissolved Air Floatation

Dissolved air floatation has been used to treat CSOs and has proved to be relatively effective in removing up to 20 to 50 percent of the suspended solids and floatables. Dissolved air floatation (DAF) relies on small air bubbles to suspend particulate matter to float to the surface for removal. Oil, grease, and other floatables can also be removed. Small and light suspended matter can be removed more efficiently and quickly by this process than by sedimentation. Chemical addition (generally polymer) is usually used to improve removal efficiency. Operating costs are relatively high due to pumping costs to pressurize the water and compressed air, and chemical requirements. The process is also sensitive to operational control.

DAF has been used primarily for processing sludges in municipal, industrial water, and wastewater treatment applications and most recently for water treatment. Due to the relatively high operating costs and sensitivity to operational control associated with DAF, other less costly and complex technologies have been developed that have replaced DAF in many applications. For these reasons, DAF is not considered feasible for CSOs and will not be considered further.

5.2.1.5.7 Swirl Concentrators

Swirl and helical concentrators operate as a solids/liquid separator removing both suspended solids and floatables through rotationally induced forces. Swirls have been reported to remove up to 50 percent of the suspended solids from the combined sewer flow. Helical concentrators are similar in design but are more effective as an inline device (rather than an offline device). The flow is separated into overflow, which is discharged to the receiving water (typically after chlorination) and underflow (a concentrated low volume of wastewater that is intercepted for treatment at a treatment facility).

Swirl and helical bend concentrators have some limitations and potential drawbacks, including:

- The rate of underflow diversion is subject to design limitations relative to the incoming combined flow.
- The relatively short detention time will require high rate disinfection or construction of contact tanks to provide adequate detention time for bacteria kill before discharge to the receiving water.
- The configuration of the swirl concentrator results in a large hydraulic headloss requirement between the influent combined sewer and the underflow pipe.
- Long-term history of inconsistent performance and reliability.

Some of the drawbacks can be satisfied by storage and pump back facilities in conjunction with a concentrator, but pumping will also require electricity, additional space, remote/automatic controls for operation and additional costs. Interceptor and treatment capacity must be available for underflow during a storm event. If underflow rates exceed the available interceptor capacity or sufficient grade is not available, the underflow may need to be stored and pumped back following the storm.

In order to operate effectively, swirl concentrators need to be cleaned following each storm event. A maintenance schedule should be established based on solids loading and accumulation rates. Some types of swirl concentrators must be dewatered and cleaned with a vacuum truck, which will increase work demands of the city's collection system maintenance crews. Other types of systems are designed to pump out the debris that is screened out of the flow, which can potentially create sedimentation and grit accumulation in downstream sewers.

The uncertainty concerning solids removal efficiencies, the lack of bacteria removal, space requirements and the level of maintenance required for swirls are some of the reason why swirl concentrators are not given further consideration in this IP.

5.2.1.5.8 Biological Treatment

Biological treatment processes, including contact stabilization, trickling filters, rotating biological contactors, treatment lagoons, and land application, have been most successfully used in the treatment of sanitary sewage and industrial wastewater. Their exclusive use for the treatment of combined sewer overflows has several drawbacks including:

- Difficulty maintaining biomass (used to assimilate nutrients in combined sewage) during dry weather (continuous operation is required);
- Difficulty in handling erratic loading conditions inherent to combined sewer overflows;
- Potential odors and snail population problems;
- High clogging potential;
- Costly operation and maintenance;
- Highly skilled operators are required; and

- Extensive level of treatment provided by biological treatment is not required for combined sewage.

Potentially, CSO discharge into wetlands could provide some level of biological treatment; however, this is not considered appropriate for the city's combined sewer area. Consequently, biological treatment will not be considered further in this study.

5.2.1.5.9 Filtration

Filtration is a physical treatment process that removes solids by straining wastewater through a filter medium, such as sand, charcoal (carbon adsorption), or membranes. Deep bed filtration has the ability to treat high and rapidly varying flows. Filtration can consistently achieve secondary treatment concentration standards for BOD and TSS. Its major disadvantage for treatment of combined sewage is the tendency to clog rapidly during use, thus limiting its hydraulic capacity and ability to remove solids; or the need for frequent backwashing to prevent clogging. It can be used after sedimentation to reduce clogging, but this level of treatment is typically not required for CSO applications. Consequently, filtration will not be considered as an LTCP technology.

5.2.1.5.10 Disinfection

Disinfection is used to destroy pathogenic microorganisms. Many disinfection technologies are available including chlorination, ozonation, and ultraviolet radiation. The most common method is chlorine addition, although recently its apparent toxicity to aquatic life has become a public concern. For this reason, dechlorination is often required.

Disinfection agents used for wastewater and stormwater treatment include gaseous chlorine, hypochlorite (calcium and sodium), chlorine dioxide, and ozone. All of these disinfection agents are oxidizing agents, corrosive to equipment, and can be highly toxic to microorganisms and other life if disinfection by-products are not properly addressed.

Ultraviolet light has been used as a disinfection agent but is sometimes ineffective for CSOs because of their turbidity and harboring of pathogens within the solids contained in wastewater.

Selecting a CSO disinfection system is based on the following considerations:

- CSOs are highly variable in quantity and quality and thus any disinfection system (and associated pre-treatment systems) must have the capability to address these fluctuations.
- Chlorine, chlorine dioxide, and ozone are all dangerous gases that must be carefully handled by trained operators. Lesser hazards are associated with hypochlorite, which requires bulk storage.

When selecting a disinfection system, the capacity and location of the treatment facility must be considered. Use of toxic gases is undesirable in densely populated areas and small-scale facilities that are only monitored periodically. For this reason, use of gaseous chlorine is not considered.

Case studies regarding the use of bromine chloride, ozone, and ultraviolet light for CSO disinfection are limited at this time. Ozone has been proven to be effective, but is an expensive process. Ultraviolet light is typically only effective for flow with lower turbidities. Large particles block much of the light, rendering this technique ineffective.

Generally, chlorination (hypochlorite) is accepted as the most cost-effective and technically reliable disinfection treatment to reduce coliform levels in CSOs. Chlorination will be considered in conjunction with screening. To eliminate the potential toxic effect of residual chlorine on biota, CSOs would be dechlorinated prior to discharge at any wet weather treatment facility being considered. General dechlorination practice indicates that sodium bisulfite is a reliable and cost-effective chemical to remove chlorine residuals from the wastewater effluent.

5.2.2 Feasibility Summary

Table 5-2: Feasibility Table

CSO Control Technology	Technology Not Applicable	Continue Current Practice	Update/ Initiate Practices	LTCP Technology
Operations and Maintenance Projects				
Best Management Practices				
Air Pollution Reduction	X			
Solid Waste Management		X		
Fat, Oil, and Grease (FOG) Control Programs			X	
Street Sweeping		X		
Fertilizer/Pesticide Control		X		
Snow Removal and Deicing Practices		X		
Soil Erosion Control		X		
Commercial/Industrial Runoff Control		X		
Animal Waste Removal		X		
Catch Basin Modifications			X	
Catch Basin Cleaning		X		
Sewer Cleaning/Flushing		X		
Existing System Management			X	
Regulator Modifications			X	
Regulating Devices and Backwater Gates		X		
Remote Monitoring and Control/Flow Diversion			X	
Rainfall Derived Infiltration/Inflow Control			X	
Capital Projects				
Collection System Controls				
Polymer Injection	X			
Relocation of CSO Outfalls & Flow Tipping/Conveyance				X
Sewer Separation				X
Green Infrastructure				
Porous Pavement			X	
Flow Detention/Retention				X
Area Drain and Roof Leader Disconnection/Rain Barrels			X	
Utilization of Pervious Areas for Infiltration				X

CSO Control Technology	Technology Not Applicable	Continue Current Practice	Update/ Initiate Practices	LTCP Technology
Surface Storage				X
Storage				
In-Line Storage				X
Off-Line Storage				X
Treatment Technologies				
Wastewater Treatment Plant Improvements				X
Screening				X
Sedimentation	X			
Enhanced High-Rate Clarification	X			
Chemical Flocculation	X			
Dissolved Air Flotation	X			
Swirl Concentrators	X			
Biological Treatment	X			
Filtration	X			
Disinfection				X

5.3 Analysis of Retained CSO Control Technologies

Lowell's goal is to reduce overflows at each CSO station to the greatest extent possible. To that end, an alternatives analysis of retained CSO control technologies (as indicated in Table 5-2 above) was performed within each sewershed. The approach means that in addition to evaluating systemwide CSO control alternatives, Lowell investigated all possible CSO control solutions that could be effective within each sewershed.

5.3.1 Constraints and Opportunities

Each sewershed is associated with unique constraints and opportunities. These unique characteristics of each sewershed are summarized in site sheets included in this Section. In general, construction of CSO control measures within Lowell is associated with the following constraints and opportunities.

Constraints

- Limited land availability
- Prohibitive land acquisition costs/eminent domain required
- High construction costs with limited financial resources
- High potential for major public disturbances due to construction (congested and narrow residential and commercial streets and neighborhoods)
- Additional stormwater pollutant loading (sewer separation)

Opportunities

- Community benefit (visible projects such as green infrastructure)
- Potential to better optimize/utilize existing infrastructure
- Some City owned land available
- Unique sewer system features (large interceptor pipe drops, large flow control gates, etc.)

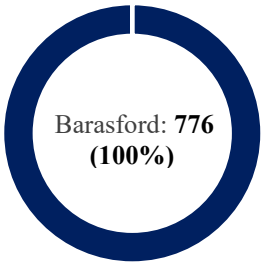
5.3.2 Site Sheets

In order to summarize the constraints, opportunities, and feasible CSO control strategies within each sewershed, one-page site sheets were developed to summarize opportunities within each sewershed. The site sheets are presented in Figure 5-1 through Figure 5-10. Descriptions of the technologies described in these sheets may be found in Section 5.2.

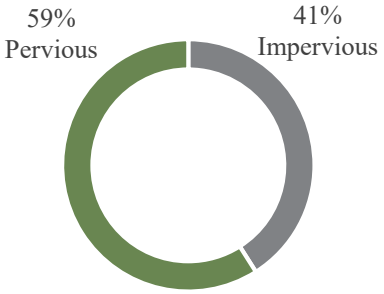
Barasford

Key Metrics:

Total Acreage: **776**



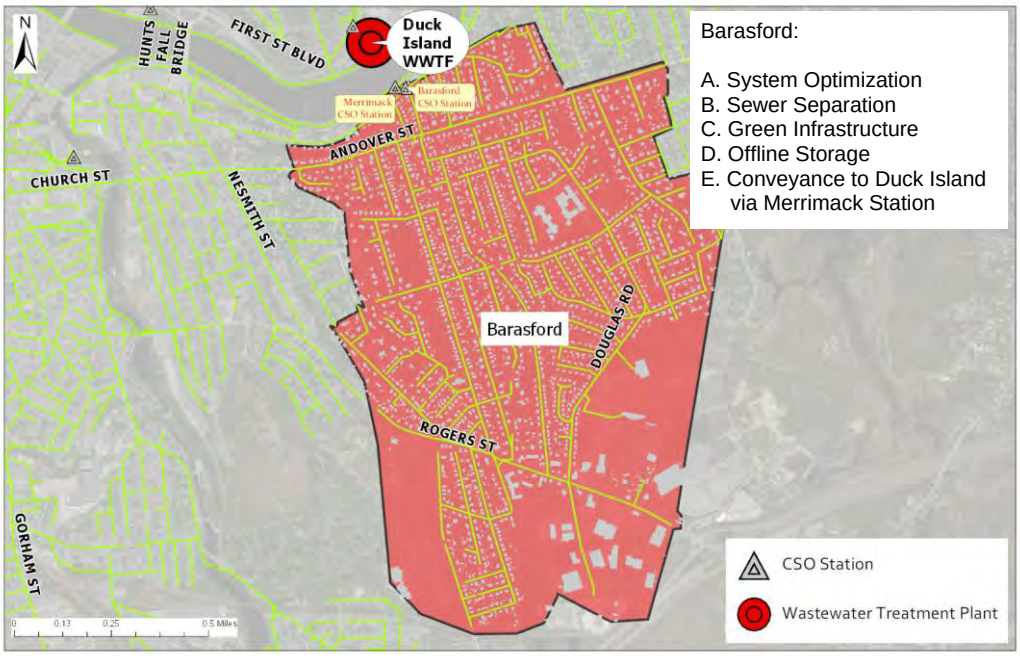
Tributary Sewersheds: N/A
Conveyance to Duck Island: South Bank



Sewershed Background

The Barasford Sewershed comprises approximately 776 acres, and is located on the south side of the Merrimack River (and east of the Concord River). Flows in the sewershed generally travel northward into the 84" Barasford Interceptor, toward Barasford Station, where CSO is regulated. From there, flows are conveyed in the 120" Merrimack East Interceptor to Merrimack Station, and then continue in the South Bank portion of the sewer system en route to Duck Island WWTP. The sewershed land use is mostly residential and includes the Belvidere neighborhood.

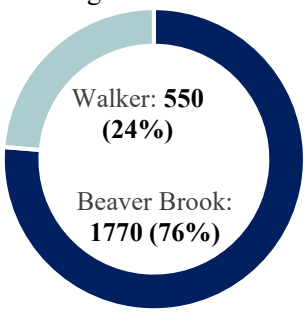
CSO Control Alternatives	System Optimization	Sewer Separation	Green Infrastructure	Offline Storage	Conveyance to Duck Island via Merrimack Station
Pros	• Maximum performance of existing infrastructure	• Reduced risk of sewer backups	• Community benefit	• High CSO reduction • Full treatment of captured CSO and SW	• High CSO reduction • Full treatment of captured CSO and SW
Cons	• Limited CSO reduction	• Highly disruptive to traffic and neighborhoods • SW load remains	• Limited CSO reduction • O&M	• Siting challenges	• Difficult construction



Beaver Brook

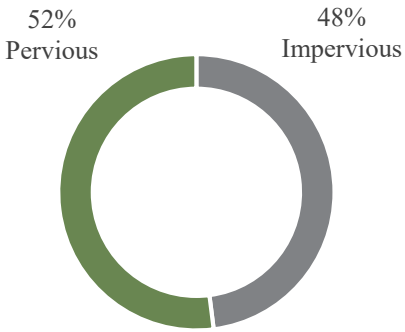
Key Metrics:

Total Acreage: **2320**



Tributary Sewersheds: Walker
Conveyance to Duck Island: North Bank

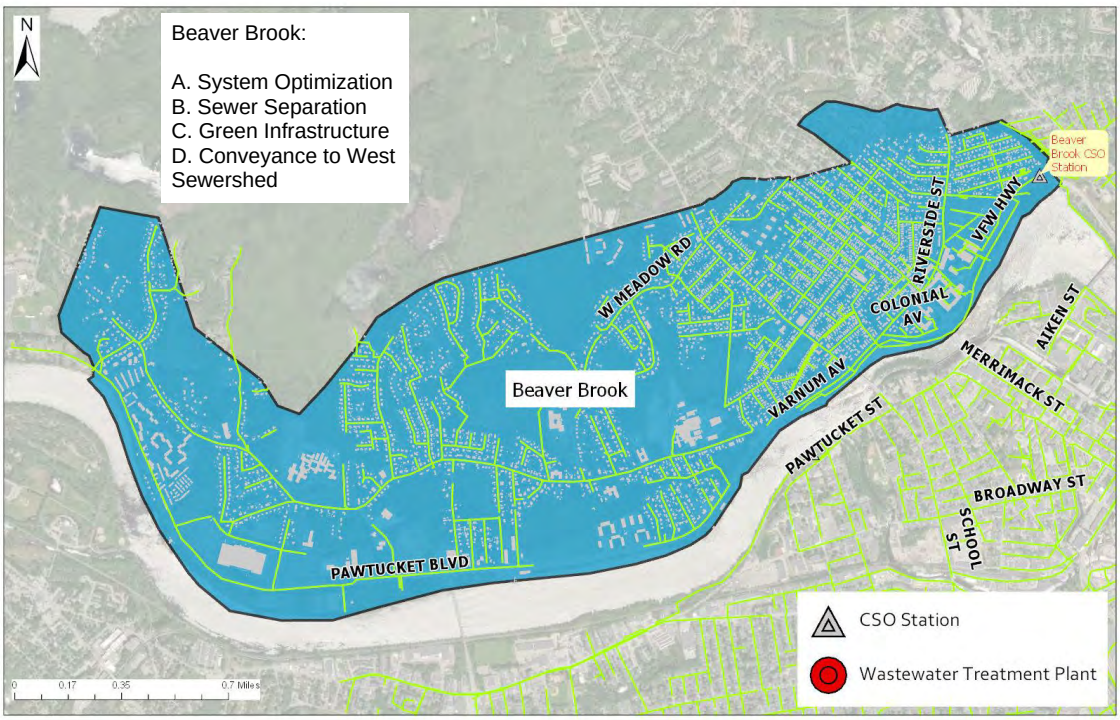
Walker → **Beaver Brook**



Sewershed Background

The Beaver Brook Sewershed comprises approximately 1770 acres, and is located on the north side of the Merrimack River. Flows in the sewershed generally travel eastward into the 96" Beaver Brook Interceptor, toward Beaver Brook Station, where CSO is regulated. From there, flows are conveyed by the North Bank portion of the sewer system en route to Duck Island WWTP. The sewershed land use is comprised of residential, commercial and open space.

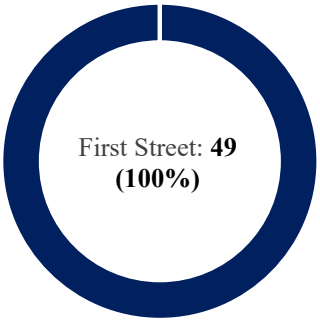
CSO Control Alternatives	System Optimization	Sewer Separation	Green Infrastructure	Conveyance to West Sewershed
Pros	• Maximum performance of existing infrastructure	• Reduced risk of sewer backups	• Community benefit	• Partial treatment of captured CSO and SW
Cons	• Limited CSO reduction	• Highly disruptive to traffic and neighborhoods • SW load remains	• Limited CSO reduction • O&M	• N/A



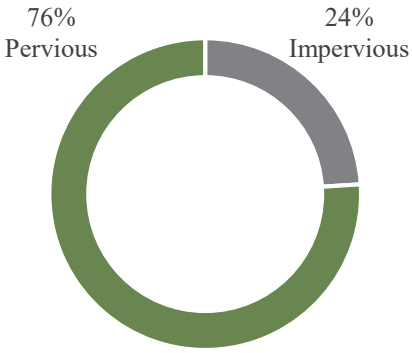
First Street

Key Metrics:

Total Acreage: **49**



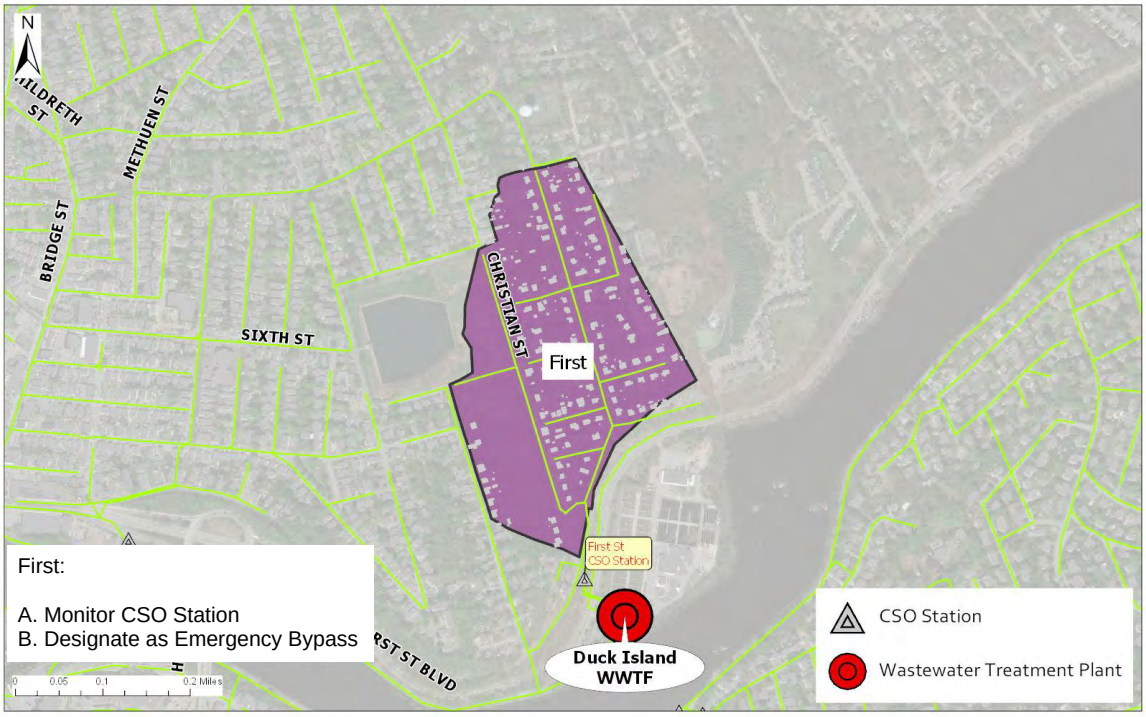
Tributary Sewersheds: N/A
Conveyance to Duck Island: North Bank



Sewershed Background

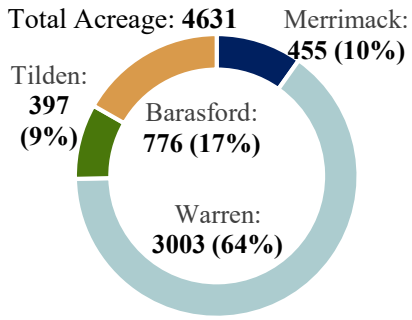
The First Sewershed comprises approximately 49 acres, and is located on the north side of the Merrimack River. Flows in the sewershed generally travel southward into First Station, where CSO is regulated, prior to entering the 96" Duck Island Interceptor en route to the Duck Island WWTP. The sewershed land use is comprised of mostly residential, and includes the Beaver Brook Reservoir.

CSO Control Alternatives	Monitor CSO Station	Designate as Emergency Bypass
Pros	• Continue to maximize flow to WWTP • Data can be used to assess re-designation as emergency bypass	• CSO eliminated for typical year • Continue to maximize flow to WWTP
Cons		

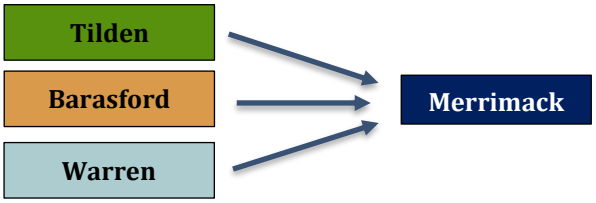


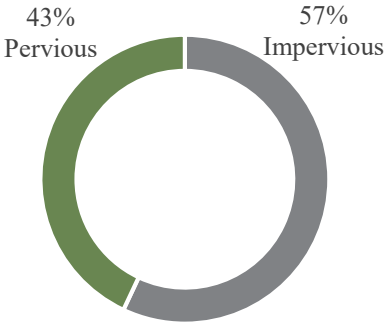
Merrimack

Key Metrics:



Tributary Sewersheds: Warren, Tilden, Barasford
Conveyance to Duck Island: South Bank

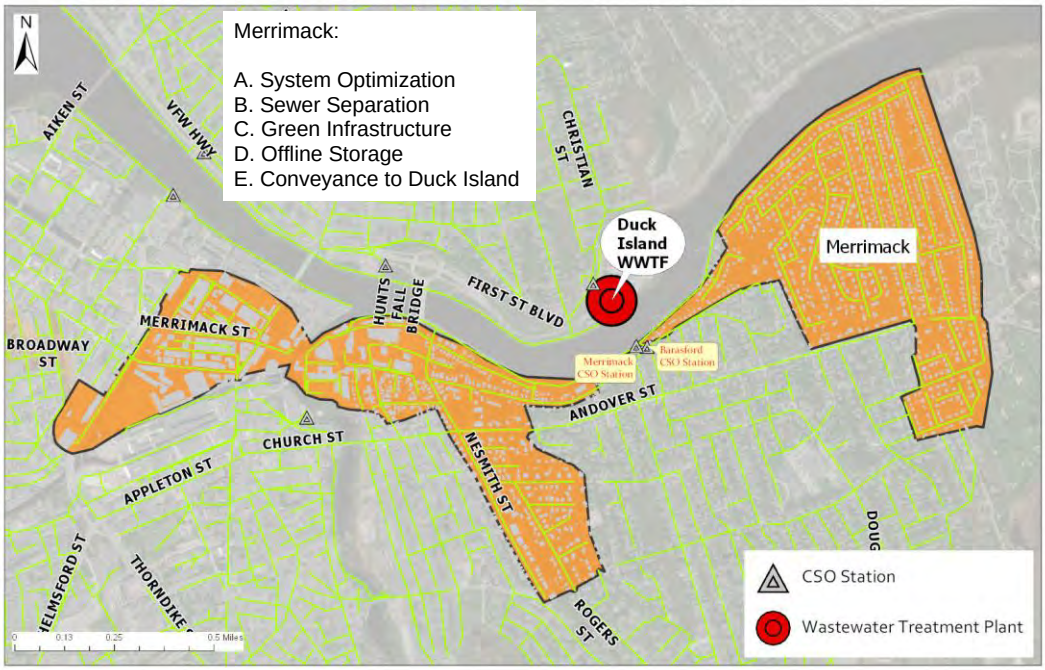




Sewershed Background

The Merrimack Sewershed comprises approximately 455 acres, and is located on the south side of the Merrimack River. Flows in the sewershed generally travel eastward into the 120" Merrimack West Interceptor and westward into the 120" Merrimack East Interceptor, toward Merrimack Station, where CSO is regulated. From there, flows are conveyed across the Merrimack River to the Duck Island WWTP. The sewershed land use is mostly residential and commercial.

CSO Control Alternatives	System Optimization	Sewer Separation	Green Infrastructure	Offline Storage	Conveyance to Duck Island
Pros	• Maximum performance of existing infrastructure	• Reduced risk of sewer backups	• Community benefit	• High CSO reduction • Full treatment of captured CSO and SW	• High CSO reduction • Full treatment of captured CSO and SW
Cons	• Limited CSO reduction	• Highly disruptive to traffic and neighborhoods • SW load remains	• Limited CSO reduction • O&M	• Siting challenges	• Difficult construction • Peak wet weather WWTP capacity limitations

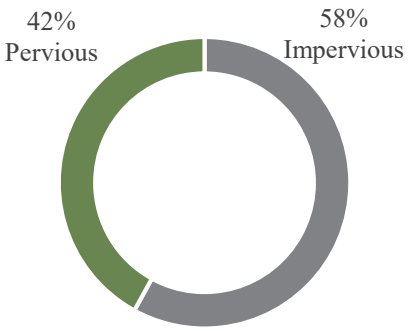


Read Street

Key Metrics:

Total Acreage: **175**

Tributary Sewersheds: N/A
Conveyance to Duck Island: North Bank



Sewershed Background

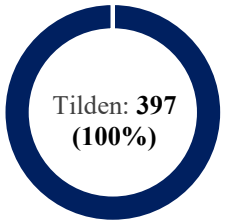
The Read Sewershed comprises approximately 175 acres and is located on the north side of the Merrimack River. Flows in the sewershed generally travel southward into Read Station, where CSO is regulated, prior to entering the 96" Read Interceptor en route to the Duck Island WWTP. The sewershed land use is mostly residential.

CSO Control Alternatives	System Optimization	Sewer Separation	Offline Storage	Wet Weather Treatment at North Bank	Conveyance to Duck Island
Pros	• Maximum performance of existing infrastructure	• Reduced risk of sewer backups	• High CSO reduction • Full treatment of captured CSO and SW	• Disinfection of CSO	• Full treatment of captured CSO and SW
Cons	• Limited CSO reduction	• Highly disruptive to traffic and neighborhoods • SW load remains	• Siting challenges	• O&M	• Peak wet weather WWTP capacity limitations

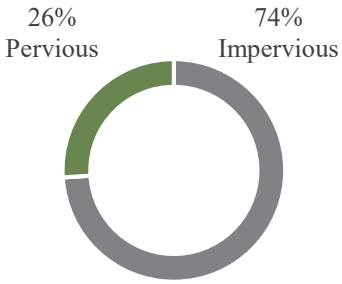
Tilden

Key Metrics:

Total Acreage: **397**



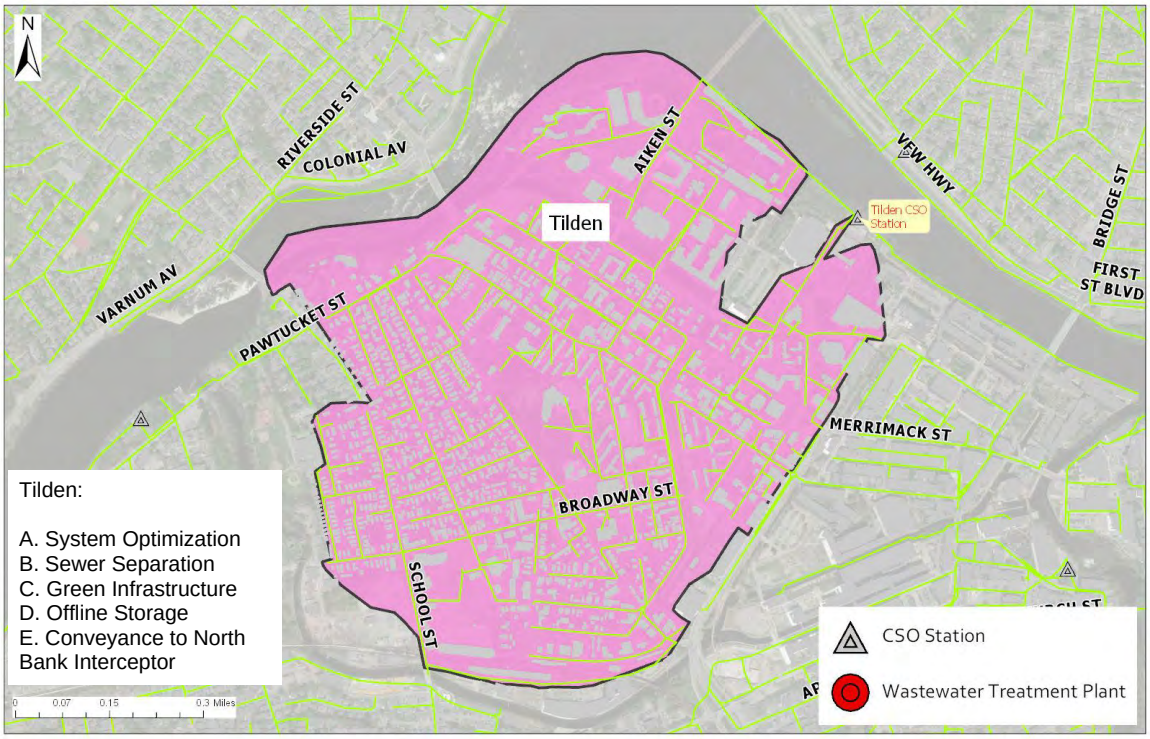
Tributary Sewersheds: N/A
Conveyance to Duck Island: South Bank



Sewershed Background

The Tilden Sewershed comprises approximately 397 acres and is located on the south side of the Merrimack River (and west of the Concord River). Flows in the sewershed generally travel northward into the 72" diameter Tilden Interceptor, toward Tilden Station, where CSO is regulated. From there, flows are conveyed by the South Bank portion of the sewer system en route to Duck Island WWTP. The sewershed land use is mostly commercial/industrial with some residential.

CSO Control Alternatives	System Optimization	Sewer Separation	Green Infrastructure	Offline Storage	Conveyance to North Bank Interceptor
Pros	• Maximum performance of existing infrastructure	• Reduced risk of sewer backups	• Community benefit	• High CSO reduction • Full treatment of captured CSO and SW	• Partial treatment of captured CSO and SW • High CSO reduction
Cons	• Limited CSO reduction	• Highly disruptive to traffic and neighborhoods • SW load remains	• Limited CSO reduction • O&M	• Siting challenges • O&M	• Peak wet weather WWTP capacity limitations • O&M (if pumped)

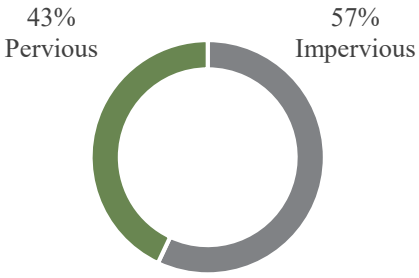


Walker

Key Metrics:

Total Acreage: **550**

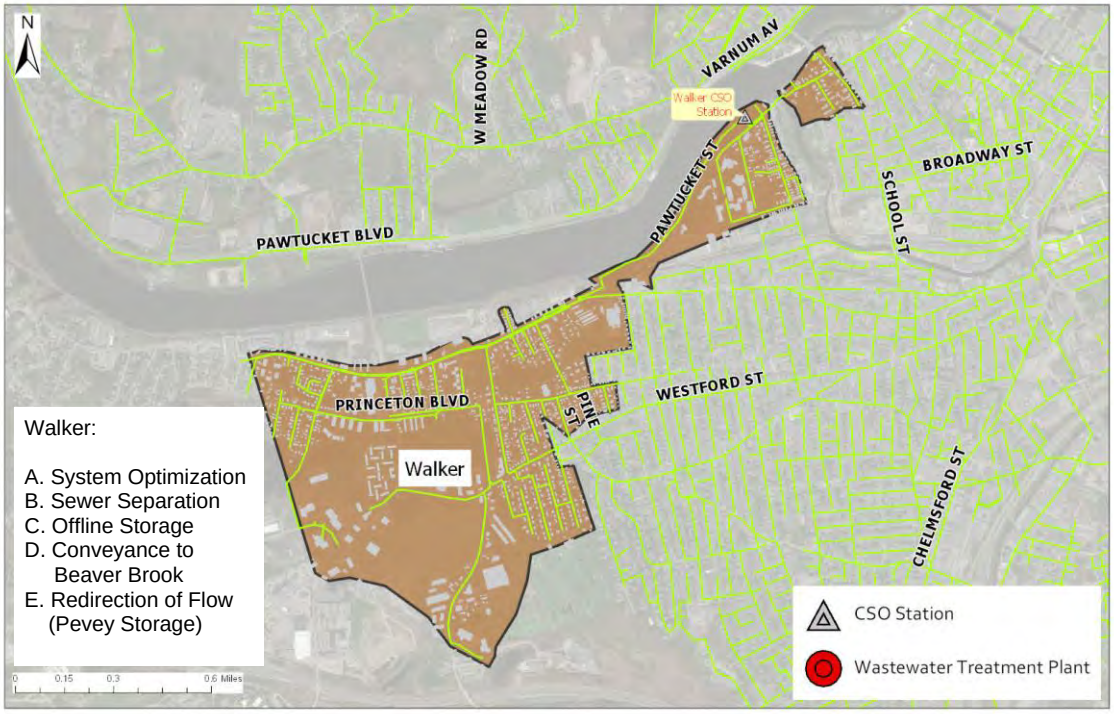
Tributary Sewersheds: N/A
Conveyance to Duck Island: North Bank



Sewershed Background

The Walker Sewershed comprises approximately 550 acres, and is located on the south side of the Merrimack River. Flows in the sewershed generally travel northward into the 48" diameter Walker Interceptor, which conveys flow into Walker Station where CSO is regulated. From there, flows are conveyed by the North Bank portion of the sewer system en route to Duck Island WWTP. The sewershed land use is mostly residential with some commercial and institutional (UMass Lowell South Campus).

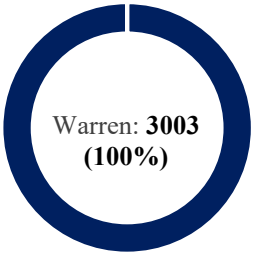
CSO Control Alternatives	System Optimization	Sewer Separation	Offline Storage	Conveyance to Beaver Brook	Redirection of Flow (Pevey Storage)
Pros	• Maximum performance of existing infrastructure	• Reduced risk of sewer backup	• High CSO reduction • Full treatment of captured CSO and SW	• Full treatment of captured CSO and SW	• Full treatment of captured CSO and SW
Cons	• Limited CSO reduction	• Highly disruptive to traffic and neighborhoods • SW load remains	• Siting challenges • O&M	• Capacity limitations of existing downstream sewers	• Conveyance sewer construction disruptive to traffic and neighborhoods



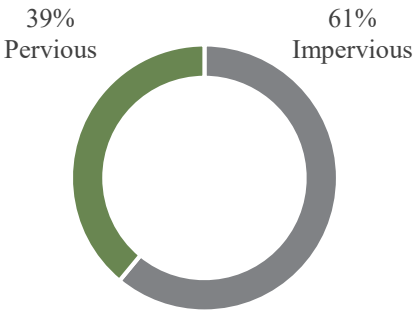
Warren

Key Metrics:

Total Acreage: **3003**



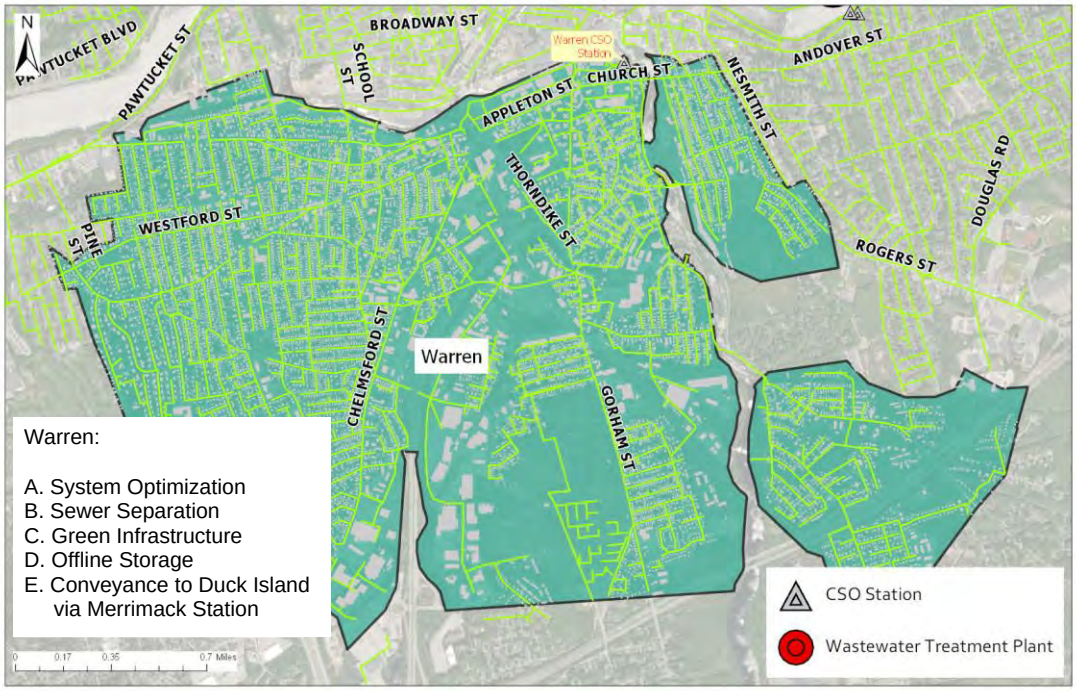
Tributary Sewersheds: N/A
Conveyance to Duck Island: South Bank



Sewershed Background

The Warren Sewershed comprises approximately 3003 acres, and is located on the south side of the Merrimack River (and west of the Concord River). Flows in the sewershed generally travel northward into the either the 52"x35" Marginal Interceptor, traveling eastward toward Warren Station, or the 84" diameter Warren Interceptor, traveling northward toward Warren Station, where CSO is regulated. From there, flows are conveyed by the South Bank portion of the sewer system en route to Duck Island WWTP. The sewershed land use is mostly residential and commercial.

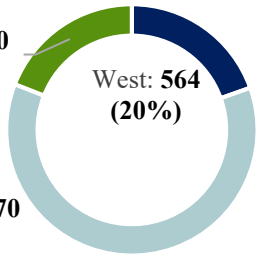
CSO Control Alternatives	System Optimization	Sewer Separation	Green Infrastructure	Offline Storage	Conveyance to Duck Island via Merrimack
Pros	• Maximum performance of existing infrastructure	• Reduced risk of sewer backup	• Community benefit	• High CSO reduction • Full treatment of captured CSO and SW	• High CSO reduction • Full treatment of captured CSO and SW
Cons	• Limited CSO reduction	• Highly disruptive to traffic and neighborhoods • SW load remains	• Limited CSO reduction • O&M	• Siting challenges • O&M	• Difficult construction • Peak wet weather WWTP capacity limitations



West

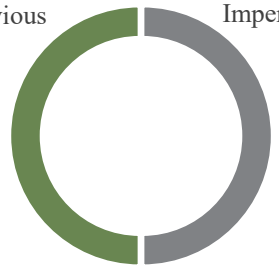
Key Metrics:

Total Acreage: **2884**



Tributary Sewersheds: Walker, Beaver
Conveyance to Duck Island: North Bank

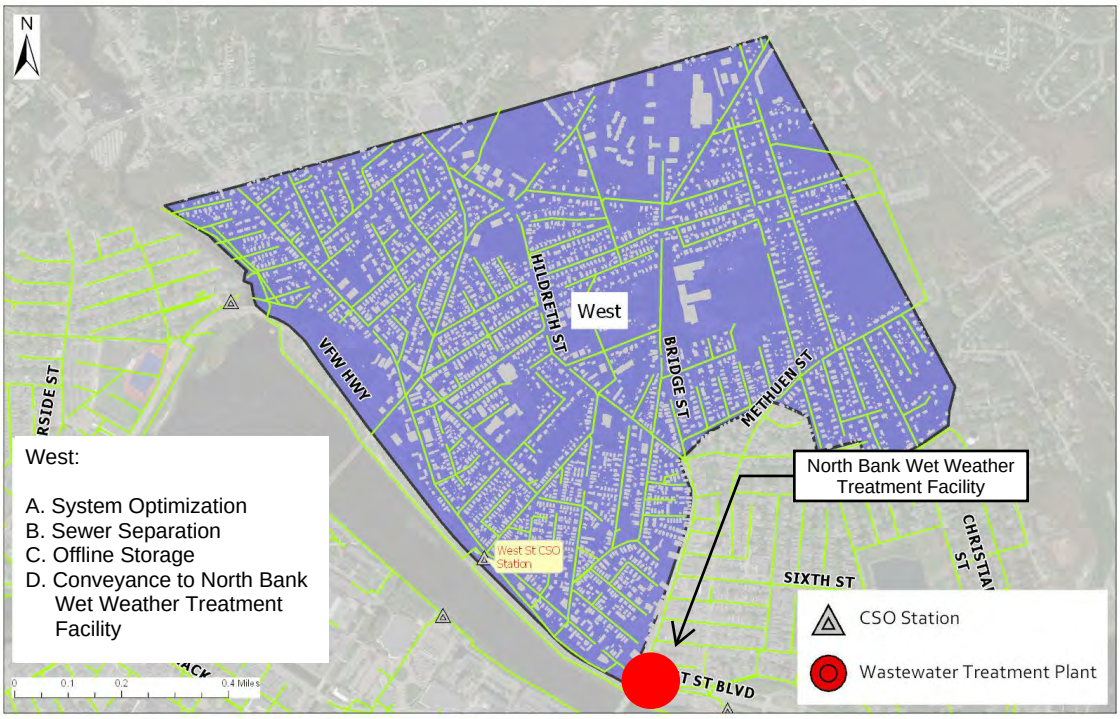
Walker → **Beaver Brook** → **West**



Sewershed Background

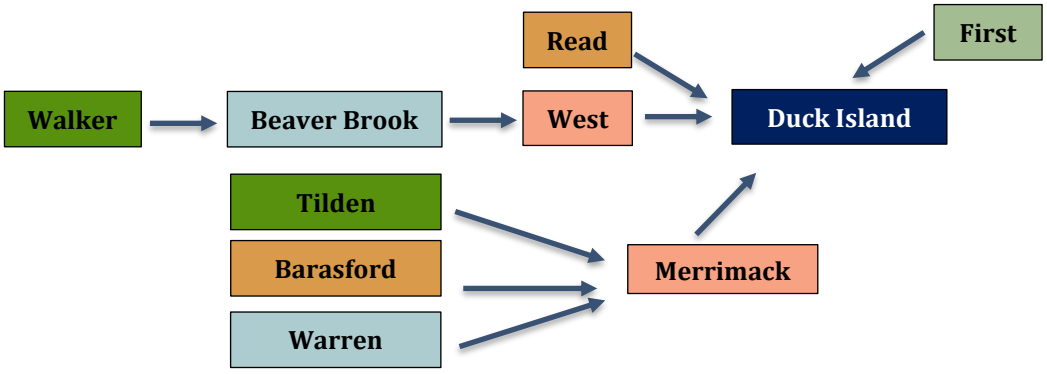
The West Sewershed comprises approximately 564 acres, and is located on the north side of the Merrimack River. Flows in the sewershed generally travel southward into the 96" West Interceptor, toward West Station, where CSO is regulated. From there, flows are conveyed by the North Bank portion of the sewer system en route to Duck Island WWTP. The sewershed land use is mostly residential with some commercial and open space also and includes the Centralville neighborhood.

CSO Control Alternatives	System Optimization	Sewer Separation	Offline Storage	Conveyance to North Bank Wet Weather Treatment Facility
Pros	• Maximum performance of existing infrastructure	• Reduced risk of sewer backup	• High CSO reduction • Full treatment of captured CSO and SW	• High CSO reduction • Partial treatment of CSO and SW
Cons	• Limited CSO reduction	• Highly disruptive to traffic and neighborhoods • SW load remains	• Siting challenges • O&M	• Capacity limitations of existing downstream sewers



Duck Island

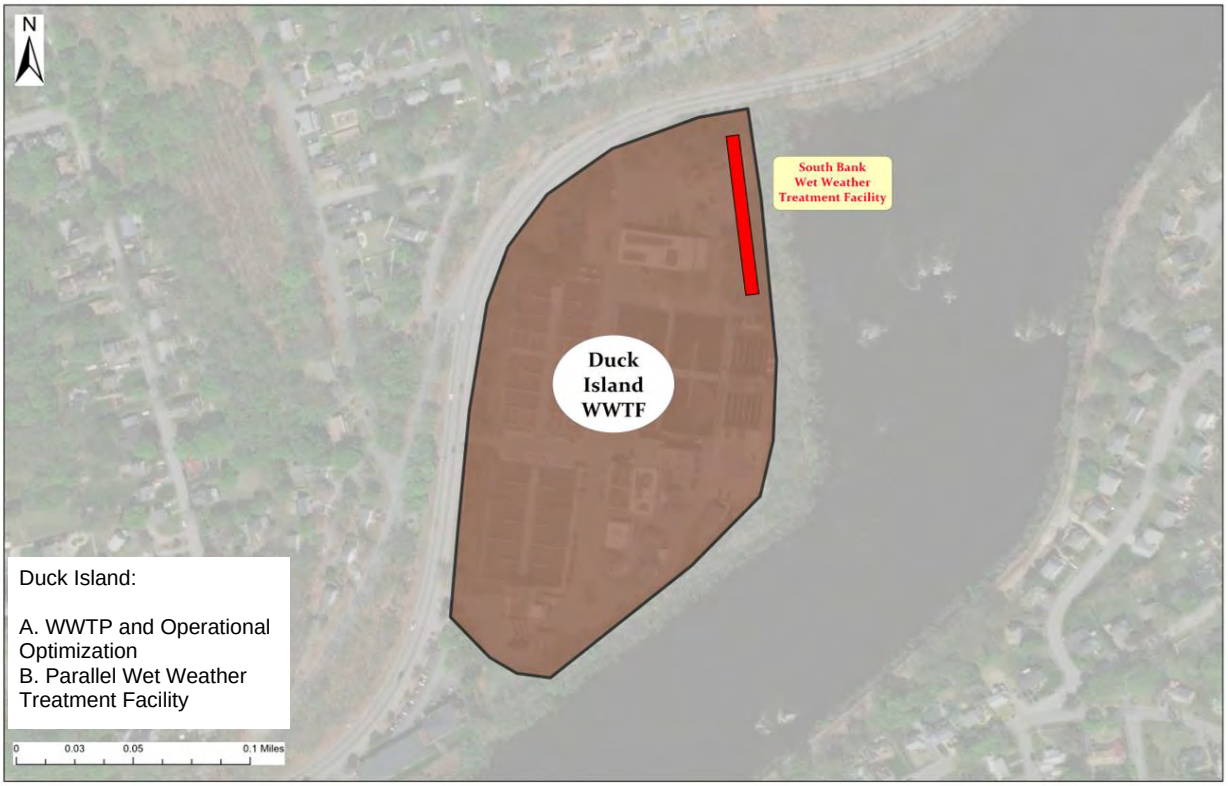
Key Metrics:



Background

Duck Island is the location of the regional WWTP that serves all sewersheds in the City, as well as separate sewersheds from four surrounding towns. The site is approximately 18 acres in size.

CSO Control Alternatives	WWTP and Operational Optimization	Parallel Wet Weather Treatment Facility
Pros	• CSO reduction • Higher level of treatment	• High CSO reduction • Partial treatment of CSO and SW
Cons	• Increased risk to process biology • Sludge management during wet weather	• WWTP site space constraints • New outfall and pumping required



5.4 Systemwide CSO Control Alternatives

In addition to controls being implemented within individual sewersheds, the CSO control alternatives analysis included an investigation of systemwide measures that have the potential to reduce untreated CSO discharges from all sewersheds. These systemwide alternatives would result in wide ranging operation changes and updates to Lowell's HFM strategy. In addition, each of the alternatives described below would be implemented in concert with control measures in individual sewersheds, providing even greater CSO control benefit.

5.4.1 North Bank WWTF

As indicated previously, a unique opportunity for CSO control exists at a specific location in Lowell's interceptor system (along the North Bank Interceptor) where there is a sudden 6-foot elevation drop in this 96-inch pipe, as shown in Figure 5-11. The North Bank WWTF alternative takes advantage of the unique system feature and would have the ability to utilize gravity to move flow through a proposed screening and disinfection facility. The proposed screening and disinfection facility would conceptually operate in an automated fashion, be gravity-driven, and include the following design elements (pending final design):

- Up to ~1 MG storage volume comprised of "plug flow" channels that accommodate disinfectant contact time and some settling of solids (pending final design), along with influent and effluent chambers
- Peak flow capacity (15-minute disinfection contact time) of 90 MGD
- Horizontally mounted CSO screen integrated with a static influent weir, keeping debris in the collection system to be handled at the WWTF
- Static effluent weir set at an elevation that accommodates sufficient contact time within the tank channels for adequate disinfection
- Automatic draining of the facility by gravity to the interceptor (en route to the WWTF) post-event
- Automatic cleaning of the facility with the use of tipping buckets and/or flush gates
- Chlorination and dechlorination of flows (pending selection of specific disinfectant method)

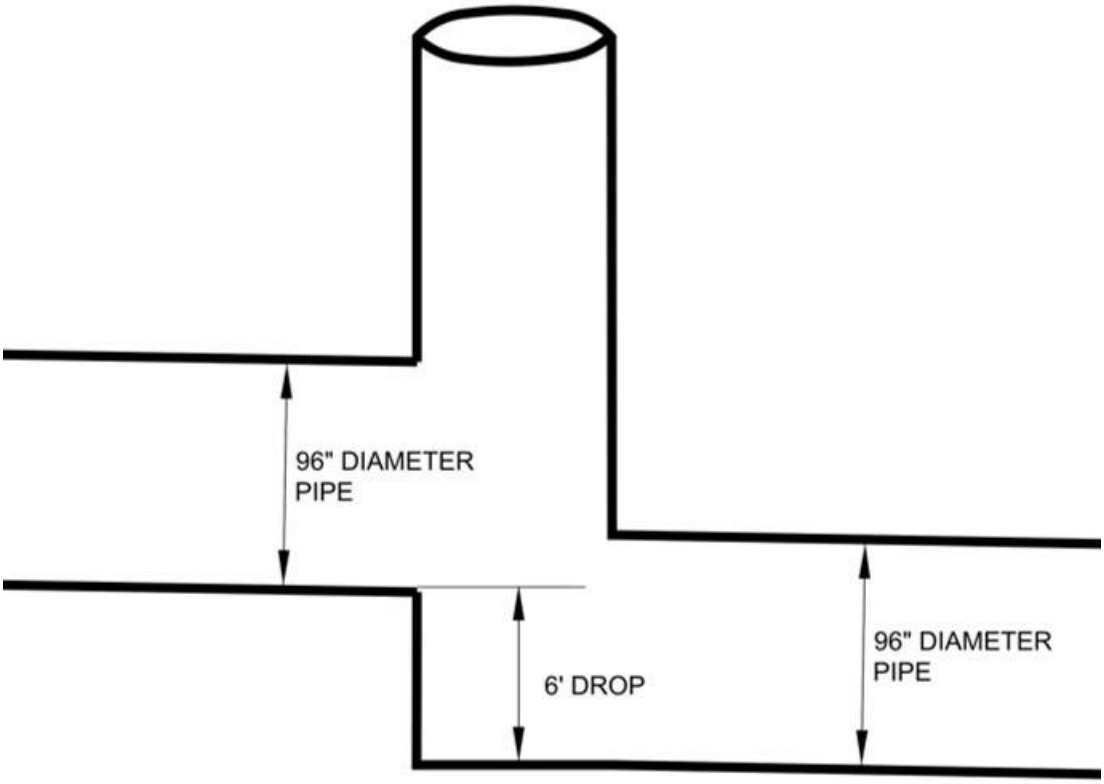
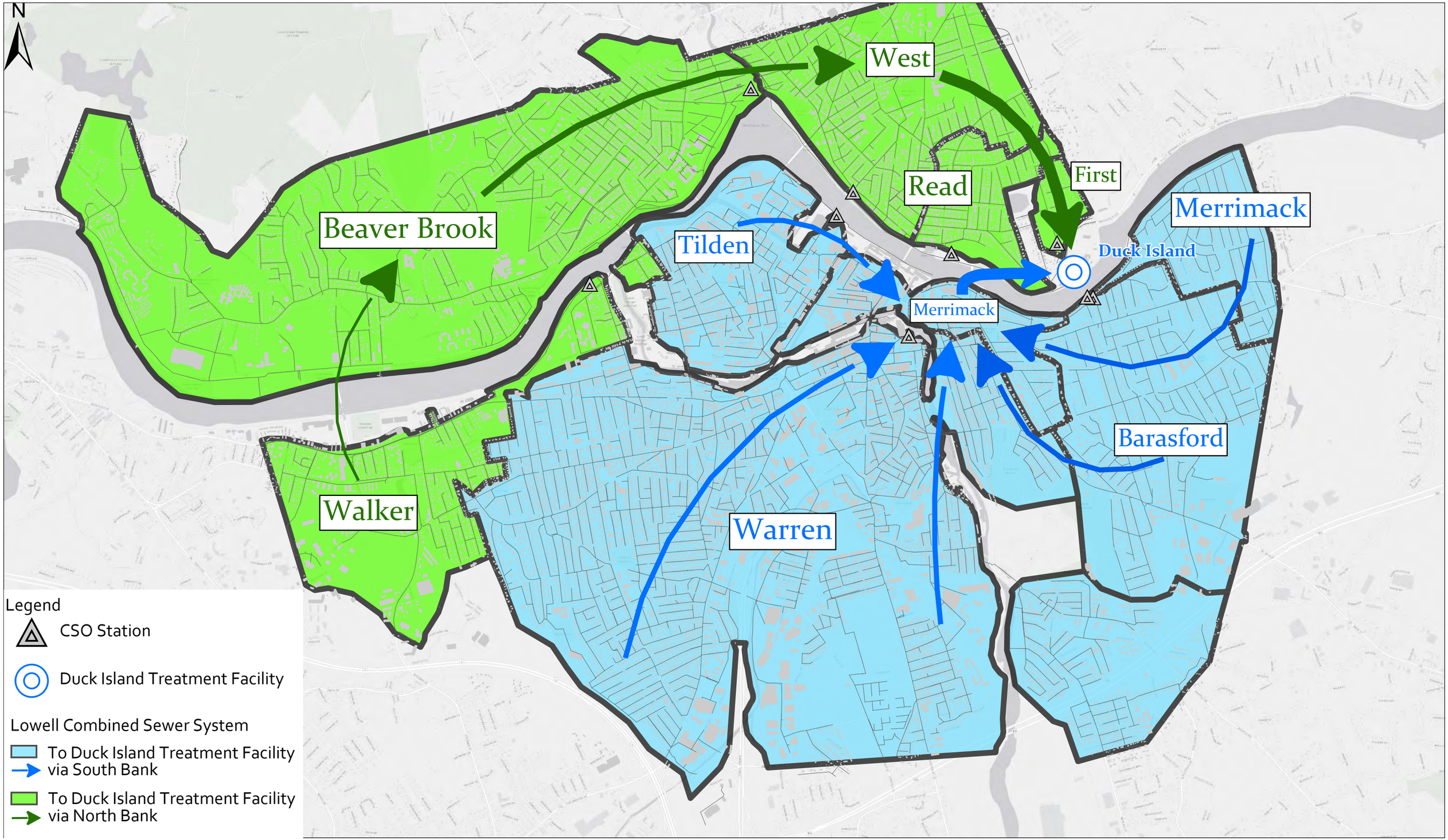


Figure 5-11: Graphic of NB invert drop

This screening and disinfection facility (SDF) would result in a significant expansion of Lowell's wet weather treatment capacity and drastically reduce the volume and frequency of CSOs along the North Bank Interceptor system. In addition, this additional treatment facility would result in additional capacity becoming available at the Duck Island WWTF to treat more flow from the South Bank (through Merrimack CSO station). Thus, this systemwide alternative would cost-effectively reduce CSOs along the North Bank Interceptor and allow additional flow conveyance from the South Bank Interceptor to reach the WWTF, reducing CSOs on that side of the collection system as well.

Figure 5-12 is a diagram depicting Lowell's existing wet weather conveyance and treatment strategy, and Figure 5-13 is a diagram depicting a possible future wet weather conveyance and treatment strategy that includes the North Bank WWTF.

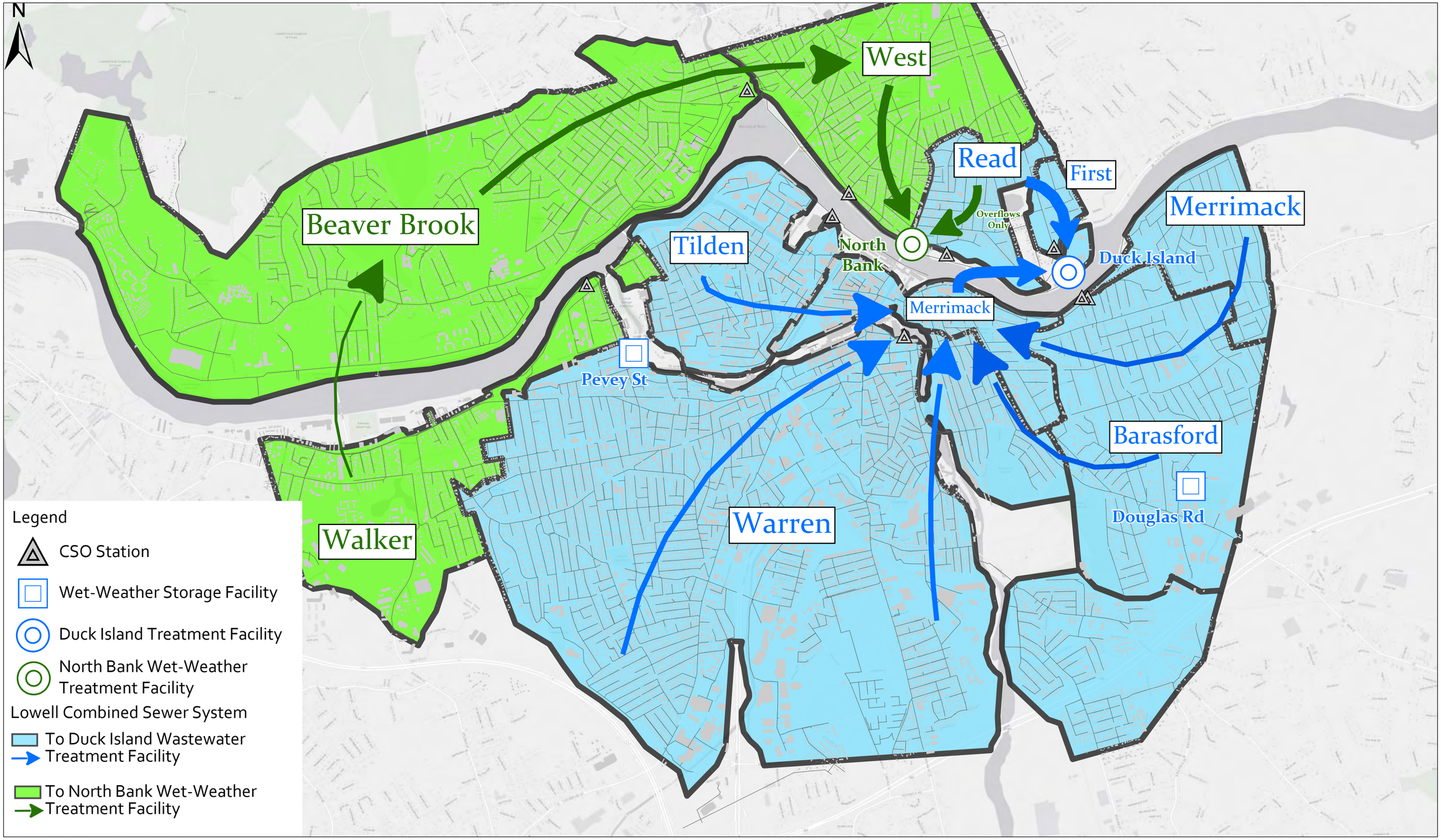


Hazen

City of Lowell Combined Sewer System
Existing Wet Weather Transport and Treatment

LOWELL WATER
Community ~ Health ~ Environment

Figure 5-12



City of Lowell Combined Sewer System
Wet Weather Transport and Treatment Alternative

Figure 5-13

5.4.2 Duck Island Improvements

Another important systemwide CSO control alternative that was evaluated was additional peak wet weather treatment capacity at the Duck Island WWTF. Currently, the WWTF can handle peak wet weather flows up to approximately 110 MGD. Flow control gates throughout the collection system (at Merrimack Station and in the North Bank Interceptor) throttle flow during wet weather to ensure that peak capacity is not exceeded.

During high flow treatment at the WWTF, the biological and secondary clarifier systems (secondary treatment) are bypassed. Bypassed flow is screened and clarified, pre-chlorinated, and remixed with the flow that received full treatment before being disinfected and discharged. Improvements at the WWTF that would bypass hydraulic bottlenecks and improve peak treatment capacity at the plant would result in more flow being conveyed to the WWTF during wet weather, reducing the volume and frequency of overflows at the CSO stations. Several alternatives for improving peak treatment capacity at Duck Island were investigated using the model, as described in Section 5.6 of this report.

5.5 Inflow and Infiltration Control

Inflow and Infiltration (I/I) may contribute to surcharged sewer conditions during wet weather in some sewer systems. In general, I/I refers to excess water entering into the sewer system in areas where a separate storm drainage system has been constructed and the sanitary sewer system is no longer designed to convey stormwater for treatment. As such, removal of I/I is of higher importance in sewer collection systems that are further separated than Lowell's. Since much of Lowell's collection system is a combined system (designed to collect and convey stormwater in addition to sanitary flow), I/I in the separated portions of Lowell's system accounts for only a negligible portion of additional flow during wet weather. Thus, I/I control is not an effective systemwide CSO control strategy. Regardless, Lowell has a three pillar approach to I/I removal that will help to provide minor improvements to CSO control long term. These three pillars are described below.

5.5.1 Site Stormwater Management and Private Inflow Removal

Lowell has enacted new regulations and requirements that new developments and properties which are redeveloped must include stormwater control measures that would prevent stormwater runoff being conveyed to the combined sewer. In addition, Lowell has enacted ordinances governing the removal of private inflow when properties are redeveloped.

5.5.2 CIPP Lining

Lowell has an on-going CIPP lining program. When a pipe is outfitted with a CIPP liner, the structural integrity of that pipe is enhanced, and infiltration is essentially eliminated. Lowell prioritizes lining based on the structural need of its aging infrastructure, which is assessed continuously via its CCTV program. It is important that Lowell continue to prioritize lining based on structural need, as a pipe collapse has the potential to creature a public health crisis, with SSOs and sewer backups, and significant disruptions with

damage to streets and roadways. As lining is completed, infiltration is reduced or eliminated in lined pipe segments. As such, Lowell plans to address infiltration by continuing to implement its CIPP lining program.

5.5.3 Conductance Testing

Lowell has recently implemented a conductance testing program. As the expected conductivity of wastewater is known, it is possible to find sources of inflow (with different conductivity) by measuring conductance in the wastewater flow at various points throughout the sewer system. This method is useful for detecting large sources of public inflow, such as canals, that may also continuously contribute dry weather inflow.

5.6 Simulation of Alternatives and Model Investigations

In order to analyze the possible effectiveness of the CSO control measures described herein, the calibrated sewer system model was used to predict system performance for future conditions with new CSO controls. To perform this evaluation and measure the potential CSO reduction benefits of alternatives from an annual average basis, a statistical analysis of historical rainfall data was performed to select a "typical" rainfall year. Through the statistical analysis described in this section, the calendar year 2000 was selected as the typical rainfall year. After this year was selected, the calibrated model was used to simulate system performance with typical year rainfall data. The results of this simulation represent existing (baseline) conditions, or current predicted system performance, and represent the benchmark against which the effectiveness of CSO controls can be assessed.

5.6.1 Typical Rainfall Year

The typical rainfall year analysis was performed using hourly rainfall data from the Boston Logan Airport Rain Gauge using data obtained from NOAA. At the time this analysis was performed, the longest possible period of record (1948-2013) was used. To determine typical rainfall conditions, average values were calculated for the following metrics:

- Number of events
- Average event length (hrs)
- Maximum peak intensity (in/hr)
- Average peak intensity (in/hr)
- Average number of days between events
- Depth of annual rainfall (in)
- Number of back-to-back events
- Number of events >0.10-inches depth

- Number of events >0.25-inches depth
- Max single event depth (in)

By comparing each of these metrics for all calendar years to the average values calculated for all years, the five most typical years were identified. Metrics for these years, and percent differences from average conditions, are shown in Table 5-3 and Table 5-4, respectively.

Table 5-3: Representative Rainfall Years and Average Typical Year Conditions

Year	Events	Average Event Length (hr)	Peak Intensity (in/hr)	Average Peak Intensity (in/hr)	Days Between Events	Annual Rainfall (in)	Number of Back to Back Events	>.10-inches	>.25 inches	Max Rainfall
Average	123.74	6.44	0.88	0.11	2.68	42.95	46	66.8	45.1	3.60
1990	128.00	6.00	0.93	0.11	2.61	46.50	45	66.0	48.0	3.91
1970	121.00	6.50	0.95	0.10	2.70	41.91	45	70.0	45.0	2.83
1991	115.00	6.20	0.72	0.12	2.86	42.25	43	67.0	44.0	3.32
1993	127.00	6.30	0.63	0.11	2.59	43.21	43	66.0	43.0	2.96
2000	**121.00**	**6.10**	**0.72**	**0.12**	**2.77**	**44.52**	**44**	**69.0**	**47.0**	**4.14**

Table 5-4: Representative Rainfall Years and Deviation from Average Typical Year Conditions

Year	Events	Average Event Length (hr)	Peak Intensity (in/hr)	Average Peak Intensity (in/hr)	Days Between Events	Annual Rainfall (in)	Number of Back to Back Events	>.10-inches	>.25 inches	Max Rainfall	Average Percent Diff
1990	3%	7%	5%	1%	2%	8%	2%	1%	6%	9%	5%
1970	2%	1%	8%	8%	1%	2%	2%	5%	0%	21%	5%
1991	7%	4%	19%	10%	7%	2%	6%	0%	2%	8%	6%
1993	3%	2%	29%	1%	3%	1%	6%	1%	5%	18%	7%
2000	**2%**	**5%**	**19%**	**10%**	**3%**	**4%**	**4%**	**3%**	**4%**	**15%**	**7%**

The year selected for use in the CSO control alternatives analysis, 2000, is a conservative choice as it includes more total rainfall, larger (>0.10- and 0.25-inch depth) events, and a larger max storm depth compared to typical (average) conditions. As such, predicted CSO volumes are larger compared to other years. This year was selected since it reasonably represents the average, or typical, rainfall condition, but with a slightly conservative bias, which could represent potential impacts due to climate change.

5.6.2 Existing Conditions – Typical Year System Performance

In order to establish a baseline against which simulated CSO control measures could be compared, the calibrated model was used to simulate the typical year (2000). The predictions from this model simulation represent how the sewer system is anticipated to perform without any additional CSO control measures during a typical rainfall year. Average annual overflow volume (AAOV) and frequency were predicted at each CSO station. Table 5-5 contains model predictions from the typical year simulation under existing conditions.

Table 5-5: Model Predicted Typical Year CSO Performance

CSO Station	AAOV (MG)	Frequency
West	121.8	34
Merrimack	115.2	21
Warren	48.8	20
Tilden	22.0	18
Read	8.1	17
Walker	7.0	8
Beaver Brook	5.7	5
Barasford	3.1	6
First	0.0	0
Total CSO Volume	**331.7**	

The results of this simulation indicate that approximately 70% of total annual CSO volume occurs due to discharges at West and Merrimack stations. These stations serve as two critical hydraulic relief points in the North and South Bank interceptors. Overflows at Warren and Tilden station account for a further 21% of predicted AAOV during the typical year. Together, these four stations (West, Merrimack, Warren, and Tilden) account for over 90% of predicted AAOV. As such, these stations were determined to be high priority locations for CSO control measures.

Note that ranked overflow bar charts for each CSO station, that depict the volume of each overflow event, are included in Section 5.6.3.5 through Section 5.6.3.12. These sections contain an alternatives analysis of retained CSO control measures for each CSO station.

5.6.3 CSO Control Alternatives Simulations

This section describes CSO control strategies that were simulated using the model. Several systemwide CSO control strategies, such as sewer separation, offline storage tanks, and additional wet weather treatment were simulated in addition to specific improvements within each sewershed and at each CSO station.

5.6.3.1 North Bank WWTF

To determine the potential of the North Bank WWTF to reduce untreated CSO discharges, several model simulations were conducted with different configurations of this facility. The facility was simulated using

a series of weirs and a storage node (the tank). Several RTCs were also revised in the model to prioritize conveying flow from the South Bank interceptor to the Duck Island WWTF. In simulations with the North Bank WWTF, the Read Interceptor inline flow control gate was allowed to close almost completely, since the North Bank WWTF serves as a hydraulic relief point and mitigates the risk of an SSO due gate closure. All overflows from Read CSO station were also conveyed to the North Bank WWTF. Figure 5-14 depicts the configuration of the North Bank WWTF in the model.

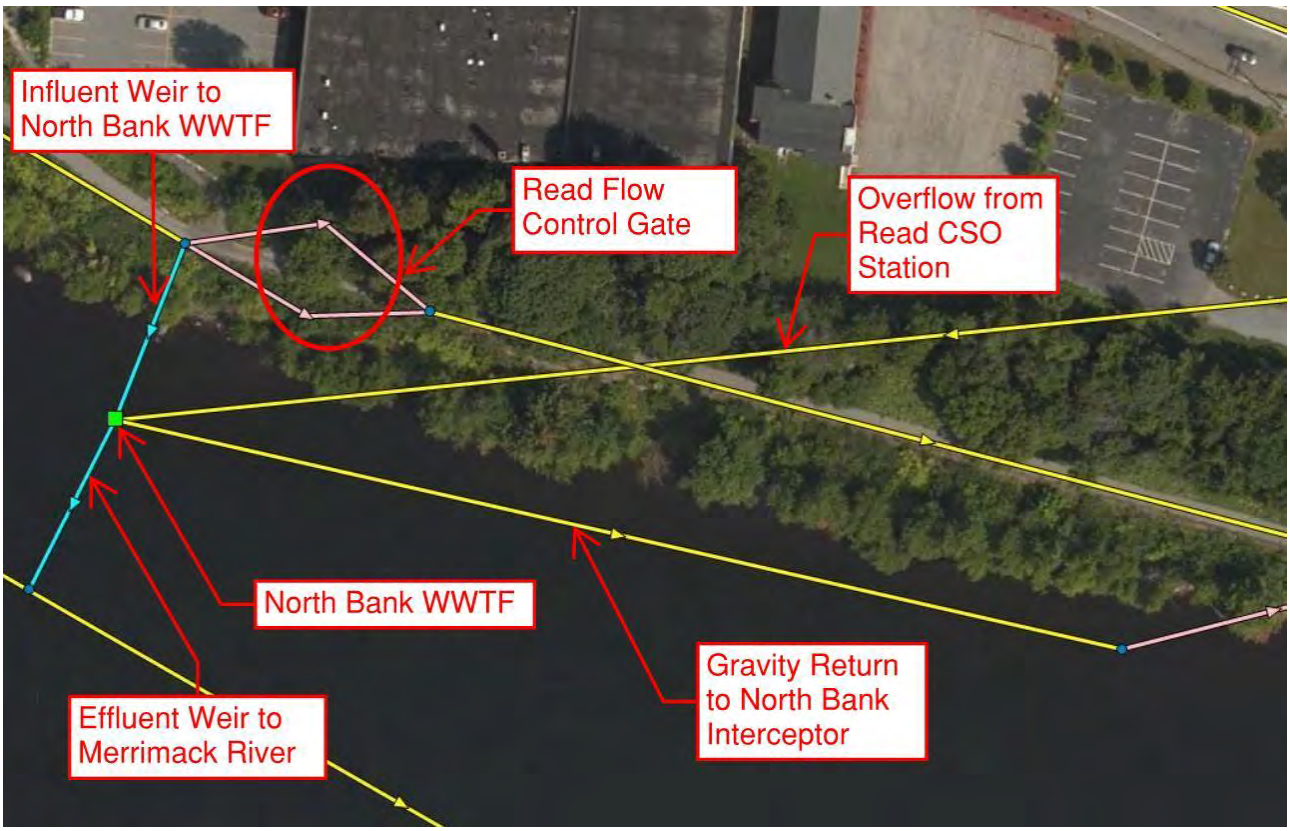


Figure 5-14: Modeled Configuration of North Bank WWTF

Since the facility is designed to operate by gravity only (no pumping), flow into and out of the facility is determined by influent and effluent weir elevations. The weir elevations also control the size (volume) of the facility. The volume of the facility impacts the amount of time flow is detained and the degree of disinfection achieved. As such, weir elevations will impact the hydraulic benefits of the facility as well as influence the design flow rate for disinfection.

Several model simulations were conducted to assess the performance associated with the range of different weir configurations. Note the interceptor has a diameter of 96 inches at the North Bank WWTF, so any height above 96 inches is above the crown of the pipe. Table 5-6 contains results from these simulations.

Table 5-6: North Bank WWTF (8.3' influent weir, 0.956 MG tank volume)

CSO Station	Existing Conditions		North Bank WWTF	
	AAOV (MG)	Frequency	AAOV (MG)	Frequency
West	121.8	34	95.7	27
Merrimack	115.2	21	62.0	12
Warren	48.8	20	49.7	20
Tilden	22.0	18	22.0	18
Read	8.1	17	0.0	0
Walker	7.0	8	6.6	8
Beaver Brook	5.7	5	3.4	4
Barasford	3.1	6	3.6	5
First	0.0	0	0	N/A
Total Untreated CSO Volume	**331.7**		**242.9**	

As shown in Table 5-6, the model predicts that the North Bank WWTF would contribute substantially to reducing untreated CSO volume, both at West Street station (21% reduction) and systemwide (27% reduction). Since overflows from Read CSO station are routed directly to the North Bank WWTF, untreated CSOs are completed eliminated from this location. By reducing the amount of wet weather flow conveyed to the Duck Island WWTF from the North Bank interceptor, more flow can be conveyed through Merrimack Station (South Bank) for treatment at Duck Island. As such, the total CSO volume at the Merrimack Station was also substantially reduced by 46% in this simulation. These findings demonstrate that the North Bank WWTF has the potential to significantly reduce the volume and frequency of untreated CSOs on a systemwide basis. Since the influent weir was above the crown of the interceptor pipe for the simulation described above, additional simulations were conducted to assess the benefit of lowering the influent weir elevation below the crown of the pipe.

Table 5-7: North Bank WWTF (7.3' influent weir, 0.849 MG tank volume)

CSO Station	Existing Conditions		North Bank WWTF	
	AAOV (MG)	Frequency	AAOV (MG)	Frequency
West	121.8	34	37.1	21
Merrimack	115.2	21	60.6	12
Warren	48.8	20	49.4	19
Tilden	22.0	18	22.3	18
Read	8.1	17	0.0	0
Walker	7.0	8	6.7	8
Beaver Brook	5.7	5	3.0	3
Barasford	3.1	6	2.9	5
First	0.0	0	0.0	0
Total Untreated CSO Volume	**331.7**		**182.0**	

As shown in Table 5-7, lowering the weir elevations such that the influent weir is below the crown of the pipe results in a substantial untreated CSO control benefit at West Station and systemwide. Overall systemwide untreated CSO is reduced further from a 27% reduction to a 45% reduction, and control at West Station improves from a 21% reduction to a 70% reduction. This finding is significant since it indicates that the North Bank WWTF has the potential to reduce untreated CSO volumes at Lowell's two largest CSO stations, West and Merrimack, by 70% and 47%, respectively, with the implementation of one project.

Table 5-8 through Table 5-11 contain model predictions for additional simulations with lower weir elevations. The model predicts that lower weir elevations consistently reduce the amount of untreated CSO discharged systemwide, and especially at West Station. Despite this, decreasing the weir elevations results in smaller facility volumes which achieve lesser degrees of disinfection for some large overflow events. As such, during detailed design, further analysis regarding weir elevations and facility volume should be conducted. A final design could provide flexibility through the use of adjustable weirs or other similar provisions.

Table 5-8: North Bank WWTF (6.8' influent weir, 0.797 MG tank volume)

CSO Station	Existing Conditions		North Bank WWTF	
	AAOV (MG)	Frequency	AAOV (MG)	Frequency
West	121.8	34	22.0	15
Merrimack	115.2	21	59.1	12
Warren	48.8	20	49.8	20
Tilden	22.0	18	22.4	18
Read	8.1	17	0.0	0
Walker	7.0	8	6.3	8
Beaver Brook	5.7	5	3.1	3
Barasford	3.1	6	3.1	4
First	0.0	0	0.0	0
Total Untreated CSO Volume	**331.7**		**165.8**	

Table 5-9: North Bank WWTF (6.3' influent weir, 0.744 MG tank volume)

CSO Station	Existing Conditions		North Bank WWTF	
	AAOV (MG)	Frequency	AAOV (MG)	Frequency
West	121.8	34	13.9	11
Merrimack	115.2	21	58.0	11
Warren	48.8	20	49.3	20
Tilden	22.0	18	22.6	18
Read	8.1	17	0.0	0
Walker	7.0	8	6.7	8
Beaver Brook	5.7	5	2.9	3
Barasford	3.1	6	3.1	3
First	0.0	0	0.0	0
Total Untreated CSO Volume	**331.7**		**156.5**	

Table 5-10: North Bank WWTF (5.8' influent weir, 0.690 MG tank volume)

CSO Station	Existing Conditions		North Bank WWTF	
	AAOV (MG)	Frequency	AAOV (MG)	Frequency
West	121.8	34	9.5	8
Merrimack	115.2	21	56.2	11
Warren	48.8	20	49.0	20
Tilden	22.0	18	22.1	18
Read	8.1	17	0.0	0
Walker	7.0	8	6.7	8
Beaver Brook	5.7	5	3.0	3
Barasford	3.1	6	3.1	4
First	0.0	0	0	0
Total Untreated CSO Volume	**331.7**		**149.6**	

Table 5-11: North Bank WWTF (5.3' influent weir, 0.637 MG tank volume)

CSO Station	Existing Conditions		North Bank WWTF	
	AAOV (MG)	Frequency	AAOV (MG)	Frequency
West	121.8	34	6.5	8
Merrimack	115.2	21	59.3	11
Warren	48.8	20	49.4	20
Tilden	22.0	18	22.2	18
Read	8.1	17	0.0	0
Walker	7.0	8	6.6	8
Beaver Brook	5.7	5	2.8	3
Barasford	3.1	6	2.9	4
First	0.0	0	0.0	0
Total Untreated CSO Volume	**331.7**		**149.6**	

Based on the simulations described above and summarized in Table 5-8 through Table 5-11, several key conclusions about the effectiveness of the North Bank WWTF for CSO control can be reached:

1. The facility's performance is sensitive to inlet weir elevation; simulations with inlet weir heights below the crown of the pipe resulted in the most significant untreated CSO reductions.

2. The North Bank WWTF results in substantial CSO reductions systemwide, and at the two CSO stations that currently discharge the most (volume and frequency) during the typical rainfall year.

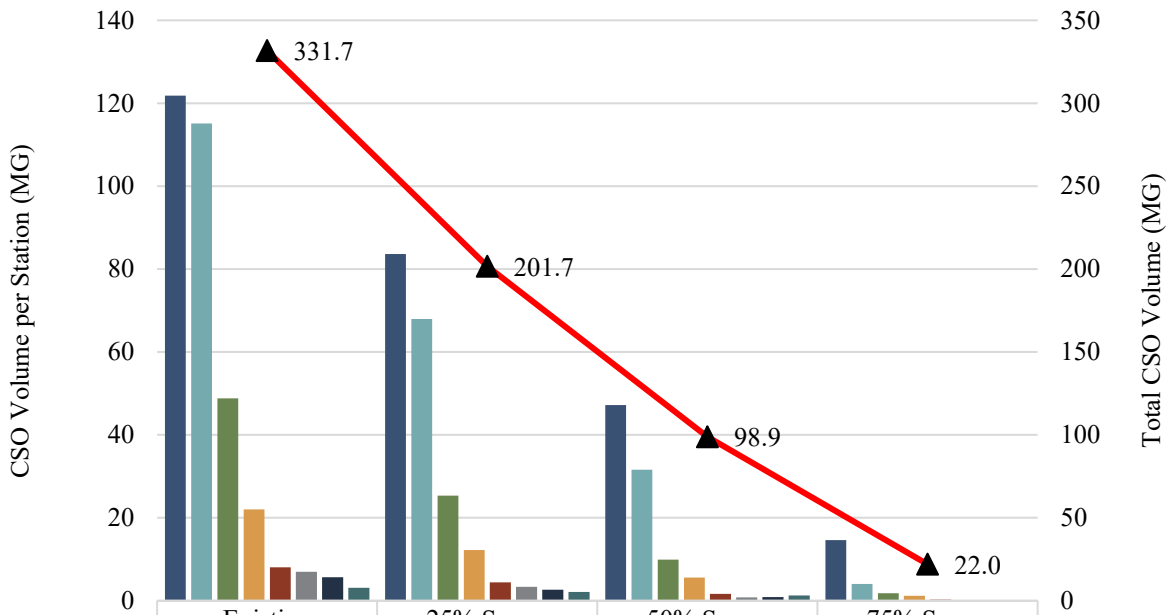
3. The North Bank WWTF does not significant impact CSO performance at Warren and Tilden stations (the third and fourth largest stations by volume) based on model predictions.

These findings indicate that the North Bank WWTF should be an important element of Lowell's CSO control plan and should be paired with other CSO control technologies to further reduce CSO, especially at Warren and Tilden stations.

5.6.3.2 Sewer Separation

Different levels of sewer separation (public and private) were simulated on a systemwide basis with the objective of achieving 25%, 50%, 75%, and 100% CSO control. Public and private sewer separation includes the removal of private inflow sources (such as flat roof drains and sump pumps) in addition to public sources (catch basins) from the sanitary sewer. Public and private sewer separation is often very costly and beset with feasibility concerns, since the construction of a new sanitary sewers or the removal of private inflow sources is often very difficult to achieve, especially in dense cities with old infrastructure, like Lowell.

For the purposes of modeling sewer separation, the contributing area of each subcatchment was reduced by a certain percentage until the target level of CSO control (25%, 50%, etc.) was achieved. Figure 5-15 displays the results of this analysis.



	Existing Conditions	25% Sewer Separation	50% Sewer Separation	75% Sewer Separation
West Street	121.8	83.6	47.2	14.7
Merrimack	115.2	68.0	31.6	4.0
Warren	48.8	25.4	9.9	1.8
Tilden	22.0	12.2	5.6	1.2
Read Street	8.1	4.4	1.7	0.2
Walker	7.0	3.4	0.8	0.0
Beaver Brook	5.7	2.6	0.9	0.0
Barasford Avenue	3.1	2.2	1.2	0.1
Total CSO	331.7	201.7	98.9	22.0

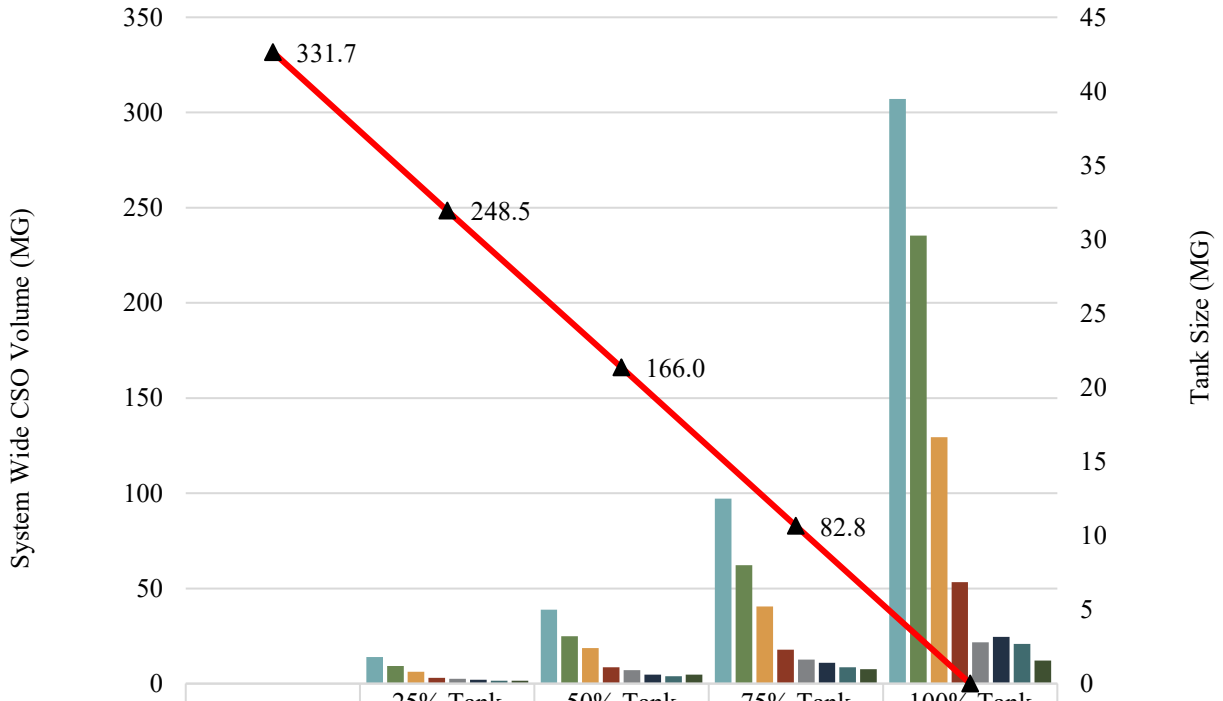
Figure 5-15: Systemwide Sewer Separation Model Predictions

It should be noted that the sewer separation simulations were conducted to determine the effectiveness (relative to cost) of sewer separation compared to other systemwide CSO control technologies (as analyzed in Chapter 6 of this report). These simulations do not consider the feasibility of large-scale sewer separation on a citywide basis. Citywide sewer separation is very difficult to achieve and costly. Further, sewer separation introduces additional pollutant loading to receiving waterbodies with untreated stormwater discharges. As such, citywide sewer separation is not an ideal CSO control strategy. Targeted sewer separation was further evaluated in sewersheds where this approach is more feasible.

5.6.3.3 Offline Storage

The model was used to determine tank sizes required to store 25%, 50%, 75%, and 100% of typical year overflow volume at each CSO station. To perform this analysis, overflows at each station during the typical year were ranked by size and the tank size required to store the specified percentage of the total overflow volume was calculated. As such, a 25% control tank would only completely store a subset of

storm events, while a 100% control tank would be equivalent in size to the largest typical year overflow event, and thus completely store all storm events. The results of this analysis are summarized in Figure 5-16.



	No Tanks	25% Tank Size (MG)	50% Tank Size (MG)	75% Tank Size (MG)	100% Tank Size (MG)
Merrimack		1.8	5.0	12.5	39.5
West Street		1.2	3.2	8.0	30.3
Warren		0.8	2.4	5.2	16.6
Tilden		0.4	1.1	2.3	6.9
Beaver Brook		0.3	0.9	1.6	2.8
Walker Station		0.3	0.6	1.4	3.2
Read Street		0.2	0.5	1.1	2.7
Barasford Avenue		0.2	0.6	1.0	1.6
Total CSO	331.7	248.5	166.0	82.8	0.0

Figure 5-16: Offline Storage Tank Sizes and CSO Performance at Each CSO Station

This analysis was useful for determining how large offline storage tanks at each CSO station would need to be to significantly contribute to increased levels of CSO control. As can be seen at locations like Merrimack, West, Warren, and Tilden, tank sizes would need to be prohibitively large to significantly contribute to higher levels of CSO control. Sufficient land is not available at many locations to construct offline storage tanks and use of eminent domain would be required to obtain land for construction. At some locations, such as Walker, adjacent City owned land could be used for construction of an offline storage tank.

5.6.3.4 Green Infrastructure

Green infrastructure (GI) can be useful for attenuating peak rates of runoff during some rain events but is typically not useful for CSO control. GI is not typically capable of handling a sufficient volume of water to significantly reduce CSO volume or frequency. Regardless, this technology was assessed to determine its potential for CSO control on a systemwide basis.

GI was simulated in the model by reducing the impervious area of a given subcatchment by a certain percentage (the percent of the impervious area managed by GI) and creating a new subcatchment representing the imperious area managed. A new rainfall profile was applied to the new "GI managed" subcatchments where the first inch of rain was eliminated to represent the attenuation of runoff and small volume reduction typically associated with GI. The results of this analysis are depicted in Figure 5-17.

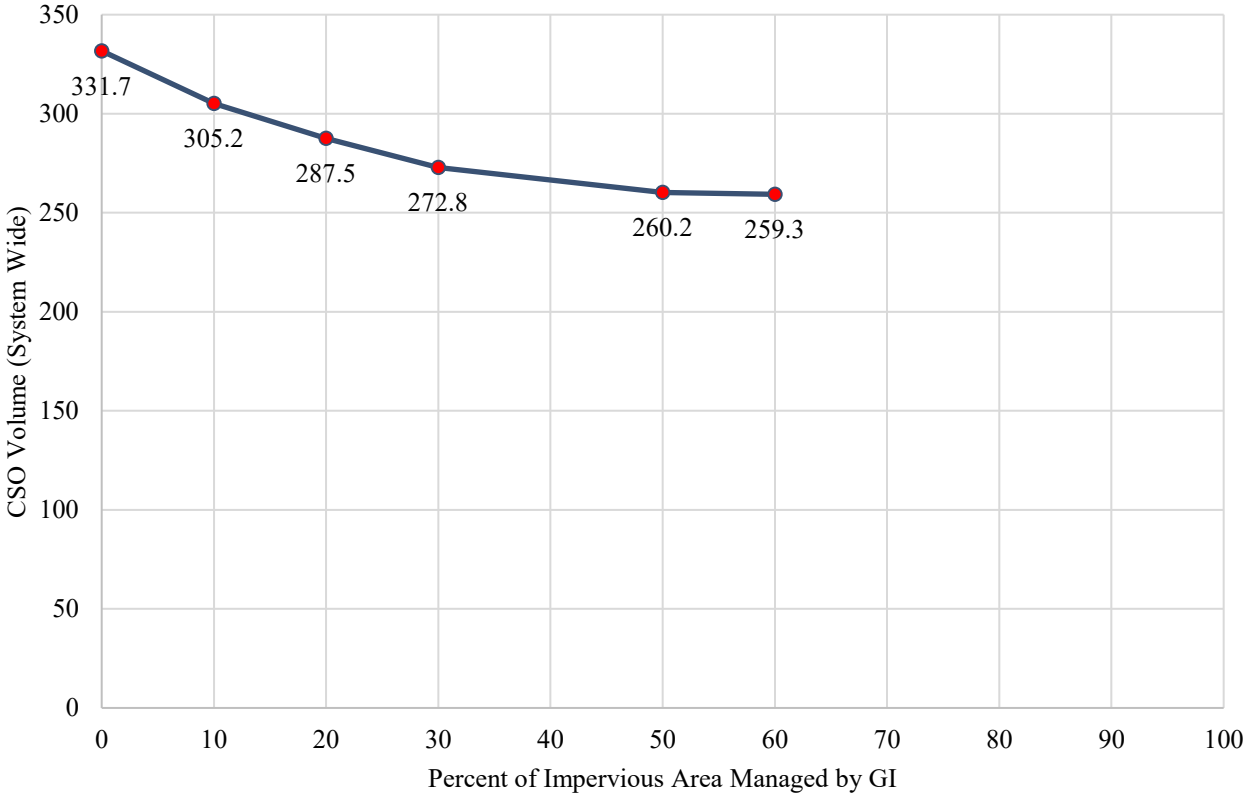


Figure 5-17: Model Predicted CSO Performance with Systemwide GI

As shown in Figure 5-17, systemwide GI does not have a significant impact on typical year CSO volumes. Further, as additional impervious area is managed by GI, CSO control benefit significantly diminishes. The model did not predict any CSO control benefit beyond 60% of impervious area being managed by GI. This reflects the fact that GI can only completely manage the runoff from very small storms, and only manages a small percentage of runoff generated by larger storm events. The diminishing predicted benefit of additional GI indicates that CSOs in Lowell's sewer system are driven mostly by large storm events which cannot be managed by GI. As such, model predictions demonstrate that GI

would not be an effective citywide CSO control technology. In some locations, however, GI may be a viable CSO control measure, when paired with other CSO control strategies.

5.6.3.5 Walker CSO Station

The Walker CSO station is the most upstream CSO station that is a part of the North Bank interceptor system. Flow that enters this station is either conveyed through three siphons to the North Bank interceptor or discharged as a CSO to the Merrimack River.

Lowell owns a vacant parcel adjacent to Walker station. This provides a unique opportunity to accomplish CSO control at this station using offline storage, that is not feasible without significant public disruption at other locations. By ranking all typical year model predicted overflows, tank sizes were estimated for 100%, 75%, 50%, and 25% levels of control, as shown in Figure 5-18.

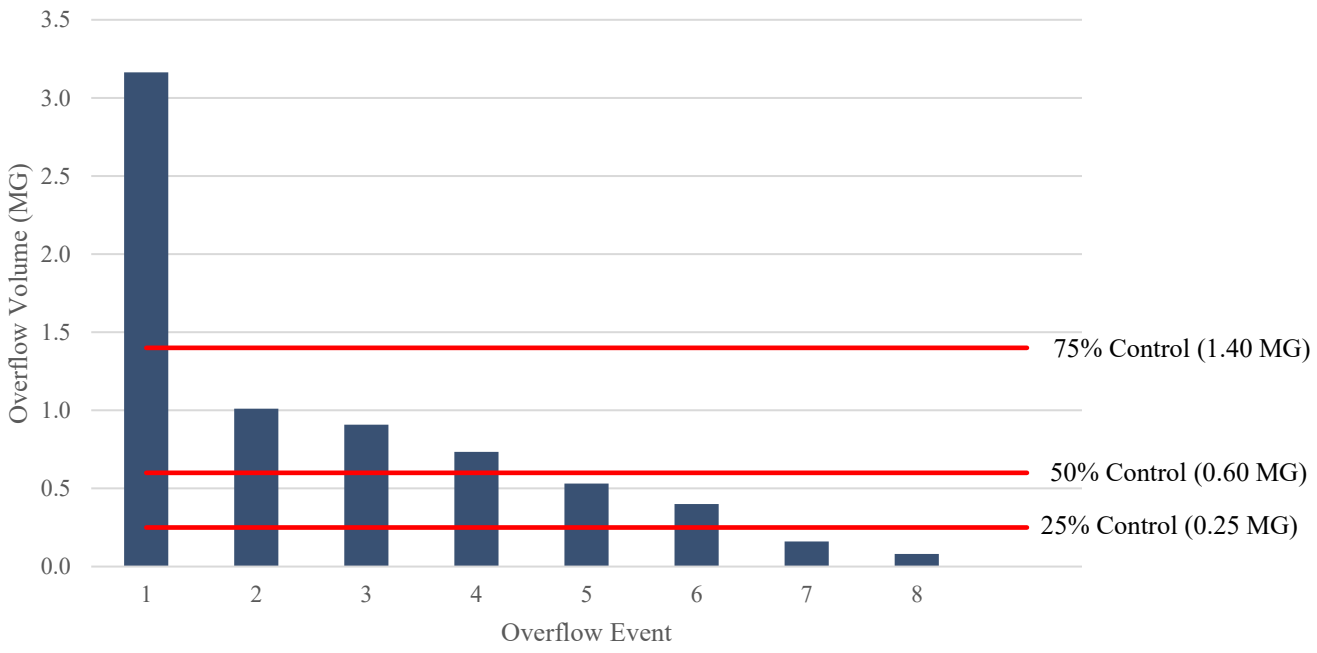


Figure 5-18: Ranked Typical Year Overflow Events at Walker CSO Station

This analysis indicates that a 3.2 MG tank constructed on this vacant parcel would achieve 100% CSO control during the typical year at the Walker CSO station. The model indicates that under existing conditions, there is no net benefit of conveying additional flow to the North Bank interceptor with an additional siphon since during some storm events that interceptor is already prone to surcharging, and the additional flow would likely be discharged as a CSO at Beaver Brook or West Station.

Sewer separation was also simulated in the area tributary to Walker Station. The results of those simulations are detailed in Section 5.6.3.2.

5.6.3.6 Beaver Brook Station

Beaver Brook is the next CSO station downstream of Walker on the North Bank Interceptor. Flow is either conveyed through three siphons underneath Beaver Brook or is discharged to the brook. Figure 5-19 depicts the volume of each overflow event that occurred during the typical year simulation, in addition to horizontal bars representing tank sizes required to achieve 25%, 50%, and 75% control.

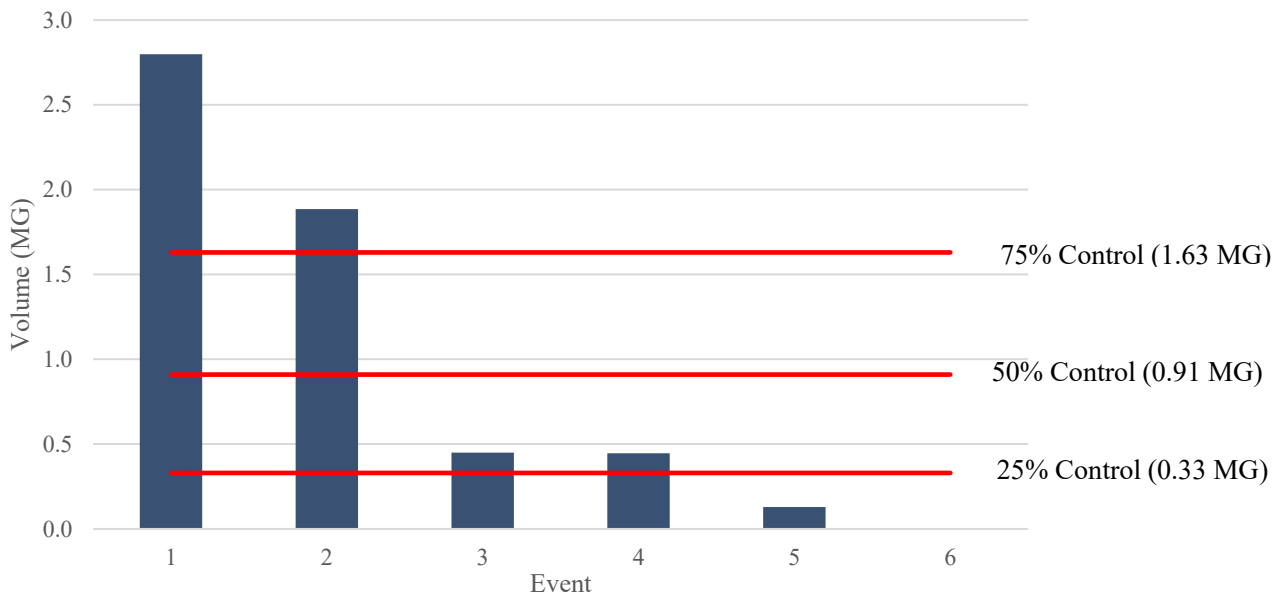


Figure 5-19: Model Predicted Typical Year Overflow Events at Beaver Brook CSO Station

Based on the above volumes, sizing for offline storage tanks was calculated, assuming a depth of 12 feet. The tank sizes were used to calculate the cost of constructing different size tanks for the purposes of the cost benefit analysis shown in Chapter 7. Due to space constraints, construction of these offline storage tanks would be difficult at Beaver Brook CSO station with the use of eminent domain to acquire additional parcels. As such, and due to the high cost of tank construction relative to other technologies, other alternatives for CSO control at Beaver Brook were analyzed using the model.

Since Beaver Brook contributes only a small fraction of the total typical year predicted CSO volume, strategies for increasing conveyance through the station were prioritized for analysis. The alternatives that were analyzed are as follows:

1. Allowing the flow control gate to remain fully open
2. Removal of an existing flume (restriction) in the station
3. Addition of a parallel 3-foot diameter siphon beneath Beaver Brook

Additional flow conveyed through the Beaver Brook station is subject to regulation at West Station (downstream). To assess the net effectiveness of the above improvements for CSO control, the total

combined CSO volumes from Beaver Brook and West stations were considered. For the purposes of these simulations, a future condition that included the North Bank WWTF, and other system improvements, was assumed. Table 5-12 contains the results of this investigation. Note that the simulated improvements in this analysis are not cumulative.

Table 5-12: Results of Increased Conveyance Analyses at Beaver Brook

	Existing Conditions	Eliminated Flow Control	Flume Removed	Additional Siphon
Beaver Brook CSO Volume (MG)	3.0	2.0	1.9	0.7
West Street CSO Volume (MG)	14.1	15.3	15.7	16.6
Combined CSO Volume (MG)	17.1	17.3	17.6	17.3

As shown in Table 5-12, based on model predictions, there is no net reduction of CSO volume between Beaver Brook and West Station if conveyance through Beaver Brook is enhanced. Although the model currently predicts no net benefit, it is possible that there may be more benefit to increased conveyance through Beaver Brook in the future if the North Bank WWTF were constructed. Post-construction monitoring and recalibration of the model (an integral activity to Lowell's adaptive management approach to the IP) would allow for more accurate predictions relating to improved conveyance through Beaver Brook.

5.6.3.7 West Station

Based on model predictions, West Station discharges the most CSO volume during the typical year. As such, achieving a high level of CSO control at this location is a high priority goal of Lowell's CSO control plan. This CSO station regulates cumulative flows from the West, Beaver Brook, and Walker sewersheds. Flow may either pass through the station, and continue in the North Bank interceptor, or discharge to the Merrimack River.

Flow is not actively regulated through West Station at present. The Read Interceptor inline control gate, which is downstream of West Station, controls flow through the North Bank interceptor in this area. The interceptor pipe downstream of West Station is large (96-inch diameter) and relatively flat and is utilized for inline storage by modulation of the Read Interceptor inline flow control gate. When the depth in West Station reaches 6.5 feet, excess flow is discharged as a CSO. Figure 5-20 depicts ranked overflow events at West Station.

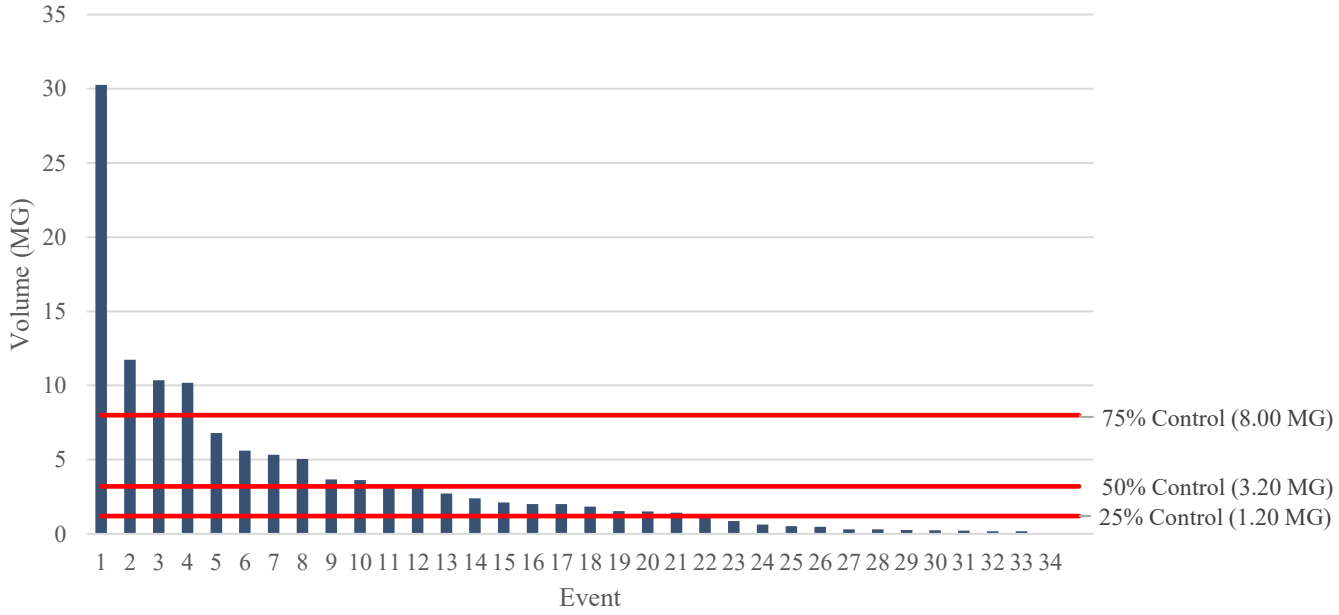


Figure 5-20: Model Predicted Typical Year Overflow Events at West CSO Station

West Station discharges a significant CSO volume and activates frequently. Consequently, very large offline storage tanks would be required to achieve significant CSO control at this location. West Street station is located in the median along the VFW Highway (a major transportation thoroughfare) and no land is available for the construction of an offline storage tank without the use of eminent domain. Tank sizes and volumes were calculated for the purpose of the cost benefit analysis shown in Section 0.

West Station regulates cumulative flow from several upstream sewersheds, meaning that sewer separation would need to occur in all upstream tributary areas (in addition to the West sewershed) to significantly impact CSO performance at this station. In addition, a flood reduction (levee and pump station) system exists along the river at this location; thus, any new piped storm drain flow (from sewer separation) would require a pump station to be constructed and would be subject to FEMA review. Due to these constraints, there are limited strategies for CSO reduction at this location.

As shown in Section 5.6.3.2, the North Bank WWTF has significant potential to reduce CSO at West Station. The model predicts that the North Bank WWTF will provide a hydraulic relief point between the Read Interceptor flow control gate that will significantly lower the Hydraulic Grade Line (HGL) upstream along the North Bank interceptor and through West Station. Since overflows at West Station are determined by level in the station, this HGL reduction has significant potential to reduce the volume and frequency of overflows at this station.

The model predicts that without any other improvements, construction of the North Bank WWTF has the potential to reduce CSO volume by 89% at West Station and reduce the number of typical year overflows from 34 to 11.

5.6.3.8 Tilden Station

The model predicts that Tilden Station is the fourth largest CSO station by total overflow volume (22 MG) and activations (18) during the typical rainfall year. This CSO station is the most upstream CSO station along the South Bank interceptor system. Flow entering the station either enters the South Bank interceptor for conveyance to Duck Island via Merrimack CSO station or may overflow to the Merrimack River. The interceptor directly downstream of the station is an undersized 36" pipe that the model predicts is prone to surcharging. In addition, data from the temporary flow monitoring program indicated backwater conditions in this pipe, providing further evidence that this pipe is undersized. As such, flow regulation at the Tilden Station is important to prevent the occurrence of an SSO. As a result, increasing conveyance through the station is not a viable strategy for CSO control. Offline storage tank sizes for CSO control were estimated by examining model predicted typical year overflow volumes, as shown in Figure 5-21.

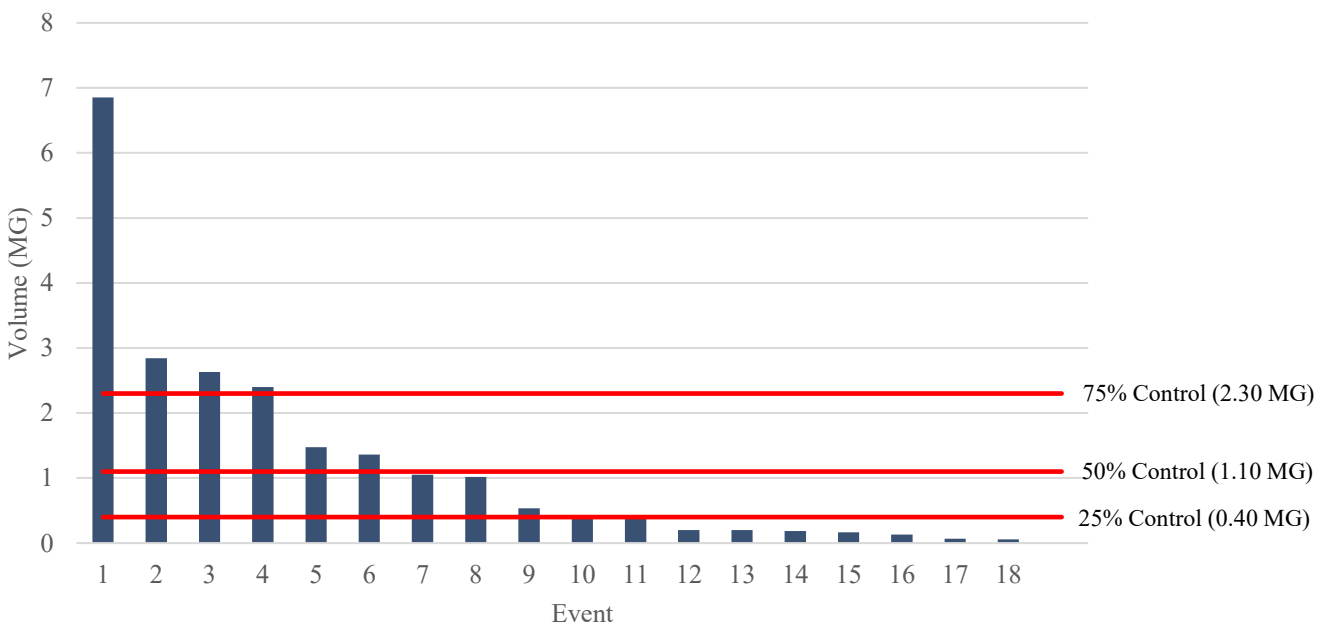


Figure 5-21: Model Predicted Typical Year Overflow Events at Tilden CSO Station

The model was used to assess strategies for reducing stormwater inflow in the areas tributary to Tilden Station. Different amounts of sewer separation and green infrastructure were simulated in the tributary areas. Through discussions with Lowell, several key areas were identified as feasible locations for sewer separation and one area was identified as a possible site for a large GI practice, near the North Common park and Murkland Elementary School.

The model simulations assumed 100% public (no removal of private inflow) sewer separation and a GI practice managing the first 1 inch of rainfall in the target area. Table 5-13 contains a summary of model predictions.

Table 5-13: Tilden Sewer Separation and GI Simulation

	AAOV (MG)	Frequency
Existing Conditions	22.0	18
Sewer Separation & GI	11.7	5

Based on the results shown in Table 5-13, sewer separation and GI have potential to be effective CSO control strategies in the Tilden sewershed. The GI project, which would be constructed in the North Common public park, would also provide educational benefits and increased public awareness of stormwater control initiatives.

5.6.3.9 Warren Station

The Warren CSO station is the third largest CSO station by model predicted typical year overflow volume (48.8 MG) and frequency (20 activations). As such, the station has been identified as a high priority location for improved CSO control. The CSO station regulates flow from a large tributary area that includes several neighborhoods such as Highlands, Back Central, Ayres City, and parts of South Lowell. Combined flows are either conveyed through three siphons to the South Bank interceptor system or discharged as CSO to the Concord River, immediately upstream of its confluence with the Merrimack River.

After the conclusion of the temporary flow monitoring program, a bar rack before the influent siphon channel was removed. Lowell reports that this bar rack restricted flow through the station and into the siphons. Since the bar rack was removed after the temporary flow metering program had concluded, it was not possible to precisely quantify any conveyance improvements that resulted from the removal of the bar rack. Regardless, Lowell has reported improved conveyance through the station. As such, to maintain appropriate conservatism and avoid overprediction of future improvements, the discharge coefficient through the orifice representing the flow control gate was increased from 0.6 to 0.8, which is a more typical value.

The model was used to predict typical year overflow volumes. Ranked typical year overflow volumes are shown in Figure 5-22. Since the station is space constrained (located between a large parking garage and a commercial/office building), construction of an offline storage tank at this location is not feasible. In addition, given the very large tributary area, significant sewer separation would be required to achieve meaningful CSO control. Consequently, model simulations that increased conveyance through the station were prioritized.

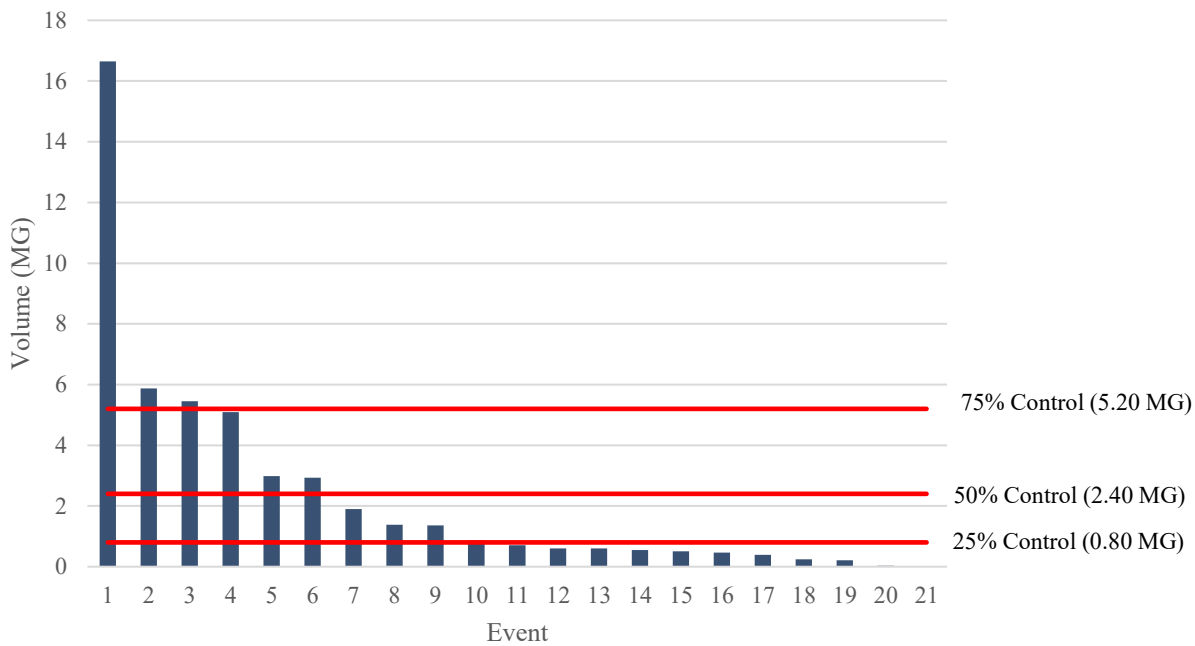


Figure 5-22: Model Predicted Typical Year Overflow Events at Warren CSO Station

Model predictions indicated that an additional siphon under the Merrimack River would not result in any CSO reduction at Warren Station. Further testing revealed two potential improvements that could be implemented:

1. Improved conveyance through the station and siphons. Although the potential benefit of the bar rack removal was already included in the existing conditions model, the model included other elements that contributed to significant flow restrictiveness through the Warren Station, including a very high value for Manning's n (0.04) in the siphons and siphon channel. The high values for Manning's n may represent a condition where the siphon was partially blocked with debris or sediment, or some other restrictive condition in the siphons/station. To simulate the impact of siphon cleaning (or other necessary actions to reduce restrictiveness), Manning's n was reduced to a more typical value of 0.013.

   By reducing the restrictiveness through the siphons and the station, the model predicted a substantial reduction in CSO volume and frequency, as shown in Table 5-14.

Table 5-14: Model Predictions for Improved Conveyance Through Warren Station

	AAOV (MG)	Frequency
Existing Conditions	48.8	20
Reduced Restrictiveness	25.4	10

   As shown in Table 5-14, reducing restrictiveness through Warren Station and the siphons has the potential to reduce typical year CSO volumes and frequency by nearly 50%, according to model predictions. Since the precise cause of the restrictiveness at this station is not fully understood,

efforts should be undertaken to fully assess all possible causes of restrictiveness before beginning the design/implementation of improvements to maximize CSO benefits.

2. In addition to reducing restrictiveness, the impact of widening the existing flow control gate and siphon channel was examined. The existing conditions model includes a 3.5-foot wide influent siphon channel and flow control gate. The model was used to assess the impact of doubling the width of the siphon channel and flow control gate to 7.0 feet. The results of this simulation are contained in Table 5-15.

Table 5-15: Model Predictions for Widened Flow Control Gate and Siphon Channel at Warren Station

	AAOV (MG)	Frequency
Existing Conditions	48.8	20
Reduced Restrictiveness	25.4	10
Reduced Restiveness + Widening	11.9	5

As shown in Table 5-15, the model predicts substantial benefit from doubling the width of the flow control gate in addition to reducing restrictiveness through the station. With these two improvements implemented the model predicts that typical year CSO volumes and number of overflows will be reduced by approximately 75%. This is a significant finding since other CSO control measures, such as offline storage or sewer separation would be difficult or impossible to implement at Warren Station without actions such as eminent domain or significant open-cut construction.

5.6.3.10 Barasford Station

This CSO station is directly tributary to the Merrimack Station. A flow control gate regulates flow out of Barasford Station as it travels to Merrimack Station. Barasford Station is directly adjacent to the Merrimack Station and located in a dense residential area. No land is available for construction of an offline storage tank or other improvements. Figure 5-23 shows model predicted typical year overflows and offline storage tank sizes at the Barasford CSO station.

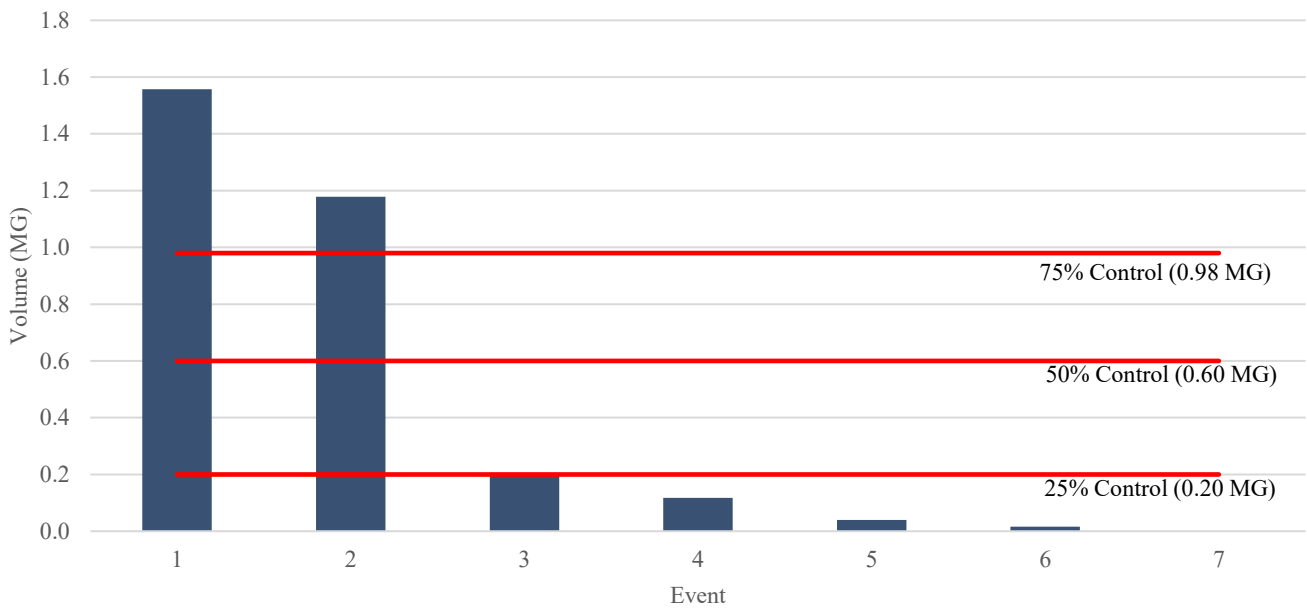


Figure 5-23: Model Predicted Typical Year Overflow Events at Barasford CSO Station

Since offline storage is not possible at Barasford Station due to space limitations, reducing the volume and frequency of CSOs at this location requires that either more flow be conveyed to Merrimack Station, or wet weather flow into the station be reduced. Barasford Station is small in terms of typical year predicted overflow volume (3.1 MG) and frequency (6 activations). As such, strategies for achieving CSO control at Barasford should be focused on increasing conveyance to Merrimack Station.

The model was used to analyze the impact of allowing the flow control gate to remain fully open during wet weather. The model did not predict any significant benefit as Merrimack Station was not able to convey additional flow to the WWTF. The model indicates that achieving greater CSO control at Barasford Station is dependent on improvements being made at Merrimack Station.

5.6.3.11 Merrimack Station

This CSO station is the second largest by volume (115.2 MG) and frequency (21 activations) during the typical year. Model predicted overflows at Merrimack Station are shown in Figure 5-24. The flows conveyed through Merrimack Station are cumulative; flows from the Tilden, Warren, Barasford, and Merrimack sewersheds combine and pass through the station. Since this station is subjected to cumulative flow from these four sewershed areas, achieving more CSO control at Merrimack requires improvements in all upstream tributary areas or the ability to convey more flow through the station to Duck Island for treatment. Merrimack station is also located in a dense residential area, and no land is available for the construction of offline storage without the use of eminent domain.

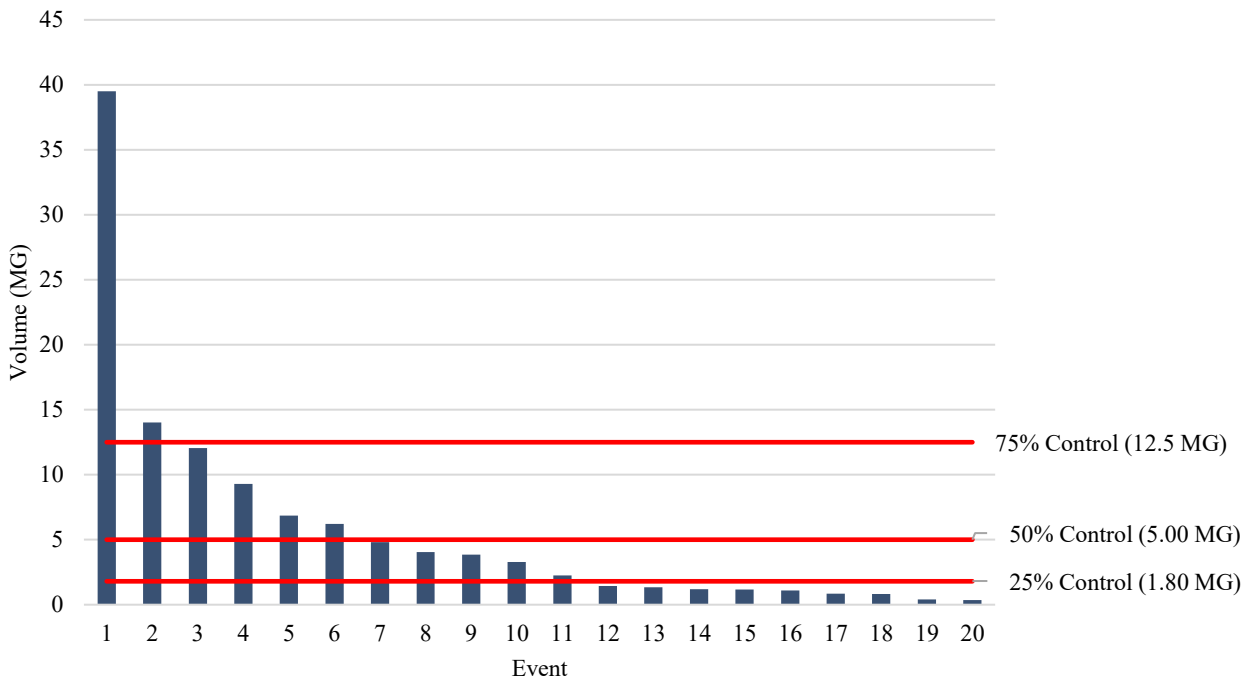


Figure 5-24: Model Predicted Typical Year Overflow Events at Merrimack CSO Station

At present, overflows at the Merrimack CSO station occur when the flow control gate restricts flow and prevents it from entering the three siphons that convey flow under the Merrimack River to Duck Island for treatment. The flow control gate modulates and restricts flow to ensure that wet weather treatment capacity is not exceeded at Duck Island. Since Duck Island treats flow from both the North Bank Interceptor (via West Station and the Read Interceptor Inline flow control gate) and the South Bank Interceptor (via Merrimack Station), the current operating strategy attempts to balance flow from both interceptors.

As a result of these factors which influence how Merrimack Station operates and its vital role in the overall collection system, achieving additional CSO control at this location is complex.

As detailed in Section 5.6.3.1, construction of the North Bank WWTF has the potential to result in a significant reduction of CSO volume and frequency at Merrimack Station by allowing the station to convey significantly more flow to Duck Island for treatment. Based on this finding, strategies for increasing conveyance through Merrimack Station were prioritized. An extensive analysis was undertaken to determine if an additional siphon would increase conveyance through the station and reduce CSO. By configurating a simulation where the capacity of Duck Island was artificially increased to 200 MGD (as described in Section 5.6.3.12) it was possible to assess where the existing conveyance infrastructure was limited due to existing operating strategies or physical limitations. During the simulation, it was found that it was possible to significantly reduce CSO frequency and volume at Merrimack Street without the addition of a new siphon. As such, increasing conveyance through the station and assessing the impact of adding additional wet weather treatment capacity were prioritized for analysis.

The impact of doubling the width of the existing flow control gate was investigated, along with increasing the peak wet weather treatment capacity at Duck Island to 126 MGD. At present, Duck Island has peak wet weather treatment capacity of 110 MGD but may briefly achieve 115 MGD. As described in Chapter 3, the existing WWTF is capable of achieving 126 MGD with upgrades to alleviate hydraulic restrictions. Table 5-16 contains the results of the analyses described above. The future conditions simulations described in Table 5-16 both included the North Bank WWTF.

Table 5-16: Merrimack Station CSO Performance with Improvements at Duck Island and Station

	AAOV (MG)	Frequency
Existing Conditions	115.2	21
Double Width Flow Control Gate	89.7	15
Duck Island Capacity Upgrade (126 MGD)	45.7	8

As shown in Table 5-16, decreasing headloss through the station, and increasing treatment capacity at Duck Island, both substantially decrease CSO volume and frequency at Merrimack Station. Since these simulations also include the North Bank WWTF, model controls were altered to prioritize conveyance of flow from the South Bank (through Merrimack Station), but also to allow to pass through the Read Inline flow control gate when the capacity at Duck Island was not being fully achieved. Due to the fact that these controls are complex and interdependent, optimization of the wet weather flow control strategy would likely need to occur after construction of any major system change such as the North Bank WWTF by observing actual system performance. As such, model predictions may not fully characterize the benefits of the improvements at Merrimack Station.

5.6.3.12 Other

Several cumulative (multiple strategies implemented together) CSO control strategies were investigated to assess other possibilities for systemwide and sewershed specific CSO control. These investigations included the following:

- Increasing Duck Island WWTF peak wet weather treatment capacity to 200 MGD in increments of 20 MGD
- Targeted sewer separation in Barasford & Merrimack sewersheds
- Full public-side sewer separation in the Warren sewershed
- Full public-side sewer separation in the Beaver Brook sewershed
- Offline storage at all CSO stations to store remaining CSO volumes

The intent of these simulations was to analyze different strategies for achieving full CSO control on a systemwide basis during the typical rainfall year. The results of these simulations are shown in Chapter 7 – where each simulation is analyzed from a cost-benefit perspective.

This page intentionally left blank.

6. Cost Estimates

In order to assess the relative cost benefit ratios of different CSO control strategies and projects, conceptual cost estimates were developed for all potential projects (including the CSO control projects/strategies identified in Chapter 5). The cost estimates herein will need to be updated and refined as retained projects are fully designed. Cost estimates, that include itemized scopes of work, are included in Appendix E for selected projects. Note that not all projects included in this Section are included in the final set of recommended IP projects.

6.1 Estimating Methodology

Cost estimates were developed based on actual data from projects previously constructed in Lowell, from projects that Lowell's consultant undertook or was involved in elsewhere in the country, from cost curves developed for this effort, and from "bottom-up" quantity estimates with labor/equipment/materials. All estimates were scaled for 2019 labor and material costs using ENR indices.

6.2 Cost Estimates

6.2.1 Cost Curves

6.2.1.1 Sewer Separation

Using construction cost data from Syracuse NY, where a public and private sewer separation project has been completed, unit costs were developed to estimate sewer separation costs in Lowell. In Syracuse, costs to install sewers adjacent to commercially zoned lots were estimated to be approximately $700/LF of sewer installed, while costs for installing sewers adjacent to residentially zoned lots were approximately $560/LF of sewer installed (based on 2003 dollars). For the purposes of this estimate, zoning throughout Lowell was assumed to be approximately 25% commercial and 75% residential. Thus, the per linear foot cost of separated sewer was evaluated as $983 based on 2019 dollars (according to ENR indices). ENR indices also indicated that Syracuse and cities in the greater Boston area have generally similar material and labor costs.

GIS data provided by Lowell, which included sewer details such as size, length and type (combined versus separated), was utilized to determine the total lengths of sewers to be installed for different CSO control levels. While GIS data is an approximate (and in some areas, incomplete) record of the system extent, it was a useful planning tool for the purposes of sewer separation cost estimating. The total length of all existing sewers in Lowell was estimated to be approximately 1,192,000 LF, including about 109,000 LF of separated sewers (based on existing GIS records). Thus, for 100% CSO control and complete replacement of all existing combined sewers in Lowell, a total of approximately 1,057,000 LF of sanitary sewers would need to be constructed. It was assumed, for the purposes of this analysis, that existing service laterals from residential houses would be reconnected to the new separated sewers and are thus, not included in the total length of piping to be installed. Additionally, new storm sewers would

not be required since the existing combined sewers could be used to convey storm flow directly to the outfalls.

Costs were estimated to achieve 25, 50, 75 and 100% sewer separation by calculating different lengths of sanitary sewers. A 35% design and engineering fee (based on estimated construction cost) was also included in these estimates.

Table 6-1: Costs for Sewer Separation

CSO Control Level	Assumed Length of New Sanitary Sewer (LF)	2019 Cost ($ Million)
25% Sewer Separation	272,000	360
50% Sewer Separation	543,000	721
75% Sewer Separation	815,000	1081
100% Sewer Separation	1,086,000	1442

6.2.1.2 Offline CSO Storage Tanks

Costs were developed for generic 12-foot deep underground offline storage tanks with varying lengths and widths to support a wide range of CSO capture volumes. Elements of this cost analysis included 24-hr pump back and associated plumbing, odor control, I&C and electrical allowances, as well as mark-ups based on labor rates, escalations and design contingencies.

The smallest tank evaluated was a 0.2 MG (35’ x 70’ x 12’) while the largest tank was sized at 39.7 MG (470’ x 940’ x 12’). Tank sizes were estimated based on model predicted overflow volumes at each CSO station. Thus, a cost curve was developed using this range of capture volumes, which was then used to estimate costs for different levels of specific control at each CSO station. Figure 6-1 shows the curve developed for CSO storage tanks as well as the second-degree polynomial equation and associated R-squared value. As the R-squared value approaches 1, the better is the fit of the curve and formula to the plotted data points.

Separate curves and equations were created for small and large tanks. The CSO Volume Captured is displayed on the X-axis while the Construction Cost is shown on the Y-axis.

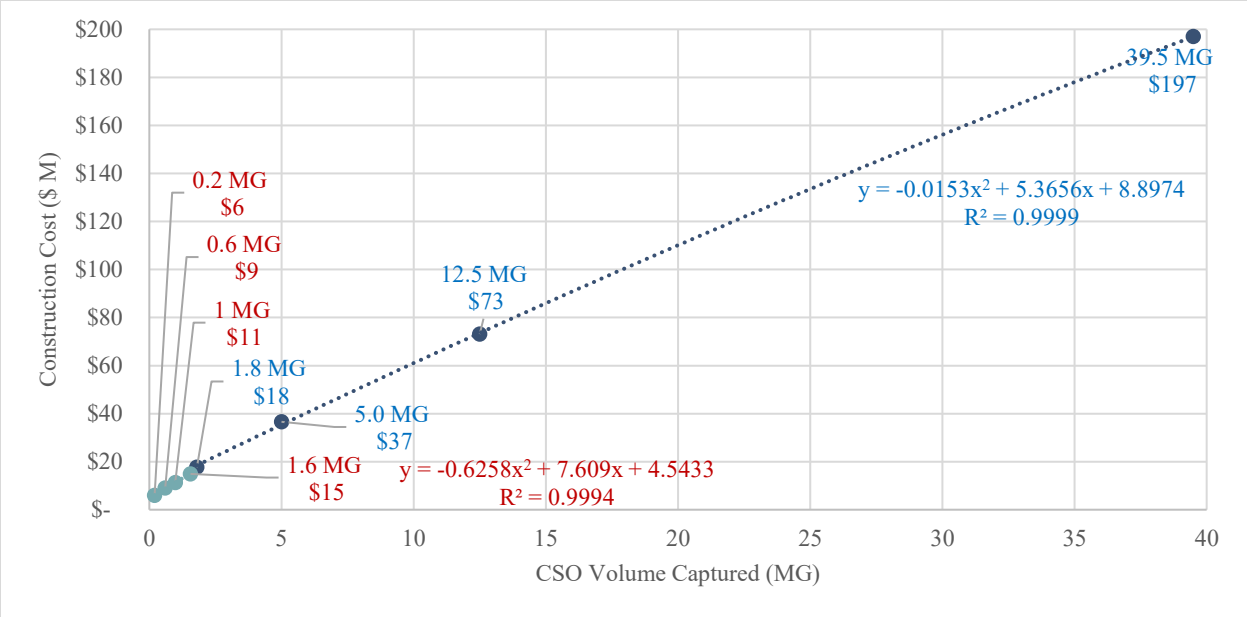


Figure 6-1: Cost Curve for Offline CSO Storage Tanks

These equations can only be used to evaluate capture volumes within the upper and lower boundaries of the curve. Thus, using these equations, costs for 25, 50, 75 and 100% CSO control at each of the following CSO stations were evaluated:

Table 6-2: Estimated Cost ($M) at Each CSO Station with Offline Storage Tanks

CSO Station	25% CSO Capture	50% CSO Capture	75% CSO Capture	100% CSO Capture
Merrimack	$18	$37	$73	$197
West	$13	$26	$51	$157
Warren	$10	$22	$36	$94
Tilden	$7	$12	$21	$45
Beaver Brook	$7	$11	$15	$24
Walker	$6	$9	$14	$26
Read	$6	$8	$12	$23
Barasford	$6	$9	$11	$15

The summary of CSO control costs for each level of control includes a land acquisition cost, which was estimated based on adjacent property values obtained through Lowell's GIS database, as well as an additional 35% engineering fee. It should be noted that although estimates were developed for the above offline storage tanks, a detailed site-by-site analysis of feasibility and constructability was not performed. The purpose of these estimates is to provide the ability to compare the cost effectiveness of offline storage compared to other CSO control strategies; these estimates do not indicate that any given project is feasible or constructible.

Table 6-3: Summary of Systemwide Costs for Offline CSO Storage Tanks

CSO Control Level	2019 Cost ($ Million)
25% CSO Capture	112
50% CSO Capture	194
75% CSO Capture	330
100% CSO Capture	785

6.2.1.3 CSO Storage Tank with a Screening and Disinfection Facility

Similar to the methodology described in Figure 6-1, a number of varying sized tanks and disinfection rates were evaluated to create a screening and disinfection cost curve from which the costs for different control measures could be interpolated.

The smallest facility evaluated was 0.02 MG (10’ x 20’ x 12’) with a peak flow rate of 1.67 MGD, while the largest facility was sized at 3.97 MG (150’ x 295’ x 12’) with a peak flow rate of 360 MGD. Facility sizes and flow rates were calculated based on model prediction for typical year overflows at each CSO station. Using this data, a cost curve was developed using this range of flow rates, which was then used to estimate costs for different levels of control at each station. Figure 6-2 illustrates the curve developed for CSO screening and disinfection and notes the second-degree polynomial equation and associated R-squared value that best fits the cost data. As the R-squared value approaches 1, the better is the fit of the curve and formula to the plotted data points.

Separate curves and equations were created for small and large facilities. The design CSO screening and disinfection flow rate is displayed on the X-axis while the construction cost is shown on the Y-axis.

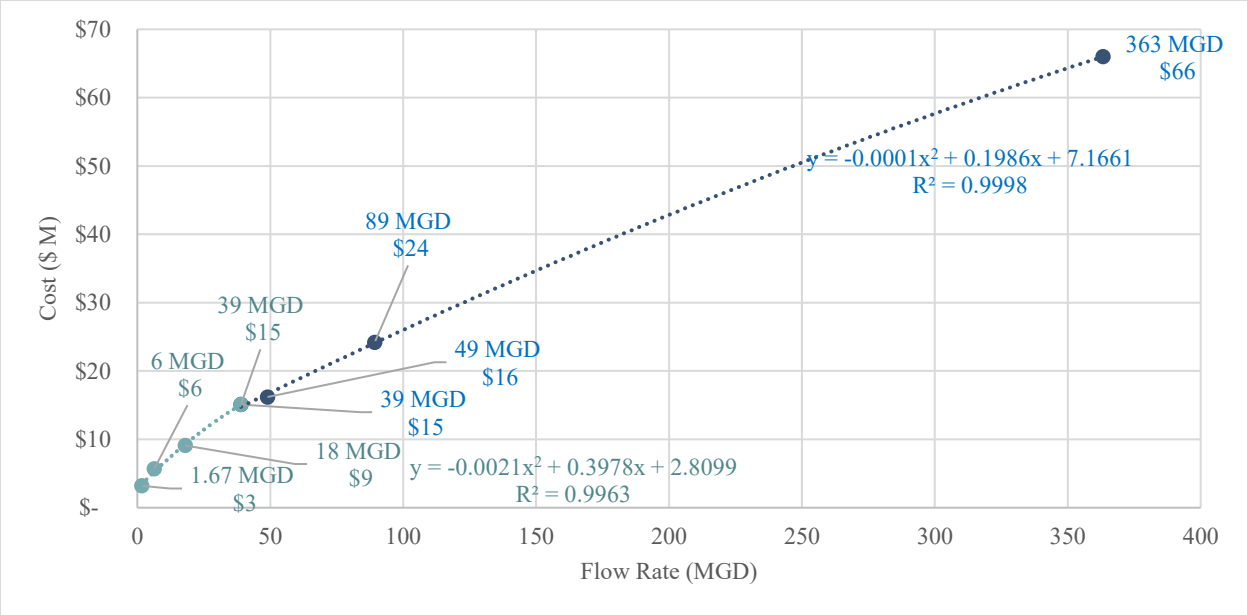


Figure 6-2: Cost Curve for CSO Screening and Disinfection Facilities

These equations can only be used to evaluate treatment flow rates within the upper and lower boundaries of the curve. Thus, using these equations, costs for 25, 50, 75 and 100% CSO control at each of the following stations was evaluated. The flow rates needed to achieve each level of control were calculated using the model and the typical rainfall year.

Table 6-4: Costs at Each CSO Station with Screening and Disinfection Facilities ($M)

CSO Station	25% CSO Control	50% CSO Control	75% CSO Control	100% CSO Control
Merrimack	$9	$17	$24	$66
West	$5	$10	$15	$51
Warren	$6	$10	$16	$63
Tilden	$5	$7	$14	$20
Beaver Brook	$7	$11	$18	$33
Walker	$3	$5	$9	$15
Read	$6	$10	$15	$31
Barasford	$5	$10	$18	$27

The summary of the CSO control costs for each level of control includes a land acquisition cost as well as an additional 35% engineering fee. The land acquisition costs were assumed to be similar to the offline storage tanks, although less land may be required pending final design.

Table 6-5: Estimated Costs for Systemwide CSO Control with Screening and Disinfection Facilities

CSO Control Level	2019 Cost ($ Million)
25% CSO Capture	76
50% CSO Capture	125
75% CSO Capture	192
100% CSO Capture	429

6.2.1.4 Green Infrastructure

Green infrastructure costs were estimated based on data available from previously completed GI projects on a national scale and in similarly situated cities/systems. This data indicates that GI has an average cost of $250,000 per impervious acre managed. Model predictions indicated that it was not possible to achieve full systemwide CSO control using GI, so it was not possible to calculate systemwide CSO control costs using GI.

A targeted GI practice in the Tilden Sewershed designed to manage 0.2 acres was estimated to cost $50,000.

6.2.2 Discrete Project Costs

The construction cost estimates for the discrete project costs for this IP were developed as AACE Class 4 or 5 estimates with typical accuracy ranges of -15% to -30% on the low end and +20% to +50% on the high end. Estimates were based on a combination of detailed take-offs, forced take-offs, and/or go-by methods, depending upon the design development progress. Adjustments for current market conditions have been omitted.

The estimates have been prepared with the understanding that contracts will be procured under M.G.L. Chapter 149 contracts with Filed Sub-bids for masonry, metals, roofing and flashing, acoustical tile, painting, and coatings, fire protection, plumbing, HVAC, and electrical.

Additionally, the following assumptions were utilized for development of the cost estimates:

- Construction Notice to Proceed varied by estimate.
- Construction durations were based on cumulative task durations.
- Labor rates were applied as per the Prevailing Wage Rates as published by the Commonwealth of Massachusetts, Department of Labor Standards, for Lowell, Massachusetts for 2019.
- Equipment rates were applied as per AED Blue Book, RS Means, AED Green Book, and/or local rental suppliers.
- Crews, equipment, and production rates were based on a combination of industry standards, RS Means, and Hazen estimator judgment.

- Escalation rates were based on current ENR indices.
- The construction cost estimates also included the following markups:
  - General Requirements (varies with design development): 15% to 20%
  - Subcontractor Overhead and Profit: 21%
  - Prime Contractor Overhead: 10%
  - Prime Contractor Profit: 5%
  - Prime Contractor Profit on Subcontracted Work: 5%
  - Labor Escalation to Midpoint of Construction: 0% to 3.5%
  - Equipment and Material Escalation to Midpoint of Construction: 0% to 5%
  - Bonds and Insurance: 3%
  - Design Contingency (varies with design development): 20% to 40%

6.2.2.1 Pevey Wet Weather Storage Facility

The costs for the Pevey Wet Weather Storage Facility include planning level estimates for the construction of an offline storage tank in the vicinity of Pevey Street. This offline storage tank would reduce sewer surcharging in an area of the collection system that is vulnerable to CSO surcharging. The cost estimate includes demolition, earthwork, concrete, gate system, yard piping, pipe jacking under railroad tracks and pavement and site restoration. The cost estimate shown in Table 6-6 below includes a 35% engineering fee.

Table 6-6: Costs for Pevey Wet Weather Storage Facility

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	10.9

6.2.2.2 Douglas Wet Weather Storage Facility

The costs for the Douglas Wet Weather Storage Facility include planning level estimates for the construction of an offline storage tank in the vicinity of Douglas Street. This offline storage tank is designed to reduce CSO surcharging. The cost estimate includes concrete/building work, flow control gate, screening equipment, odor control, flushing gates, bending weir, tipping buckets, earthwork, contaminated soil allowance, bypass pumping and yard piping. Land acquisition costs have not been included in this estimate, since it was assumed that a public parking lot could be utilized. The cost estimate shown in Table 6-7 below includes a 35% engineering fee.

Table 6-7: Costs for Douglas Wet Weather Storage Facility

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	8.6

6.2.2.3 Diversion Stations: Wet Weather Conveyance

The costs for the Diversion Stations: Wet Weather Conveyance project include planning level estimates for a gate replacement at Merrimack Station and a gate replacement at Warren Station. Model predictions indicate significant CSO control benefits by doubling the width of existing flow control gates at these locations. The cost estimate includes removal and replacement costs, temporary bypass pumping and site restoration at each of the sites. The cost estimate shown in Table 6-8 below includes a 35% engineering fee.

Table 6-8: Costs for Diversion Stations: Wet Weather Conveyance

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	0.4

6.2.2.4 Duck Island Peak Flow Optimization

The costs for the Duck Island Peak Flow Optimization project include planning level estimates for increasing peak flow capacity at the WWTF to 126 MGD. The cost estimate includes demolition costs, earthwork, new bar screens, a third influent channel and site restoration. The cost estimate shown in Table 6-9 below includes a 35% engineering fee.

Table 6-9. Costs for Duck Island Peak Flow Optimization

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	7.8

6.2.2.5 Drinking Water Treatment Facility Upgrades

The cost estimate for upgrades at the Drinking Water Treatment Facility project include new influent gates at the river intake station, new lagoons with underdrains, new lab benches and cabinets, new instrumentation and analyzers (including turbidometers, pH, fluoride, and others), electrical upgrades and backup power transfer switches, a new chloride dioxide system at the intake station, and a new video surveillance system. The cost estimate shown in Table 6-10 below includes a 35% engineering fee.

Table 6-10. Costs for Drinking Water Treatment Facility Upgrades

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	7.2

6.2.2.6 North Bank WWTF

The costs for the North Bank WWTF project include planning level estimates for the North Bank WWTF, as described throughout this report. The cost estimate includes earthwork, pre-cast concrete culvert sections, screens, gate system, flushing systems, new chemical building with chemical feed systems and storage tanks, yard piping, temporary bypass pumping and site restoration. The cost estimate shown in Table 6-11 below includes a 35% engineering fee.

Table 6-11. Costs for North Bank WWTF

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	26.6

6.2.2.7 Drinking Water Backflow and Meter Improvements

The costs for the Drinking Water Backflow and Meter Improvements project include planning level estimates for a backflow survey and the replacement of 1500 large water meters. The cost estimate shown in Table 6-12 below includes a 35% engineering fee.

Table 6-12. Costs for Drinking Water Backflow and Meter Improvements

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	11.9

6.2.2.8 Duck Island WWTF Centrifuge

The costs for the Duck Island WWTF Centrifuge project include planning level estimates for a new centrifuge to be installed in the existing WWTF. The cost estimate includes demolition, new centrifuge and associated appurtenances and structural modifications to existing buildings. The cost estimate shown in Table 6-13 below includes a 35% engineering fee.

Table 6-13. Costs for Duck Island WWTF Centrifuge

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	5.9

6.2.2.9 Duck Island WWTF Upgrades

The costs for the Duck Island WWTF Upgrade project include planning level estimates for a variety of modifications to the WWTF that will increase the reliability of treatment and maximize the ability to treat wet weather flows. The cost estimate includes demolition, new aeration diffusers, cyclones, classifiers, bar racks, odor control, duct repairs and chlorination injection into spray headers. The cost estimate shown in Table 6-14 below includes a 35% engineering fee.

Table 6-14. Costs for Duck Island WWTF Upgrades

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	10.0

6.2.2.10 Redundant Transmission Main

The costs for the Redundant Transmission Main project include planning level estimates for the installation of a new 4,000 LF, 24-inch ductile iron water main. The cost estimate includes new piping, trench excavation and backfill, pipe bedding and subbase, dewatering and site restoration. The cost estimate shown in Table 6-15 below includes a 35% engineering fee.

Table 6-15. Costs for Redundant Transmission Main

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	6.9

6.2.2.11 Tilden Sewer Separation and GI

The costs for the Tilden Sewer Separation and Green Infrastructure project include planning level estimates for separating sewers and installation of green infrastructure. Costs for this CSO control alternative were estimated based on previous sewer separation work that was recently completed within Lowell. The cost estimate shown in Table 6-16 below includes a 35% engineering fee.

Table 6-16. Costs for Tilden Sewer Separation and GI

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	6.4

6.2.2.12 200 MGD Treatment Facility at Duck Island

The cost estimate for the construction of an additional wet weather treatment facility at Duck Island (to achieve 200 MGD total wet weather treatment capacity) includes demolition, earthwork, new masonry building, new bar screens, slide gates, grit removal system, microsand system, chemical feed systems, pumps, plumbing, HVAC, electrical, and site restoration. The cost estimate shown in Table 6-17 below includes a 35% engineering fee.

Table 6-17. Costs for Duck Island Wet Weather Treatment Facility

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	46.2

6.2.2.13 Distribution System Improvements

Based on assessment of possible distribution system needs and improvements, Lowell developed an allowance to account for these costs. A study to prioritize improvements will allow for a more precise cost estimate. The allowance is shown in Table 6-18.

Table 6-18. Costs for Distribution System Improvements

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	2.7

6.2.2.14 Walker Wet Weather Storage Facility

The costs for the Walker Wet Weather Storage Facility alternative include planning level estimates for an offline storage facility to fully capture model predicted typical year CSOs at the Walker CSO station. The cost estimate includes earthwork, new concrete storage tank, gate system, yard piping, temporary bypass pumping system and site restoration. The cost estimate shown in Table 6-19 below includes a 35% engineering fee.

Table 6-19. Costs for Walker Wet Weather Storage Facility

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	32.0

6.2.2.15 Satellite Station Upgrades

Based on an assessment of needs at the existing satellite (remote) CSO diversion and pump stations, Lowell developed an allowance to account for these costs. The allowance for these upgrades is shown in Table 6-20.

Table 6-20. Costs for Satellite Station Upgrades

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	8.0

6.2.2.16 Finished Drinking Water Storage Tank

The cost estimate for a new 12 MG water storage tank includes site work, concrete work, a composite tank and pump station, yard piping, and allowances for electrical and instrumentation work. The estimate includes a 35% engineering fee and is shown in Table 6-21.

Table 6-21. Costs for Finished Drinking Water Storage Tank

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	24.8

6.2.2.17 Duck Island Phosphorous Removal Project

A limit of 1.08 mg/L was assumed for Tier 1 nutrient limits. To meet Tier 1 nutrient limits an anaerobic-oxic (AO) secondary treatment process configuration was used as the design basis. Lowell is in the process of converting Cell 1 of each aeration tank from an aerobic zone to an anaerobic zone with mechanical mixing to improve sludge settling characteristics and achieve biological phosphorus removal. When operating at a low (1.5 – 2 day) SRT with minimal nitrate being recycled to the anaerobic zone through the return-activated sludge, the modified secondary process is expected to meet total phosphorus

concentrations of approximately 1.5 to 2.0 mg/L as phosphorus. To reliably meet a limit of 1.08 mg/L, the ability to add metal salts to the primary and secondary clarifiers is required. The cost estimate of work required to achieve the anticipated Tier 1 nutrient limit is shown in Table 6-22 (with a 35% engineering fee).

Table 6-22. Costs for Duck Island Phosphorous Removal Project

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	1.8

6.2.2.18 Lead Service Replacements

The costs for the Lead Service Replacement program include planning level estimates for the removal of 550 existing lead service pipes and replacement with 1-inch copper tubing. The cost estimate includes demolition, trench excavation and backfill, dewatering, resetting of curbing, hydroseeding and site restoration. The cost estimate shown in Table 6-23 below includes a 35% engineering fee.

Table 6-23. Costs for Lead Service Replacements

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	5.4

6.2.2.19 Nitrogen Removal Upgrade

If regulatory requirements (in the future) dictate the need to meet Tier 2 nutrient limits (seasonal limit of total nitrogen of 3 mg/L), additional aeration tank volume is required for nitrification and denitrification to occur. In addition, the process must operate at a higher aSRT to promote the growth of nitrifying/denitrifying microorganisms. An anaerobic-anoxic-oxic (A2O) process configuration was used as the basis of design to maximize the use of influent carbon for nutrient removal. To meet the assumed low total nitrogen of 3 mg/L, a secondary anoxic zone with carbon addition and denitrification filter following the secondary clarifier were assumed. The denitrification filter serves as a secondary barrier for total nitrogen and phosphorus. Table 6-24 contains the estimated cost to complete this work, with a 35% engineering fee.

Table 6-24. Costs for Nitrogen Removal Project

Item	2019 Cost ($ Million)
Estimated Cost with Engineering Fee	224.2

7. CSO Control Knee of the Curve Analysis

In order to compare the relative cost benefit ratios of different CSO control technologies, charts depicting CSO control effectiveness versus cost were developed. These charts are useful to determine the predicted point at which continued spending on CSO control results in a diminishing benefit, and to compare the relative effectiveness of different CSO control technologies. In the knee-of-the-curve (KOC) charts, the percentage by which typical year CSO volume is reduced is shown on the Y-axis, and engineering and construction cost is shown on the X-axis. As such, the cost-benefit performance of each CSO control project can be generally assessed based on the region of the KOC chart it is plotted. Figure 7-1 is a simplified chart that depicts the cost-benefit performance associate with each region.

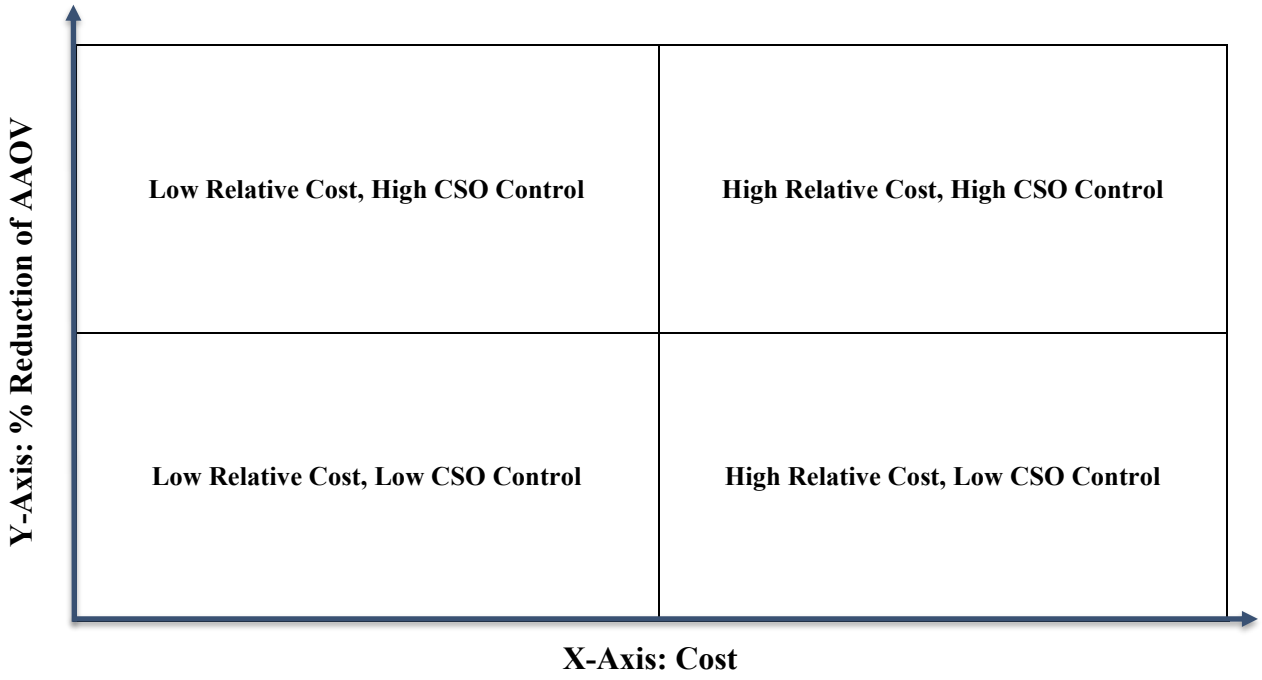


Figure 7-1: Example Cost-Benefit Chart

As additional CSO control projects are plotted, the points can be connected with a smooth curve. A steep curve indicates favorable cost-benefit performance. The inflection point on a curve (point at which the slope changes and starts to flatten) represents the point at which additional cost results in diminishing CSO control benefits. At some point at, or to the right of, this inflection point there is a “knee” on the curve where it becomes more horizontal than vertical, indicating significant cost is required to achieve only marginal additional CSO control benefits. The CSO control projects that lie beyond the knee of the curve are characterized by poor cost-benefit performance.

Since the model’s predictive ability decreases with cumulative changes (more CSO control technologies implemented), the knee of the curve (KOC) represents the point at which Lowell should “pause” further implementation of CSO control projects (i.e., the end of CSO Control Phase 3). At this point Lowell should undertake a post-construction monitoring plan (PCMP) and assess the effectiveness of CSO controls that have been implemented. This pause is consistent with Lowell’s adaptive management

strategy and is an important step during which the model should be recalibrated and updated to reflect system changes due to CSO controls implemented at that time. The model can then be used to accurately predict the impacts of additional CSO control measures that could be a part of Lowell's next phase of CSO control (Phase 4), which may be a part of updates to this IP or a future IP.

7.1 Cost Benefit Analysis

Figure 7-2 is a KOC chart showing the different CSO control projects and strategies that were assessed for Lowell. As shown in this chart, sewer separation and offline storage tanks perform poorly from a cost-benefit perspective when implemented on a systemwide basis. This chart also demonstrates the poor performance of GI for CSO control from a cost-benefit perspective.

The steep line on the left side of the chart represents cumulative CSO control projects that result in a favorable cost-benefit ratio. The projects included on this purple line include the following:

1. North Bank WWTF ($26.6M)
2. Duck Island Peak Flow Optimization ($7.8M)
3. Diversion Stations: Peak Flow Conveyance ($391.5K)
4. Tilden Sewer Separation and GI ($6.37M)
5. Douglas and Pevey Wet Weather Storage Facilities ($19.6M)

This chart indicates that the North Bank WWTF would achieve drastically better cost-benefit performance than any other systemwide CSO control project. The North Bank WWTF is estimated to achieve a 53% reduction in untreated CSO volumes for $26.6M. By contrast, offline storage tanks and sewer separation would require approximately $200M and $780M of investment to achieve the same level of control. The chart further demonstrates the effectiveness of increasing peak flow capacity at the WWTF and constructing conveyance enhancements at several CSO stations after the North Bank WWTF has been constructed.

The chart indicates that after implementation of the Tilden Sewer Separation/GI and Douglas and Pevey Wet Weather Storage facilities, the cost-benefit performance of subsequent CSO control projects begins to significantly decrease.

Figure 7-3 is a focused (zoomed-in) KOC chart that more clearly defines the leftmost region of the chart and the CSO control projects.

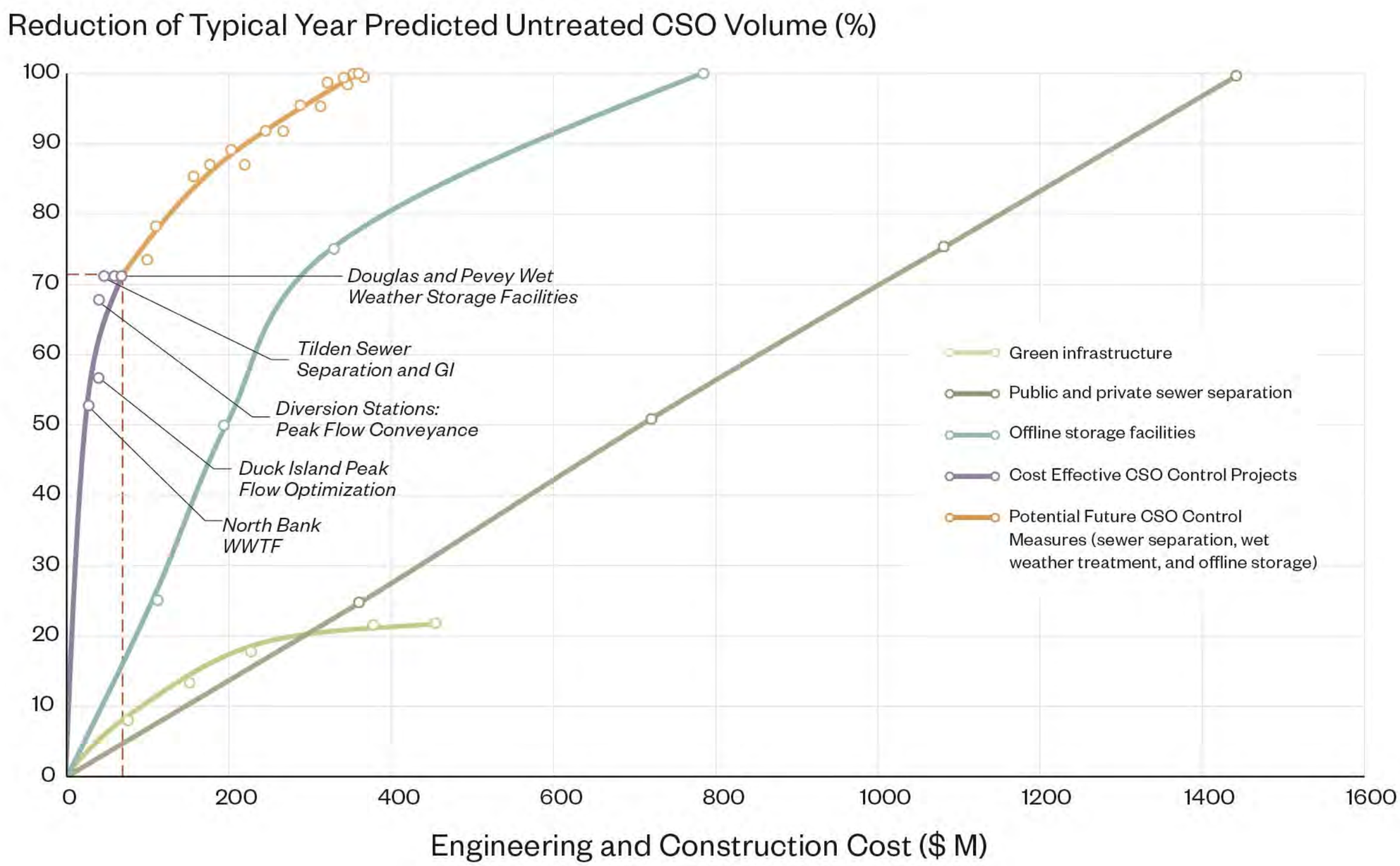


Figure 7-2: Volumetric CSO Control Cost Benefit Chart

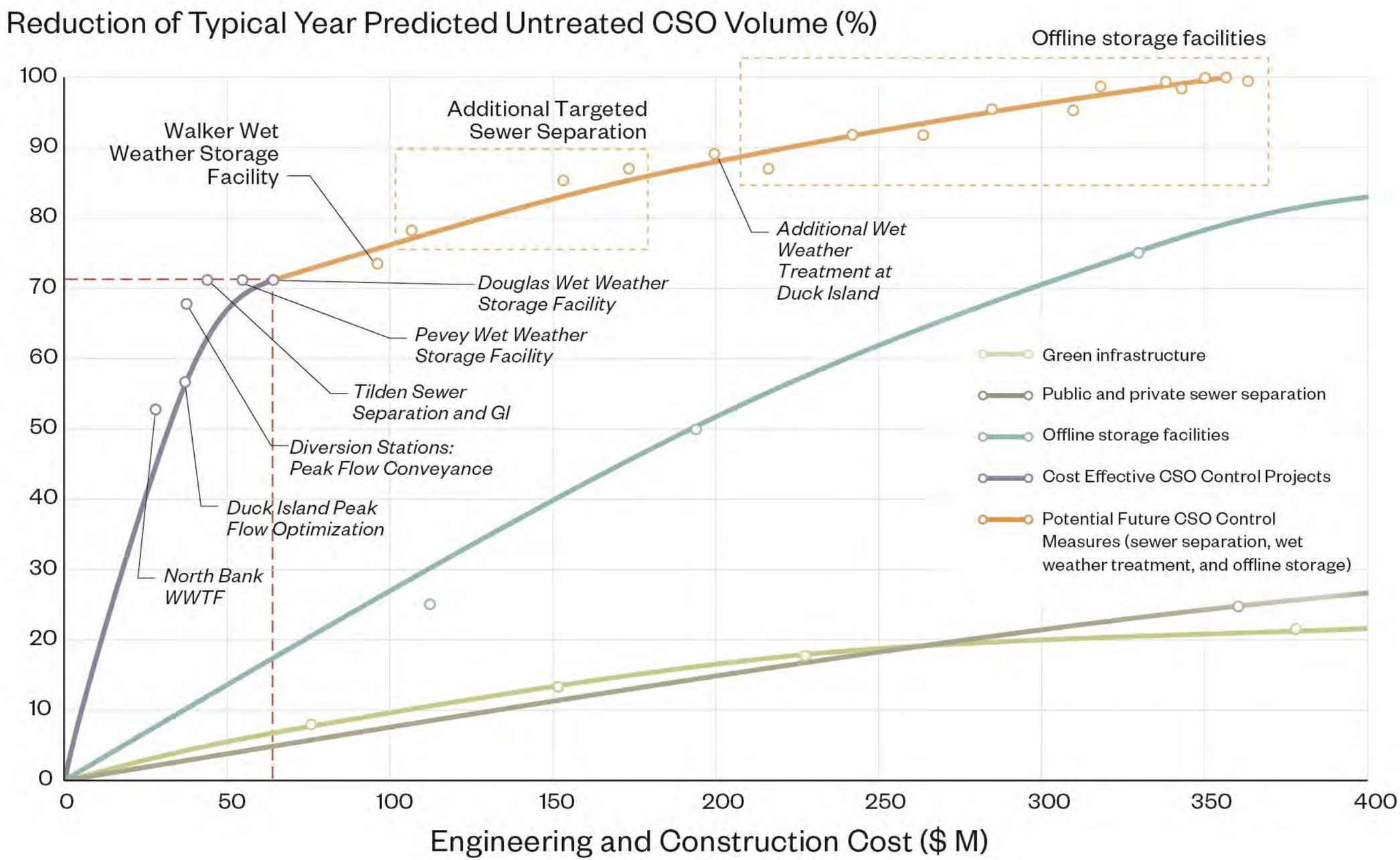


Figure 7-3: Focused Volumetric CSO Control Cost Benefit Chart

As shown in the focused cost-benefit chart, after implementation of the North Bank WWTF and several subsequent CSO control projects, the line depicting the relationship between cost and benefit begins to flatten, indicating higher additional costs for diminishing additional benefits. This region of the chart is also correlated with model simulations that have less predictive accuracy due to several cumulative major system changes. As such, projects in this region are considered beyond the "knee" of the curve and represent poor performance from a cost-benefit perspective.

The projects that lie beyond the "knee" include the following:

1. Wet weather storage facility at Walker CSO station
2. Targeted sewer separation in the Merrimack tributary area
3. Targeted sewer separation in the Warren tributary area
4. Targeted sewer separation in Beaver Brook tributary area
5. Construction of an additional Wet Weather Treatment Facility at Duck Island

The sewer separation projects were simulated in the model by simulating full public separation in targeted neighborhoods. Additional offline storage projects are included as well, and represent tanks that were sized to capture remaining typical year overflows at each CSO station. As shown in Figure 7-3, these projects perform poorly from a cost-benefit perspective and add significantly more cost for a small amount of additional CSO control. Further, the model's predictions in this region are associated with significantly more uncertainty.

As such, the point associated with the Douglas Wet Weather Storage Facility is considered the "knee" of the curve. After this point, additional CSO control projects provide limited benefit for greatly increased cost and are associated with significant uncertainty in benefits.

Table 7-1 contains the model-predicted performance for each CSO station associated with the knee of the curve. On a systemwide basis, total untreated CSO volume is reduced by approximately 72%, and the maximum number of activations (at West Station) is reduced from 34 to 12. CSO volumes at West, Merrimack, Warren, and Tilden stations (which currently discharge 93% of typical year CSO volume) are reduced by 87%, 60%, 76%, and 54%, respectively. Untreated CSO discharges at the fifth largest station (Read) are eliminated.

Model predictions also indicate that by completing the CSO control projects up to the knee, 94.8% of combined sewage collected in the CSS during precipitation events is captured and conveyed to the WWTF for treatment on a systemwide annual average basis. Under existing (baseline) conditions, this wet weather capture is 83.7% based on model predictions. This finding indicates that by constructing the projects associated with the knee-of-the-curve, Lowell may achieve compliance with the CWA according to the presumption approach. This finding, combined with the cost-benefit analysis and uncertainty associated with additional cumulative changes in the model, indicates that the "knee" should define the end of Lowell's Phase 3 CSO control program that will be implemented as part of this IP.

Table 7-1: Model Predicted Typical Year CSO Performance for the Knee-of-the-Curve

CSO Station	Existing Conditions		Knee-of-the-Curve	
	AAOV (MG)	Frequency	AAOV (MG)	Frequency
West	121.8	34	15.8	12
Merrimack	115.2	21	45.7	8
Warren	48.8	20	11.9	5
Tilden	22.0	18	10.2	9
Read	8.1	17	0.0	0
Walker	7.0	8	7.1	8
Beaver Brook	5.7	5	1.8	2
Barasford	3.1	6	3.1	3
First	0.0	0	0.0	0
Total CSO Volume	**331.7**	**N/A**	**95.6**	**N/A**

As previously stated, the above projects that will be completed as part of the Phase 3 CSO control program will allow Lowell to achieve compliance with the CWA according to the EPA's presumptive approach, with 94.8% capture of combined sewage for treatment during wet weather. After completion of the Phase 3 CSO control program, post-construction monitoring will be undertaken to determine if CWA compliance has been achieved. If CWA compliance has not been achieved, additional CSO control projects may be required. This CSO control alternatives analysis has already identified several strategies to achieve additional CSO control, as shown in Figure 7-3.

After post-construction monitoring has been completed, if it is determined that Lowell must implement another phase (4) of CSO control projects to achieve compliance with the CWA, then these strategies should be reassessed with a recalibrated model. As previously stated, the predictive ability of the model diminishes with cumulative changes, and the projects that were simulated beyond the "knee" should be re-evaluated with a recalibrated model. In addition, new CSO control technologies and strategies may be available, so a thorough CSO control alternatives analysis should be undertaken at that time. Regardless, this IP establishes several possible strategies to achieve further CSO control and has quantified the possible benefits of specific projects associated.

8. Financial Capability Assessment

A financial capability assessment (FCA) is a method used primarily to establish schedules for implementing CSO controls and/or meeting other CWA mandates in a manner that is affordable and sustainable. As such, FCAs are a useful planning tool for prioritizing capital investments and identifying and assessing short and mid-term financial stresses on the permittee and its ratepayers.

The USEPA issued guidelines for performing FCAs in 1997[1] which established a two-step process to assess:

- Residential Ratepayer Affordability; and
- Municipal Financial Strength

Step 1 is performed to generate the Residential Indicator, or RI, which is defined as the total annual wastewater and CSO control cost as a percentage of median household income (MHI). Step 2 involves generating six indicators covering a municipality's financial strength based on municipal debt levels, financial management factors, and local or regional economic conditions. The combined result of the two-step assessment is then used to rate the municipality's capital investment or Long-Term Control Plan (LTCP) designed to meet CWA obligations as imposing a "Low", "Medium" or "High" burden on the municipality's ratepayers and financial capability. Although these categories are qualitative, a "High" burden rating indicates that the municipality's capacity to fund its LTCP is not sustainable because either the cost of the LTCP is unaffordable to the ratepayer base or the financial management or economic conditions prevailing in the local economy would significantly burden the municipality's finances under the prescribed schedule.

In the two decades since the CSO FCA guidance was issued, numerous methodological issues have been raised regarding the applicability and accuracy of the metrics used to rate a municipality's overall financial capability, including ratepayer affordability. For example, the 1997 guidance set a threshold for a "high economic impact" when the average monthly sewer bill exceeds 2 percent of the service area's median household income (MHI). However, numerous studies have shown that minor differences in MHI, particularly in large cities, often result in significant variations in poverty rates. One study found that in a sample of 21 of the largest US Cities that had deviated from the national MHI in 2010 by only $3,000, poverty rates ranged from 14.1 percent to 23.3 percent.[2] Even in smaller jurisdictions such as Lowell, the MHI can be a poor indicator of affordability if small but deep pockets of poor populations reside in the service area. Significant disparities in household incomes can exist in small and mid-sized jurisdictions as well as in large cities. These impacts could be further exacerbated in high cost of living communities where low-income households are compelled to spend a higher portion of their income on non-discretionary expenditures such as housing, food, electricity, and transportation. The MHI metric also lacks the granularity to capture economic impacts to potentially vulnerable populations residing in the

[1] Combined Sewer Overflows – Final Guidance for Financial Capability Assessment and Schedule Development, Office of Wastewater Management, EPQ 832- B-97-004, February 1997
[2] Affordability Assessment Tool for Federal Water Mandates, USCM, AWWA, WEF 2013.

service area, such as households headed by elderly persons or minority households. In short, the MHI often provides a low-resolution picture of ratepayer affordability and often fails as a stand-alone indicator of poverty rates or affordability of water and sanitation services.

Methodological questions have been raised regarding other FCA metrics as well. For example, the unemployment benchmark used by EPA as one of its financial capability indicators, is expressed not in absolute terms (i.e., unemployment rate), but relative to the national unemployment rate. The indicator does not differentiate between a high employment rate and a low employment rate, but instead measures the difference between the local and national rates. Using the EPA benchmark, if a municipality had a 10 percent unemployment as did the nation, it would receive the same "Strong" rating it would if both the local and national unemployment rate stood at 4 percent. As recently as 2009, it was not uncommon for many US cities to have unemployment rates at 9 percent or higher, but within a percentage point of the national rate. Although not relevant under the favorable employment conditions that prevail throughout the United States, this indicator illustrates the potential limitations on relying solely on the standard metrics.

In response to these concerns, EPA has reassessed its approach to performing FCAs and has introduced greater flexibility in the way municipalities can develop programs to comply with their CWA obligations. EPA has through various memoranda clarified its policy on required expenditures and in November 2014 issued revised guidance on performing FCAs. One of the key clarifications that EPA made in its January 2013 memorandum was that:[3]

"A common misconception is that the EPA requires communities to spend to a level of 2% of MHI to meet CWA obligations. Rather, the percent MHI calculation is guidance, and is considered along with a suite of other financial indicators to assess the overall burden on a community. The guidance recommends that communities with higher burdens be given longer time periods to complete the needed work".

EPA used its 2014 Final Guidance to more clearly articulate the flexibility available under the existing guidance. Although the Agency did not modify the metrics established in the 1997 guidance, the 2014 Final Guidance explicitly allows for municipalities to supplement the core metrics with additional information that would "create a more accurate and complete picture of their financial capability that may "affect the conclusion" of the analysis."

For example, EPA will consider:

- All CWA costs presented in the analysis described in the FCA Guidance; and
- Safe Drinking Water Act (SDWA) obligations as additional information about a permittee's financial capability

The Agency will also consider alternative disaggregation of household income (e.g., quintiles) as well as economic indicators including actual poverty rates, rate of home ownership, and absolute unemployment rates. The purpose of presenting these data is to demonstrate that the local conditions facing the

[3] Office of Water, USEPA. Assessing Financial Capability for Municipal Clean Water Act Requirements, Memorandum from Nancy Stoner, Acting Assistant Administrator. January 13, 2013

municipality deviate from the national average to the extent that the metrics established in the 1997 guidance are inadequate for accurately assessing the municipality's financial capacity for constructing, operating, and implementing its LTCP in compliance with its regulatory mandates.

8.1 FCA Methodology for Lowell, Massachusetts

The FCA for the City of Lowell has been prepared using the EPA's 1997 *Guidance for Financial Capability Assessment and Schedule Development* supplemented by information allowed for consideration under the 2014 Final Guidance. This entails implementing the two-step approach whereby an RI is generated in the first step, and the municipality's overall financial capability is evaluated in the second step using the standard metrics established in the 1997 guidance.

Calculating the RI portion of the FCA requires additional analyses because the Lowell Regional Wastewater Utility is a regional enterprise and serves four other communities besides the City of Lowell, including the towns of Tewksbury, Tyngsborough, Chelmsford, and Dracut. Hence, the cost and the burden of operating the system extends beyond the geographical and political boundaries of Lowell.

To determine the financial burden placed on Lowell residents, it was necessary to estimate the other town's annual contribution to covering the cost of operating and maintaining the WWTF (including debt service costs) and remove that from the total. The cost per household for Lowell is calculated based on Lowell's residential contribution to the total annual cost of operating and maintaining the WWTF and the collection system within Lowell's jurisdiction. A breakdown of these cost contributions was determined based on the municipal agreements made between Lowell and the other communities as well as an analysis of Lowell's sewer accounts to separate residential revenue from nonresidential revenue.

Because the other towns have a much higher level of household income than Lowell, aggregating the household incomes over all five jurisdictions and estimating cost on a per household basis would likely underestimate the financial burden on the residents of Lowell. In addition, because, the City of Lowell is responsible for the financing, operation and management of the wastewater utility, the financial capability metrics are calculated using only the municipal financial and economic data for Lowell. It should also be noted that although the IP includes approximately $62.8 million in expenditures for the City's drinking water infrastructure, only wastewater costs of the IP were explicitly considered in this FCA for the calculation of the residential indicator. Therefore, the projected financial impact of the IP estimated by the FCA should be considered conservative.

Consistent with EPA's Final Guidance, the FCA provides additional data analyses to ensure that the FCA accurately reflects the actual financial and economic conditions of Lowell. For example, the affordability evaluation also assesses the cost per household (CPH) using household income quintile data as well as the MHI. Specifically, ratepayer affordability is assessed for those households at the upper limit of each of the two bottom quintiles (i.e., 20 percent and 40 percent of the ratepayer households). Other factors of economic vulnerability are also assessed including Lowell's high cost of living index. Using this supplemental information provides a more detailed and complete evaluation of the affordability and sustainability of Lowell's wastewater management program and will assist in planning, sequencing, and funding of future capital projects that will be required to remain in compliance with CWA mandates.

8.2 Residential Indicator Calculation

The Residential Indicator (RI) is calculated by first determining the total cost of wastewater treatment and collection and wet weather control. A portion of the total cost is then allocated to residential customers based on their portion of total revenue paid to the Utility for wastewater services. This method was used as a surrogate for residential flow because Lowell bills all customers the same rate and does not collect flow data by customer class. Finally, the total residential cost is allocated amongst the total number of residential accounts in the community to determine the wastewater treatment, collection and storm water management cost per household. Once the wastewater program implementation cost per household is determined, the RI is calculated by dividing the wastewater treatment cost per household (CPH) by the MHI of the community and is compared to the EPA criteria for classifying the financial impact as "low," "mid-range," or "high." Table 8-1 presents EPA's criteria for classifying the financial impact based on the calculated RI.

Table 8-1: Financial Impacts Categories

Financial Impact	Residential Indicator
Low	Less than 1.0 Percent of MHI
Mid-Range	1.0 – 2.0 Percent of MHI
High	Greater than 2.0 Percent of MHI

Source: EPA 1997 CSO – Final Guidance for FCA and Schedule Development

8.2.1 Identification of Wastewater Management Costs

Current and projected IP wastewater costs for Lowell's wastewater management operations were used to calculate a Residential Indicator. It should be noted that wet weather or stormwater management costs are not itemized, and accordingly are included in the Utility's overall wastewater management costs. Appendix F presents the EPA guidance worksheets and documentation of the financial capability assessment.

8.2.1.1 Current Wastewater Management Operation and Maintenance and Debt Service Costs

The EPA defines current wastewater management costs as the current annual operation and maintenance (O&M) expenditures (excluding depreciation) plus current annual debt service payments (principal and interest). This definition also applies to wastewater collection and storm water management costs. These costs are intended to represent the cash expenditures of current wastewater management operations. For the FCA, current costs represent conditions in FY2019, the last year for which complete data are available.

Operation & Maintenance Costs

Total O&M expenditures for Lowell Water for FY2019 were $15,877,366, based on budget information provided by the Utility for this FCA.[4] As shown in Table 8-2, Ordinary Expenses account for the largest component of the wastewater utility's budget and encompass annual expenditures for energy, chemicals, laboratory supplies, maintenance and repair of equipment, and other services such as sludge removal and technical services. For FY2019, sludge removal, which was budgeted for $2.83 million, was the largest line item expenditure. Energy and chemical supply expenditures accounted for an additional $2.1 million.

Personnel costs include salary, leave and health benefits for current workforce as well as benefits paid to retired workforce. Salaries and wages accounted for about $3.4 million.

Indirect costs are expenditures paid to the City of Lowell for administrative, computer, and legal services provided by the City to Lowell Water. It should be noted that the City imposes an indirect charge based on the total revenue Lowell Water receives from its user charges and is not based on the actual cost of the Utility's use of the City's support services. The formula used to calculate Lowell Water's indirect charge is applied to all departments.

Table 8-2: FY2019 Operation and Maintenance Costs for Lowell's Wastewater Management Program

Expenditure Category	Wastewater Management Program
Ordinary Expenses	$7,455,042
Personnel	3,398,611
Indirect Costs	$5,023,683
Total	$15,877,336

Source: City of Lowell FY 2019 Sewer Actual; Expenditures Worksheet, August 2019 .

In accordance with the 1997 EPA guidance document, reserves for depreciation, capital replacement, and other types of reserves are not included in the current O&M costs shown above.

Current Debt Service

Debt service is included in the assessment, because it represents a cost associated with wastewater management. Lowell finances its projects using funds obtained through the issuance of General Obligation Bonds and through below market loans obtained from the State of Massachusetts through its Clean Water Trust Fund (MCWT). As of June 30, 2018, the long-term outstanding debt for the Sewer Enterprise Fund totaled $87.8 million that is supported by the sewer rates and future MCWT principal and

[4] City of Lowell 2019 Actual Sewer Expenditures Provided by Lowell City CFO, August 2019.

interest subsidies. Lowell does not use revenue bonds as a financing instrument for its wastewater infrastructure.

Table 8-3 presents the total annual costs to maintain the Utility's wastewater management programs including the expenditures for servicing related debt.

Table 8-3: Total Annual Cost for Lowell Wastewater Management Program

	Operating Costs	Debt Service Costs	Total
Expenditure Category	$15,877,336	7,443,094	$23,320,430

8.2.1.2 Integrated Plan Projected Capital, Operation and Maintenance and Debt Service Costs

Consistent with the 1997 EPA guidance document, estimates of projected costs are composed of annual debt service payments (principal and interest) associated with future wastewater treatment plant and collection system capital improvements and incremental O&M expenditures associated with implementing the proposed projects.

Projected Integrated Plan – Capital Costs

The projected costs of the IP are based on the engineering cost analyses described in Chapter 6 is $160.3 million. The total IP cost for the wastewater management component of the Integrated Plan is $97.5 million

Financing the Integrated Plan Projects

Lowell could use a combination of financing vehicles for funding its IP. It is likely to use a mix of sewer bonds and SRF Funds loaned through the MWCT. Lowell's most recent financial statement indicates that it pays 2 percent interest on MWCT notes and up to 6 percent for sewer bonds. For the purposes of the FCA, it is assumed that Lowell will obtain a mix of low interest MCWT loans and Municipal Sewer Bonds with a combined average interest rate of 3 percent. The FCA also assumes 20-year bonds are issued for the planned capital investments. As shown in Table 8-4 below, using these assumptions, the annual service debt would total $6,553,531.

Table 8-4: Annual Projected Debt Service Costs

Total Capital Cost	Annual Debt Service Cost (20 years)
$97,500,000	$6,553,531

Projected Incremental O&M Costs

Incremental O&M costs are estimated at 2 percent of the capital costs which equates to $1,950,000 per annum.

Total Wastewater Management Cost including Integrated Plan Costs

The FCA combines the current annual wastewater management costs with the projected incremental costs of the IP to estimate the annual costs of the program. As shown in Table 8-5, the annual costs would increase by about $8.5 million to $31.8 million compared to the current annual costs of $23.3 million

Table 8-5: Annual Projected Wastewater Management Program Service Costs under the Integrated Plan

Category	Cost
Current Annual Wastewater Management Costs	$23,320,430
Incremental Annual Debt Service Costs	$6,553,531
Incremental Annual O&M	$1,950,000
Total Annual Integrated Plan Cost	**$31,823,961**

8.2.1.3 Cost per Household Under the Integrated Plan

Because EPA's methodology for assessing affordability focuses exclusively on residential ratepayers, the costs of the current and IP wastewater management program were allocated between residential customers and all other customers (i.e., commercial, industrial, and public). The cost per household was determined by dividing residential cost by the estimated number of residential customers.

As noted above, because Lowell Water's billing system does not separate ratepayer bills by customer class (sewer fees are uniform across all customer classes), or by location, a two-step analysis was performed to estimate the Lowell residential burden for operating and maintaining the wastewater infrastructure. Firstly, Lowell has signed municipal agreements with the surrounding Towns regarding their contribution to the cost of debt service which comports with their demand for wastewater services. These agreements allocate approximately 81 percent of the wastewater management costs to Lowell and 19 percent to the other towns collectively. Accordingly, for purposes of the FCA it is assumed the Lowell residents and commercial entities are responsible for 81 percent of the costs for operating and maintaining the wastewater treatment plant, including future debt service costs. Lowell sewer accounts will cover 100 percent of the costs for Lowell's own collection system.

The second step of the analysis entailed estimating the residential burden of Lowell's contribution to these costs. The was accomplished by entering all of Lowell's sewer accounts into a database and sorting the accounts by customer class based on account names and addresses. Commercial, government, and industrial accounts were separated from residential accounts to the extent possible and annual revenues generated for FY2018 were totaled for each customer class yielding an estimate of 82 percent of total revenues attributed to Lowell's residential accounts. Hence, for the FCA, it is assumed that Lowell's residential customers incur about 66 percent of the Utility's total annual cost (81% times 82%).

The number of Lowell residential accounts had to be estimated by analyzing the entire account list and as shown in Table 8-6, allocating 66 percent of the Utility's current and estimated IP wastewater

management costs to the Lowell residential customer base, yields an estimate of $21.14 million borne by those ratepayers, and $10.7 million borne by Lowell non-residential ratepayers and the ratepayers of the other towns.

Table 8-6: Wastewater Management Cost Allocation under the Integrated Plan

Cost Allocation by Customer Category	Cost
Total cost allocated to all customers	$31,823,961
Portion Allocated to Lowell (81%)	$25,777,409
Lowell Portion allocated to Lowell residential customers (82%)	$21,137,475
Portion allocated to all others (Non-Residential Lowell and other towns)	$10,686,486

Finally, the total cost allocated to Lowell residential customers was divided by the total residential accounts identified in Lowell's sewer account database (20,056) to determine the cost per household, which yields a cost per household of $1,054. This calculation is shown in Table 8-7.

Table 8-7: Wastewater Management Cost Per Household under the Integrated Plan

Cost Allocation	Cost
Total cost allocated to Lowell residential customers	$21,137,475
Estimated number of residential customers	20,056
Cost per household	$1,054

Calculated RI for Integrated Plan

To calculate the RI, it is necessary to estimate the current median household income (MHI). Table 8-8 presents inflation adjusted MHI and the CPH as a percent of MHI based on the 2017 American Community Survey (ACS) data adjusted to 2019 dollars using the Consumer Price Index (CPI) through July 2019 as published by the Bureau of Labor Statistics (4.0 percent).[5] The cost per household of 2.1 percent results in a RI of 2.1.

Table 8-8: Calculated RI under the Integrated Plan

Year	City of Lowell Inflation Adjusted Median Household Income	Cost per Household	Cost per Household as a Percentage of MHI
2017	$50,524	$1,054	2.1

MHI Source: American Community Survey, 2013- 2017 (5-year data). Inflated to 2019 dollars

Based on the USEPA 1997 Guidance Document criteria, because the CPH is above 2 percent of the adjusted MHI, the financial impacts to households under the IP would be classified as "High Range," indicating that the IP would impose a "High" burden on Lowell's ratepayers.

[5] Bureau of Labor Statistics, CPI through August 2019. http://www.bls.gov/news.release/pdf/cpi.pdf

8.3 Municipal Financial Capability

EPA uses six standard indicators to assess the financial capability of a municipal or utility permittee. The indicators cover categories of municipal debt, local socioeconomic conditions, and financial management practices to provide a snapshot of the municipality's overall financial strength both in absolute terms and relative to the national economy. EPA has recognized that the six indicators provide only a partial and static picture of the economy in which the utility operates. Subsequently, EPA modified the guidance in 2014 to allow utilities, where appropriate, to submit supplemental information to put these indicators into a broader historical perspective, and within the context of other potentially important economic and financial factors. As noted in the previous section, the Duck Island WWTF is owned, operated, and financed by the City of Lowell; therefore, for the purpose of this FCA, financial capability indicators are calculated for the City of Lowell only. Table 8-9 lists the six standard EPA indicators for measuring financial capability.

Table 8-9: City of Lowell Financial Capability Indicators

Financial Capability Indicators
DEBT
Bond Rating (GO Bonds)
Net Debt as percent of Full Market Value
SOCIOECONOMIC
Unemployment Rate
Median Household Income
FINANCIAL MANAGEMENT
Property Tax Revenue as Percent of Value
Property Tax Collection Rate

Source: EPA 1997 CSO – Final Guidance for FCA and Schedule Development

Based on EPA's 1997 benchmarks, scores of 1 to 3 corresponding to "Weak," "Mid-Range," or "Strong" ratings, respectively, are assigned to each of the 6 indicators which then are averaged into a single score. An average score below 1.5 would fall into the "Weak Range"; 1.5 to 2.5, "Mid-Range"; and greater than 2.5 would indicate "Strong" financial capacity. This score is combined with the RI to generate an overall financial capability matrix. Table 8-10 presents the financial capability indicators.

Table 8-10: EPA Benchmarks for Financial Capability Indicators

Indicator	Strong	Mid-Range	Weak
Bond Rating	Aaa-A1 (Moody's) AAA-A (S&P)	Baa (Moody's) BBB (S&P)	Ba-C (Moody's) BB-D (S&P)
Net Debt as a Percent of Full Market Property Value	Below 2%	2% to 5%	Above 5%
Unemployment Rate	More than 1% Below the National Average	Within 1% of National Average	More than 1% of National Average
Inflation Adjusted Median Household Income	More than 25% Above Inflation Adjusted National MHI	Within 25% of Inflation Adjusted National MHI	More than 25% Below Inflation Adjusted National MHI
Property Tax Revenues as a Percent of Full Market Property Value	Below 2%	2%-4%	Above 4%
Property Tax Collection Rate	Above 98%	94%-98%	Below 94%

8.3.1 Debt Indicators

The USEPA debt indicators were used to assess the current debt burden of Lowell and its ability to issue additional debt to finance the proposed IP. The indicators include Lowell's bond rating and the overall net debt as a percent of full market property value.

8.3.1.1 Indicator 1: Bond Rating

The City of Lowell's bond rating from Standard and Poors (S&P) is AA with a stable credit watch/outlook. The AA rating was issued on September 11, 2019 in conjunction with the City's issuance of $62.230 million of General Obligation (GO) bonds due September 01, 2039 [6]

Moody's Analytics also assigns bond ratings; in April 2016, it issued an A1 rating on the City of Lowell's Long-term GO Bonds and but it also removed its positive outlook.[7] Regardless of which rating agency is used, since both Standard and Poors and Moody's assign a rating of at least a single "A", the Bond Quality Indicator for Lowell yields a "Strong" rating.

8.3.1.2 Indicator 2: Net Debt as Percent of Full Market Value

According to FY2019 financial data provided by Lowell's Chief Financial Officer (CFO), its net bonded General Obligation Debt was $246,269,331 as of June 30, 2018. In addition, Lowell's CFO reported that the Net Assessed Valuation of all property in Lowell totaled $8,192,679,800. Accordingly, the total net debt as a percent of assessed value is 3.01 percent. Under EPA's rating system, a debt level between 2 and 5 percent of assessed value of all property in the service area yields a "Mid-Range" rating.

8.3.2 Socioeconomic Indicators

Socioeconomic indicators were calculated as an indicator of the economic wellbeing of Lowell's residential customers. The two socioeconomic indicators considered, per the EPA guidance document, were the unemployment rate and median household income.

8.3.2.1 Indicator 3: Unemployment Rate

As of July 2019, Lowell's unemployment rate was 3.0 percent, compared to 3.0 percent for the State of Massachusetts, and 3.7 percent for the Nation. The unemployment rate has been in an almost continuous decline from the peak level of 11.8 percent reached in September 2009.

---

[6] Standard and Poors. Ratings Action https://www.standardandpoors.com/en_US/web/guest/ratings/details/-/instrument-details/sectorCode/PUBFIN/entityId/1846/issueId/1582163, Accessed on October 2, 2019

[7] Moody's. Rating Update: Lowell (City of) MA, 12 April 2016. https://www.moodys.com/MdcAccessDeniedCh.aspx?lang=en&cy=global&Source=https%3a%2f%2fwww.moodys.com%2fviewresearchdoc.aspx%3fdocid%3dPBM_1021105%26lang%3den%26cy%3dglobal Accessed on October 2, 2019

EPA's rating system is based not on absolute rate but on the rate relative to the national unemployment rate. Lowell's unemployment rate of 3.0 percent is within 1 percent of the national unemployment rate and hence yields a "Mid-Range" rating.

8.3.2.2 Indicator 4: Median Household Income (MHI)

The most recent data from the Bureau of Census (BoC) American Community Survey estimated an MHI for Lowell of $48,581 in 2017 compared to the national MHI of $57,652.[8] Adjusting for inflation using the CPI through July 2019, generates an adjusted MHI of $50,524 compared to a national adjusted MHI of 59,958. Under EPA's rating system, Lowell's MHI would receive a "Mid-Range" rating because it is only 84 percent of the national MHI. To achieve the "Strong" rating the MHI must be more than 25 percent greater than the national MHI.

8.3.3 Financial Management Indicators

8.3.3.1 Indicator 5: Property Taxes as a Percent of Full Market Value

In FY2018, Lowell collected a total of $125,847,879 in property taxes. As a percentage of full market value, property taxes accounted for only 1.4 percent of Lowell's $8.19 billion in assessed property. Lowell would receive a "Strong" rating for this financial management indicator as the property tax levy is below the 2 percent threshold.

8.3.3.2 Indicator 6: Property Tax Collection Rate

For FY2018, Lowell received 98.8 percent of real estate taxes billed.[9] This collection rate yields a "Strong" rating in the EPA scoring system.

8.4 Summary Rating (Combination of 6 Financial Strength Indicators with Residential Indicator)

As shown in Table 8-11, using the most recently available data, the City of Lowell would receive "Mid-Range" ratings for two indicators, a "Strong" rating for three indicators, and a "weak" rating for the unemployment indicator yielding an average score of 2.5 for all six indicators. A 2.5 score falls into the "Mid-Range" rating for financial management.

[8] Bureau of Census, American Community Survey (2017- 5-year data). https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_16_5YR_S1903&prodType=table

[9] Finance Department, City of Lowell, Per. Communication, November 2018

Table 8-11: Lowell City's Financial Capability Indicator Ratings and Scores

Indicator	Value	EPA Indicators Rating	City of Lowell Score
DEBT			
Bond Rating (GO Bonds)	AA	Strong	3
Net Debt as Percent of Full Market Value	3.3%	Mid-Range	2
SOCIOECONOMIC			
Unemployment Rate	3.3%	Mid-Range	2
Median Household Income	$49,970	Mid-Range	2
FINANCIAL MANAGEMENT			
Property Tax Revenue as Percent of Full Market Value	1.7 percent	Strong	3
Property Tax Collection Rate	98 percent	Strong	3
Average Score			**2.5**

To determine the overall Financial Capability, EPA combines the financial capability and residential indicator scores in a matrix that is shown in Table 8-12. A calculated Residential Indicator of "High Impact" combined with an average Financial Capability Score of 2.5 yields a result that places the City of Lowell's wastewater management program in the **"**High Burden**"** Category.

Table 8-12: Summary Financial Capability Table for Lowell City

Permittee Financial Capability Indicators Average Score	Residential Indicator (Cost Per Household as a Percentage of MHI)		
	Low (Below 1 Percent)	**Mid-Range (Between 1 and 2 Percent)**	**High (Above 2.0 Percent)**
Weak (Below 1.5)	Medium Burden	High Burden	High Burden
Mid-Range (Between 1.5 and 2.5)	Low Burden	Medium Burden	High Burden
Strong (Above 2.5)	Low Burden	Low Burden	Medium Burden

However, although indicating a "High Burden", the standard EPA metrics may still underestimate the actual financial burden on Lowell's ratepayers. The following section more fully demonstrates the magnitude of the financial impact of the proposed IP when the projected annual costs are placed in the context of Lowell's substantial low-income population and the high cost of living relative to the average jurisdiction in the United States.

8.5 Supplemental Information for Assessing Financial Capability

As described in the introduction, EPA issued new guidance on conducting an FCA in November 2014. A key aspect of the new guidance is EPA's openness to reviewing supplemental information beyond the data used to generate the standard indicators comprising the 1997 FCA guidance.

8.5.1 Using Household Quintile Income Data for Calculating the Residential Indicator for the City of Lowell

Although Lowell's household income is not nearly as skewed as it is in many large metropolitan areas such as New York or Washington DC, it still has significant pockets of poverty and substantial disparities

in household income levels which are not captured in the MHI metric. According to the American Community Survey (5-year estimates) most recent data from 2017, the City of Lowell's poverty rate of 22.4 percent significantly exceeded the national rate of about 14.6 percent. The mean (i.e., average) household income of the bottom 20 percent of Lowell's households earned only $8,776 in 2017 (2019 dollars). Even at the top of this quintile, Lowell households earned only $16,175 (2019 dollars) or less than a third of the City's MHI. Poverty levels for its large Hispanic population are just short of 50 percent. Finally, household incomes at the upper limit of the 40th percentile are also substantially lower than the MHI. According to the 2017 ACS data, households at the upper limit of the 40th percentile earned $36,854 or almost 27 percent lower than the MHI of $50,524.

Hence, using 2 percent of MHI as the threshold for affordability does not capture the potential financial impacts on large swaths of Lowell's households. The financial impact of the costs of the IP wastewater management program in terms of cost per household becomes clearer when the cost per household estimates are compared against household income quintiles (adjusted to 2019 dollars) as well as MHI. This is shown in Table 8-13.

Table 8-13: Calculation of the RI Using Household Income Quintile Data

Income Level	RI
MHI	2.1
1st Quintile	6.5
2nd Quintile	2.9

As shown in Table 8-13, using the upper limits of each quintile, the cost per household of projected wastewater management expenditures is 2.9 percent or greater of household income for 40 percent of Lowell's households. Measured against the top earners in the bottom 20 percent of the population, the cost per household is 6.5 percent of their household income.

8.5.2 Cost of Living Adjustment for City of Lowell

Even using the quintile household income metric can be inadequate in measuring affordability because t it fails to capture location-specific cost of living. With the large disparities in living costs across the United States, a 2 percent expenditure of MHI for wastewater management expenditures does not have a uniform financial impact across all households with the same income. In communities where housing and other non-discretionary expenditures are relatively low, even a 2 percent household expenditure on wastewater management program costs may not impose a high impact. However, in a very high cost jurisdiction, expenditures below the 2 percent threshold could be impactful on household finances for lower income households who are compelled to spend higher proportions of their income on non-discretionary expenditures such as rent, food, electricity, and transportation. As described below, the City of Lowell is in a high cost of living region.

The Council for Community and Economic Research (C2ER) measures the cost of living index (COLI) for municipalities and communities throughout the country and publishes this index on a quarterly basis. Although the City of Lowell is not included in the list of cities for which the COLI is estimated, COLIs

are generated for the City of Boston and for Middlesex County, the county in which Lowell is located. For 2018, Boston's COLI averaged 150 and C2ER's 2018 County Index for Middlesex County was 136.74.[10] While the C2ER COLI calculations are a useful indication of the region's high cost of living, they are not fully representative of Lowell since it is far less affluent than some of the other towns, especially those to the east and closer to Boston; therefore those COLI's would likely overstate Lowell's cost of living. To use a more realistic COLI, the FCA averaged the cost of living indices published by several commercial websites, including "Sperlings Best Places" and "Payscale" which provide users with information of the relative cost to move to a particular city, were consulted. These sites published COLIs for Lowell that ranged from 120 to 125. Accordingly, for the purposes of the FCA a COLI of 122 was used for Lowell.

A COLI of 122 means that the cost of living for an average household in Lowell is 22 percent higher than that for an average household in the United States. Accordingly, the COLI, when divided by 100, shows how much someone in each urban area must spend to have the equivalent buying power of one dollar. For example, a 122 COLI means that the buying power of one dollar in the average US City costs $1.22 in Lowell. MHI values can be adjusted using the cost of living index to show the true purchasing power of a household's annual income. Table 8-14 shows that it would take $50,524, for a household in Lowell to purchase the same basket of goods and services (e.g., housing, transportation, food) that would cost $41,413 in the average U.S. city.

Table 8-14: COLI Adjusted Median Household Income for Lowell Massachusetts

Median HH Income for City of Lowell	Cost of Living Index	Adjusted Median HH Income for City of Lowell
(a)	(b)	(c) = (a/(b)/100)
$50,524	122	$41,413

The same logic can be used to adjust incomes for all quintiles to understand how cost of living affects households in different income brackets. Table 8-15 shows the adjusted upper limit income for each quintile for Lowell in 2017 and the mean for the second quintile. These adjustments show that for the lowest quintile, the upper limit of income falls from $16,175 to $13,258 and the upper limit of the second quintile falls from $36,854 to $30,209. Households at the mean income of the second quintile have a COLI adjusted income of just $21,036. These measures indicate that when considering the high cost of living in Lowell, unadjusted MHI estimates do not adequately characterize the financial burden of utility expenses paid by a substantial portion of Lowell households.

Table 8-15: COLI Adjusted Upper Limit Income Levels for City of Lowell

	Upper Limit Income Levels	Adjusted Income
Lowest Quintile	$16,175	$13,258
Second Quintile (Upper Limit)	$36,854	$30,209
Second Quintile (Mean)	$25,664	$21,036

Source: U.S. Census Bureau, 2017 American Community Survey, Table B19081; Adjusted to 2019 dollars.

[10] J. Allison 2019 County Index Center for Regional Economic Competitiveness Per Communication October 30, 2019

Table 8-16: COLI adjusted RI for Lowell Households

Income Levels	RI
Lowest Quintile	7.9
Second Quintile (Upper Limit)	3.5
Second Quintile (Mean)	5.0
MHI	2.5

As shown in Table 8-16 above, accounting for Lowell's high cost of living indicates all households at or below the MHI would experience a "high economic" impact from the projected cost per household under the IP.

8.6 Proposed Modification of City of Lowell's Financial Capability Rating using Supplemental Information

Using the types of supplemental information EPA referred to in its November 2014 guidance provides a more detailed characterization of Lowell's financial capability for implementing the proposed IP. The supplemental information also brings EPA's indicators into better context given Lowell's skewed income distribution and relatively high cost of living compared to the average US City.

The supplemental data suggest that the RI, using the standard MHI, underestimates the financial impact of Lowell's proposed IP on its ratepayers. Evaluating residential impacts using only the MHI metric indicates that the IP would impose a "High Burden", albeit with an RI just slightly above the 2 percent threshold. However, when the costs are measured against the upper limit of the 40th percentile and 20th percentile households, the RI increases to 2.9 and 6.5 respectively. Those RIs are much more substantially above the 2 percent threshold for high impact, especially for the bottom 20 percent of households.

The financial impact on lower income households increases even more when Lowell's high cost of living is taken into account. When the purchasing power of Lowell's residents is factored into the RI calculation, the resulting RI is 3.5 for households at the upper limit of the 40 percentile and 7.9 for households at the upper limit of the 20th percentile. The 2 percent threshold is substantially breached at the MHI level as well. Hence, using the COLI adjustment renders the IP affordable for more than 50 percent of Lowell's population.

The standard metrics for assessing Lowell's financial management appear appropriate. Property taxes are a major source of Lowell's revenue and therefore provide a good sense of the City's capacity to further increase revenues to invest in capital projects. Lowell's debt and bond ratings are relatively strong, and these are good indicators of the municipality's overall financial health. Hence, there is no pressing need to modify the standard financial management metrics for the purposes of the FCA. Modifying only the RI metrics results in an adjusted Financial Capability Matrix shown in Table 8-17. As shown in this table, the combination of the Mid-Range financial capacity score with a High Impact RI score, results in a "High" Burden" rating for the Integrated Plan's wastewater program.

Table 8-17: Summary of COLI Adjusted Financial Capability Matrix for City of Lowell

Permittee Financial Capability Indicators Average Score	Residential Indicator (Cost Per Household as a Percentage of MHI)		
	Low (Below 1%)	Mid-Range (Between 1 and 2%)	High (Above 2.0%)
Weak (Below 1.5)	Medium Burden	High Burden	High Burden
Mid-Range (Between 1.5 and 2.5)	Low Burden	Medium Burden	High Burden
Strong (Above 2.5)	Low Burden	Low Burden	Medium Burden

8.7 Summary and Conclusions

The FCA using EPA's updated guidance to allow for supplemental information to tailor the analysis finds that the wastewater management program under the proposed IP would impose a "High Burden" on the City of Lowell and its ratepayers. Critical to this assessment is taking into account Lowell's income distribution and the high cost of living. The high poverty rate of 22.4 percent together with the skewed income distribution argues for using quintile data instead of the MHI, which fails to capture the percentage of low-income ratepayers in the service area. Also, Lowell's relatively high cost of living should be factored into the financial burden that the wastewater management program places on the service area's population. Based on these additional factors, the FCA concludes that the proposed IP would pose a high financial burden on the City of Lowell and its residents.

Finally, it should be noted that the IP would also invest $62.8 million to improve water supply infrastructure and that these costs would also be borne by the same Lowell households bearing the cost of the wastewater management program. If included in the RI calculations, the estimated burden would be higher than reported in this FCA.

9. Integrated Planning Framework

The overall purpose of the IPF is to prioritize and provide a plan for implementation for the infrastructure needs of Lowell related to the water and wastewater systems. The IP is based on a set of procedures that generally sought to follow the EPA's 2011 Guidance for Integrated Planning Framework. The IPF has allowed Lowell to identify necessary infrastructure projects (for its wastewater, stormwater, and drinking water systems) and rank these projects according their potential environmental and community impacts.

The project rankings developed through the IPF are independent of the CSO control alternatives analysis and are based exclusively on the potential environmental and community impacts of each individual project. As such, the project rankings developed through the IPF have allowed Lowell to assess the potential community and environmental benefits of wastewater, stormwater, and drinking water projects according to a consistent methodology.

9.1 IP Project List

Lowell developed a list of projects to be considered in this IP based on the infrastructure needs identified in Chapter 2 of this report and based on their potential to provide significant CSO control benefit as derived in the alternatives evaluations herein. Table 9-1 contains a listing of these projects, along with estimated project costs and durations.

9.2 IPF Model Development

As the FCA in Chapter 8 demonstrated, spending due to the IP has the potential to cause significant and burdensome rate increases for much of Lowell's population. As such, a ranking system was developed to score and rank projects so as to maximize environmental and community benefits to the greatest extent possible. To do this, criteria that measure environmental and community impacts were developed and each project was scored according to these criteria. Criteria were also weighted based on their importance. Development of criteria, weighting, and scoring of projects was a collaborative effort between City staff and its consultant.

9.2.1 Criteria Development and Weighting

To develop criteria for scoring projects, City staff determined that projects should be ranked based on their possible environmental and community benefits. As such, through several meetings, City staff identified criteria that were used to quantify potential benefits of each project. After the criteria were identified, they were weighted so that the relative importance of each could be established. Criteria were weighted by City staff voting on pair-wise comparisons, where voters were asked to numerically rate the relative important of one criterion versus another. Then, the relative weight of each criterion was established as a percentage (totaling 100%). This weighting ensures that criteria that are of greater importance to Lowell have a more significant impact on the overall score of each project. By following the pairwise comparison process with City staff, the resultant weights are reflective of the needs and priorities of Lowell. Table 9-2 contains the criteria and a description and the weight associated with each.

Table 9-1: IP Projects and Programs

Project Name	Estimated Duration (years)
CMMS/Utility Technologies	Ongoing Program
Drinking Water O&M	Ongoing Program
Permitting & Legal Services	Ongoing Program
Planning (Outfall Monitoring & Adaptive Management)	Ongoing Program
Stormwater O&M	Ongoing Program
Wastewater O&M	Ongoing Program
Lead Service Replacements	15
Drinking Water Backflow & Meter Improvements	4.5
Diversion Stations: Wet Weather Conveyance	3
Duck Island Peak Flow Optimization	3
Duck Island WWTF Upgrades	3
Finished Drinking Water Storage Tank	3
North Bank WWTF	3
Satellite Station Upgrades	3
Distribution System Improvements	2
Douglas Wet Weather Storage Facility	2
Drinking Water Treatment Facility Upgrades	2
Duck Island Phosphorus Removal Project	2
Duck Island WWTF Centrifuge	2
Pevey Wet Weather Storage Facility	2
Redundant Transmission Main	2
Tilden Sewer Separation and GI	2

Table 9-2: Project Scoring Criteria and Weighting

Category	Criterion	Description	Weight
Environmental	Protection of Aquatic Life	*Ability to support healthy flora and fauna*	*8.04%*
	Recreational Use Attainability	*Ability to safely support recreational activities (swimming, boating, etc.)*	*4.04%*
	Drinking Water Supply	*Protection of the Merrimack River's status as a drinking water supply*	*5.50%*
Community	Public Health	*Protection of public health and quality of life for Lowell residents*	*20.43%*
	Municipal Liability	*Vulnerability to litigation against Lowell*	*4.40%*
	Ratepayer Satisfaction	*Protection of ratepayer interests, needs, and environmental justice*	*5.14%*
	Property Protection	*Protection against building and property damage*	*8.04%*
	Economic Development	*Potential for cleaner river to support growth of new businesses*	*6.02%*
	Human Life/Safety	*Ability to mitigate catastrophic failures, accidents, and unforeseen events (drought, major flooding, etc.)*	*15.06%*
	Funding/Financial Advantages	*Potential cost-benefit performance*	*6.78%*
	System/Equipment Reliability	*Ability to support day-to-day reliability of water/wastewater infrastructure*	*18.39%*

9.2.2 Project Scoring

In order to score each project, a rating system for measuring the effectiveness (positive impact) of each project relative to each criterion was developed. The system developed allowed for each criterion to be assigned three possible scores:

- 0 = no positive impact
- 1 = limited positive impact
- 2 = most significant positive impact

Several meetings occurred among City staff, and between City staff and Lowell's consultant, to develop scores for each criterion for each project. As summarized by the formula below in Figure 9-1, the score for each criterion was then multiplied by its weight, and the total project score was determined by the sum of weighted scores for each criterion. Programs were not scored and were instead "locked in" to the IP as they are essential to the operation and maintenance of the utilities.

$$S_w = \sum_{k=1}^{n} C_k \times W_k$$

Where:

$\mathbf{S_w}$ = Sum of Weighted Score
$\mathbf{C_k}$ = Raw Score for a given criterion (k)
$\mathbf{W_k}$ = Calculated Weight for a given criterion (k)
n = 11, or the number of criteria

Figure 9-1: Sum of Weighted Score Equation

Table 9-3 contains the raw scoring of each project for each criterion and the resulting score (calculated based on the weight of each criteria).

Table 9-3: Project Scoring

Project Name	Public Health	System/Equipment Reliability	Human Life/Safety	Property Protection	Funding /Financial Advantages	Aquatic Life	Economic Development	Drinking Water Supply	Ratepayer Satisfaction	Municipal Liability	Recreational Use	Sum of Weighted Score
Redundant Transmission Main	2	2	2	2	2	0	2	0	2	2	0	1.69
Drinking Water Backflow & Meter Improvements	2	2	1	2	2	0	2	1	2	2	0	1.59
North Bank WWTF	0	2	2	2	2	2	2	2	2	1	2	1.55
Lead Service Replacements	2	2	1	2	2	0	2	0	2	2	0	1.53
Douglas Wet Weather Storage Facility	2	2	2	2	1	0	1	0	2	1	0	1.51
Pevey Wet Weather Storage Facility	2	2	2	2	1	0	1	0	2	1	0	1.51
Duck Island Peak Flow Optimization	0	2	2	1	2	2	2	2	2	2	2	1.51
Diversion Stations: Wet Weather Conveyance	0	2	2	1	2	2	2	2	2	2	2	1.51
Drinking Water Treatment Facility Upgrades	2	2	1	1	0	0	0	0	1	2	0	1.15
Duck Island WWTF Upgrades	0	2	1	0	2	1	2	1	1	2	2	1.11
Tilden Sewer Separation and GI	1	1	1	1	0	2	1	1	1	1	2	1.03
Satellite Station Upgrades	0	2	2	2	0	0	1	0	1	2	0	1.03
Distribution System Improvements	1	2	1	0	0	0	1	0	0	2	0	0.87
Finished Drinking Water Storage Tank	1	1	2	0	0	0	1	0	0	2	0	0.84
Duck Island Phosphorus Removal Project	0	1	0	0	0	2	0	1	0	2	1	0.49
Duck Island WWTF Centrifuge	0	1	0	0	0	2	0	1	0	2	1	0.49

9.3 Project Optimization and Scheduling

In order to maximize benefits as quickly as possible during IP implementation, a model was developed to maximize benefits early-on. This model uses an algorithm to determine the optimal sequencing of projects. The algorithm considered the following to compute the optimal start time for each project:

- Project score (benefits)
- Project cost
- Project duration

Based on these factors, an optimal start time for each project was computed to maximize benefits as early in the IP as possible. Programs were also included in the model, but their benefits were not calculated nor factored into the algorithm. Table 9-4 illustrates the benefits associated with each project. The algorithm that the model uses to schedule the project accounts for the fact that a long project with a high benefit score may result in fewer early-on benefits than a shorter project with a smaller benefit score due to the length of time required to achieve the benefits associated with the project (see Figure 9-2).

$$S_B = \ln\left(\frac{T_H}{T_P}\right) + \left(S_f \times S_w\right)$$

Where:

S_B = Benefits Score = **Duration Contribution** + *Weighted Score Contribution*
T_H = Initial Planning Horizon (10 years)
T_P = Project Duration (years)
S_f = Weighted Score Factor = 1000
S_w = Sum of Weighted Score

Figure 9-2: Project Benefits Equation

Table 9-4: Project Benefits

Project Name	Benefits Score
Redundant Transmission Main	1686.81
North Bank WWTF	1548.60
Douglas Wet Weather Storage Facility	1514.81
Pevey Wet Weather Storage Facility	1514.81
Diversion Stations: Wet Weather Conveyance	1512.20
Duck Island Peak Flow Optimization	1512.20
Drinking Water Treatment Facility Upgrades	1148.41
Duck Island WWTF Upgrades	1112.80
Tilden Sewer Separation and GI	1036.21
Satellite Station Upgrades	1030.60
Distribution System Improvements	872.51

Project Name	Benefits Score
Finished Drinking Water Storage Tank	838.80
Duck Island Phosphorus Removal Project	492.91
Duck Island WWTF Centrifuge	492.91

9.3.1 Ranking Evaluation and Refinement

Several meetings between Lowell and its consultant were held to review and assess projected project benefits and calculated project start times. In some situations, the calculated start time was incompatible with other requirements that could not be fully characterized by the project scoring methodology alone. These exceptions are summarized below:

- Pevey & Douglas Wet Weather Storage Facilities. In addition to being a part of Lowell's Phase 3 control plan, these facilities are urgently required to address CSO surcharging and overflows at key locations throughout Lowell. CSO surcharging may occur at sensitive locations in Lowell, including near the Lowell Boy's and Girl's club and a daycare facility. These issues present a clear and significant public health threat and must be addressed as early as possible during implementation of the IP. Lowell has already completed a conceptual design for the Pevey Wet Weather Storage Facility.

- Duck Island Phosphorus Removal Project and WWTF Centrifuge. In order to comply with its permit, Lowell must complete a phosphorus removal project at the WWTF early on in the IP. Despite this, the phosphorus removal project ranked very low based on its score. It is Lowell's opinion that this nutrient removal project is significantly less important than CSO mitigation projects. Regardless, this project must occur early-on during IP implementation to maintain permit compliance. It is also logical to bundle the WWTF Centrifuge upgrade project with the phosphorus removal project from a construction perspective, so this project will occur early in the IP as well.

9.4 Adaptive Management

Adaptive management of the IP is an important strategy that will allow the IP to remain updated as conditions in Lowell change over time. As projects are implemented, actual benefits may differ from projected benefits. Further, the conditions that govern other IP elements such as affordability, criteria, weighting, and others, may change throughout the implementation period. For example, a new regulatory requirement may change the weighting of project criteria or require the addition of a new criterion. An economic recession has the potential to impact affordability, and greatly increase the burden of rate increases on much of Lowell's population. Adaptive management of the IP will allow Lowell to adjust IP elements as necessary to respond to these changes and ensure that benefits continue to be maximized without overburdening Lowell's most vulnerable residents with unaffordable rate increases. Chapter 11 includes a more complete discussion of Lowell's IP Adaptive Management Framework.

9.5 Public participation

Public participation during the development of the IP was an important opportunity for Lowell to solicit feedback from the public and environmental advocates. As such, three opportunities for public participation occurred during development of the IP:

1. City Council meeting on 6/11/19
2. Public meeting #1 on 6/14/19 with environmental advocates and planning directors
3. Public meeting #2 on 10/23/19 with environmental advocates and planning directors

Appendix G contains the materials shared at each meeting along with sign-in sheets. In general, meeting participants were given briefings about the goals of Lowell's IP, the status of its development, and the major elements of the CSO control plan. Participants engaged in discussions with Lowell staff and consultant staff about the IP and the need to balance competing priorities for limited funding. Participants were generally supportive of the IP and the projects included. It should also be noted that several meetings between Lowell, its consultant, and regulators occurred throughout development of the IP. These meetings were valuable forums during which initial feedback from regulators (regarding IP development and direction) was received by Lowell and its consultant.

This page intentionally left blank.

10. Recommended Plan

10.1 Rate Analysis and Scheduling

Based on the start dates calculated by the project optimizer, an unconstrained scenario was developed. Affordability was not considered for the development of this scenario, and no maximum expenditure in a given year was defined. Several important projects begin immediately in 2020, including lead service replacements and a redundant transmission main. These two projects are essential to mitigating critical public health risks and infrastructure vulnerabilities. Construction of the North Bank WWTF must be delayed to accommodate the phosphorus removal project at Duck Island, a regulatory requirement.

To determine if the unconstrained IP implementation was unaffordable, monthly expenditure forecasts were developed using industry standard distributions, as shown in Figure 10-1, that predict project/program expenditures during design and construction. The budget for each discrete project has been split into design costs and construction costs. The design cost was assumed linear, spread evenly across the design duration, and the construction costs were assumed to be incurred based on a bell curve for the estimated construction duration.

These monthly expenditure forecasts were analyzed by Lowell's CFO to forecast the sewer rate increases needed to support the IP. It is important to note that only costs associated with wastewater projects and programs were included in this analysis, per EPA guidelines. As such, the full cost of the IP is not accounted for, meaning actual rate increases will be significantly higher when the cost of drinking water projects is considered.

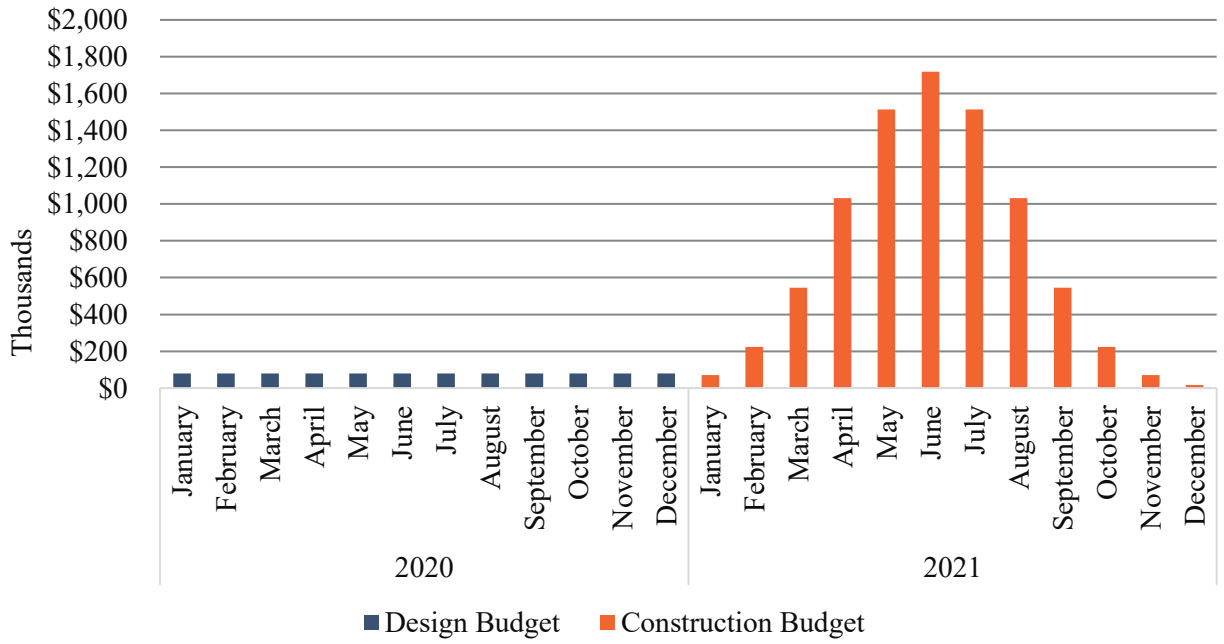


Figure 10-1: Sample Budget Loading

Several iterations of rate forecasting were completed to determine the most rapid possible schedule for implementation that did not greatly exceed affordability thresholds. This rate modeling indicated that the fastest possible schedule for IP implementation is 15 years.

Once the 15-year implementation period was determined, project costs were adjusted for inflation based on when they were scheduled to occur. As shown in Table 10-1, most project costs were also escalated for inflation according to their predicted start and end dates for this rate analysis. Some projects without clearly defined scopes (that were estimated using allowances instead) were not escalated. Project costs include a 35% markup for engineering services (design and construction).

Table 10-1: IP Project and Program Cost Summary

Project Name	Project Category	Budget	Project Start Date	Project End Date
Redundant Transmission Main	Drinking Water	$6,750,000	1/1/2020	12/1/2021
Drinking Water Treatment Facility Upgrades	Drinking Water	$7,425,000	1/1/2021	12/1/2022
Finished Drinking Water Storage Tank	Drinking Water	$25,110,000	1/1/2025	12/1/2027
Distribution System Improvements	Drinking Water	$2,700,000	1/1/2029	12/1/2030
Drinking Water Backflow & Meter Improvements	Programs	$11,880,000	1/1/2020	7/1/2024
Lead Service Replacements	Programs	$5,400,000	1/1/2020	1/1/2035
CMMS/Utility Technologies-Wastewater	Programs	$1,824,505	1/1/2020	Ongoing
Permitting & Legal Services-Wastewater	Programs	$1,824,505	1/1/2020	Ongoing
Planning (Outfall Monitoring & Adaptive Management)-Wastewater	Programs	$1,824,505	1/1/2020	Ongoing
CMMS/Utility Technologies-Water	Programs	$1,175,495	1/1/2020	Ongoing
Permitting & Legal Services-Water	Programs	$1,175,495	1/1/2020	Ongoing
Planning (Outfall Monitoring & Adaptive Management)-Water	Programs	$1,175,495	1/1/2020	Ongoing
Douglas Wet Weather Storage Facility	Wastewater	$9,450,000	1/1/2020	12/1/2021
Duck Island Phosphorus Removal Project	Wastewater	$1,965,600	1/1/2021	12/1/2022
Duck Island WWTF Centrifuge	Wastewater	$6,075,000	1/1/2021	12/1/2022
Pevey Wet Weather Storage Facility	Wastewater	$10,800,000	1/1/2022	12/1/2023
North Bank WWTF	Wastewater	$28,080,000	1/1/2023	12/1/2025
Diversion Stations: Wet Weather Conveyance	Wastewater	$459,000	1/1/2027	12/1/2029
Duck Island Peak Flow Optimization	Wastewater	$9,045,000	1/1/2028	12/1/2030
Duck Island WWTF Upgrades	Wastewater	$11,745,000	1/1/2028	12/1/2030
Satellite Station Upgrades	Wastewater	$8,000,000	1/1/2030	12/1/2032
Tilden Sewer Separation and GI	Wastewater	$6,366,600	1/1/2033	12/1/2034

The projects and programs in the Table 10-1 lead to a cost distribution of $97.5M being spent on wastewater and $62.8M being spent on drinking water by 2035.

Using a $97.5 million capital cost (wastewater expenditures only, adjusted for inflation) expended over a 15-year period, Lowell forecasted annual sewer rates required to generate the required revenue to pay for the associated debt service. The forecasted rates are shown in Table 10-2.

Table 10-2: Forecasted Sewer Rates 2020-2035 (per hundred cubic feet)

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Rate	$4.68	$5.10	$5.56	$6.23	$6.60	$7.06	$7.28	$7.28	$7.46	7.65	7.95	$7.95	$7.95	$8.19	$8.19	$8.19

Using these rates and an average household monthly consumption of 10 hundred cubic feet (7,500 gallons) per month, an average monthly bill was estimated for each, as shown in Table 10-3.

Table 10-3: Projected Monthly Bills 2020-2035

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Bill	$47	$51	$56	$62	$66	$71	$73	$73	$75	$76	$79	$79	$79	$82	$82	$82

To assess affordability, Lowell residential incomes were forecasted for the 15-year period ending in 2035. A review of historical data from the Census Department shows that Lowell incomes have been in an almost constant state of decline for more than a decade. Household incomes, especially in the lower income brackets, continued to decline even well after the official Great Recession ended in 2009. For example, incomes at the upper limit of the 40th percentile decreased from $45,600 in 2012 to $36,854 in 2017 (using 2019 dollars). For the bottom 20th percentile, household incomes dropped from $21,582 to $16,175. Median household incomes (MHI) decreased by 20 percent in real dollars from 2009-2017.

It is difficult to project whether stagnant incomes will persist over the next decade or return to a positive trajectory. However, despite recent robust growth in national household incomes, Lowell MHI actually decreased from 2015-2017. Unless structural changes occur in the Lowell economy, near-term high household income growth is not likely to materialize.

The affordability analysis assumes a positive but slow growth rate of 1 percent. There is and will remain a large disparity in income among the different quintile income groups with the bottom 20th percentile earning less than a third of the MHI. Hence, incomes are quite skewed in Lowell.

Lowell has been (and remains) a relatively high cost of living city with the most recent cost of living index (COLI) estimated at 122, or 22 percent higher than the average American city. This translates into lower purchasing power for both nondiscretionary and discretionary goods and services. Therefore, the reduced purchasing power Lowell residents experience relative to the average US household must be considered. Application of the COLI factor results in a Residential Indicator as shown in Table 10-4.

Table 10-4: Sewer Bills as Percentages of Monthly HHI with COLI Adjustment

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
MHI	1.3%	1.4%	1.5%	1.7%	1.8%	1.9%	1.9%	1.9%	1.9%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
40th Percentile	1.8%	1.9%	2.1%	2.3%	2.4%	2.6%	2.6%	2.6%	2.7%	2.7%	2.8%	2.7%	2.7%	2.8%	2.7%	2.7%
20th Percentile	4.1%	4.4%	4.8%	5.3%	5.6%	5.9%	6.0%	6.0%	6.0%	6.1%	6.3%	6.3%	6.2%	6.3%	6.3%	6.2%

This RI indicates that for all households at the upper limit of the 40th percentile and lower the IP is close to, or above, the affordability threshold for almost the entire 15-year period. The income growth rates used in the analysis are conservative since they assume positive growth rates that have not been achieved in more than a decade. Furthermore, the affordability analysis does not consider the significant IP expenditures dedicated to water infrastructure upgrades. These expenditures are equal to about 65% of the wastewater projects and will impact water rates. If these expenditures were to be accounted for, unaffordability of the IP would increase, further demonstrating that a faster implementation of the IP is not possible.

10.2 Implementation Schedule & Plan Benefits

Based on an implementation period of 15 years and the optimized project rankings, Figure 10-2 was developed to demonstrate the overall IP project implementation schedule, and shows accumulation of benefits and costs.

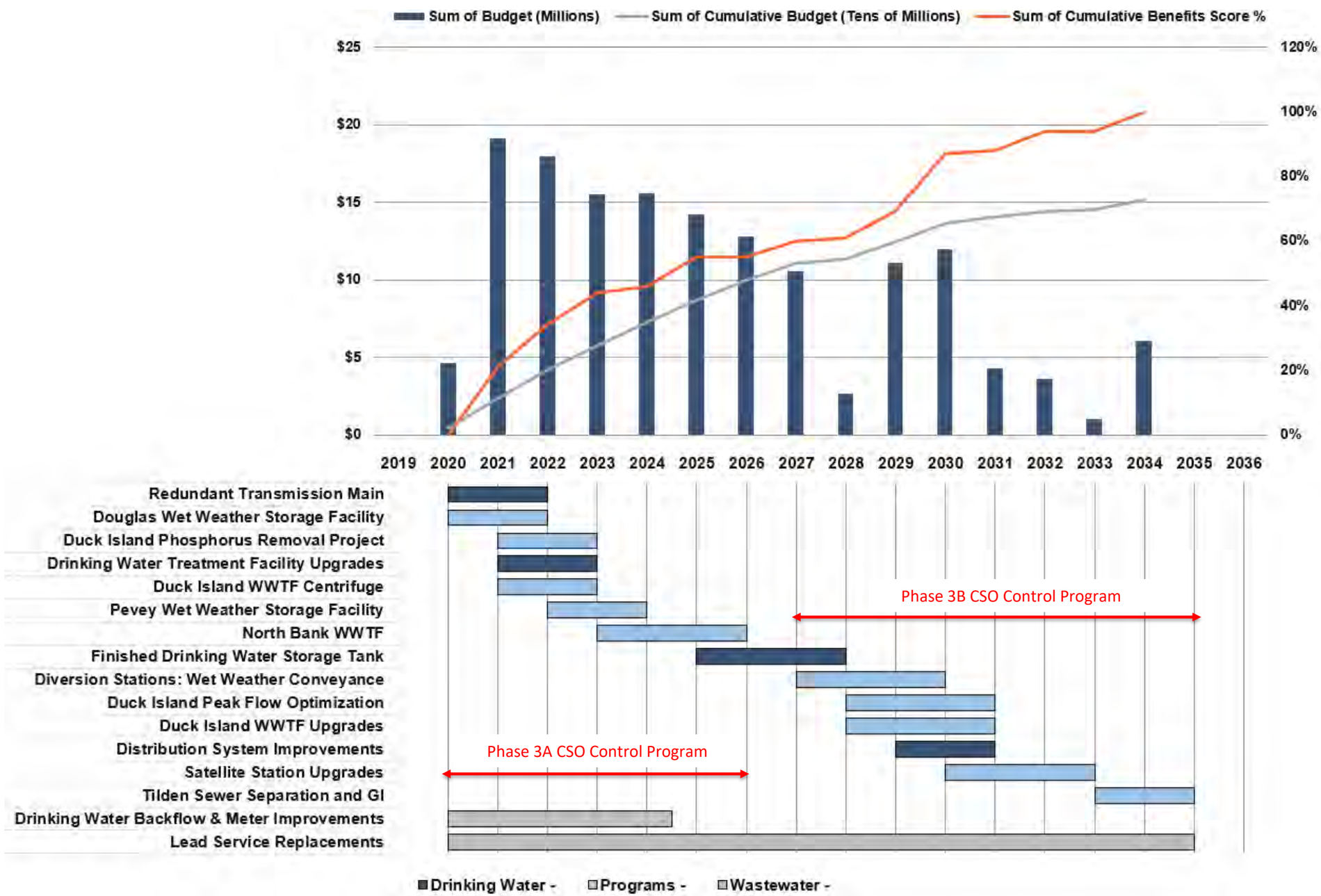


Figure 10-2: Recommended Plan Summary

The following conclusions can be drawn from the final IP implementation plan:

1. A high level of CSO control is achieved early-on in IP implementation. The North Bank WWTF is scheduled to be constructed by 2026. According to model predictions, construction of the North Bank WWTF will reduce untreated CSO discharges by more than 50%. As such, this schedule results in a substantial reduction of untreated CSOs within the first six years.

2. Other critical CSO surcharge mitigation projects, namely the Douglas and Pevey Wet Weather Storage Facilities, are constructed early in IP implementation. These projects are crucial to protecting public health and will help to mitigate CSO surcharges and discharges to waterbodies as well as directly to the street and homes.

3. Necessary drinking water projects that protect public health are completed or started early-on in the IP. The redundant transmission main project is scheduled to begin immediately in 2020, and a project to complete upgrades at the drinking water treatment plant is scheduled to begin in 2021. These projects are essential to ensuring a safe, resilient, and reliable drinking water supply in Lowell.

4. Lowell will begin a program to identify and replace lead services throughout the City, beginning in 2020. This important program will protect public health and ensure that lead services are systematically removed and replaced.

5. Several key drinking water and CSO projects, including the Finished Drinking Water Storage Tank and WWTF Peak Flow Optimization projects, must be implemented at a later date to accommodate the Phosphorus Removal project at Duck Island. The Phosphorus Removal project received a low ranking and is associated with a small benefit score but is a new regulatory requirement (in the draft permit), and must be completed by 2023 to maintain compliance.

6. After completion of the North Bank WWTF project in 2026, Lowell will have completed its Phase 3A CSO control program. The schedule includes a 1-year pause before the next CSO control project (Diversion Stations: Wet Weather Conveyance, the first project of the Phase 3B CSO control program) is started. This pause is necessary to avoid significantly exceeding affordability thresholds and to allow Lowell to optimize operation of its new sewer system infrastructure. As described in Sections 10.3, 10.6, and throughout Chapter 11, maximizing the benefits of the new North Bank WWTF will require iteration and an update to Lowell's HFM plan. This HFM update, which will occur between the Phase 3A and Phase 3B CSO control programs, will require post-construction sewer system monitoring and an update to Lowell's sewer system model. The sewer system characterization undertaken during this time will be important to determine the effectiveness of the Phase 3A CSO control program and facilitate adaptive management of the Phase 3B program, and the remainder of the IP.

10.3 Post-construction Monitoring

Post-construction monitoring is an important activity that will help determine the effectiveness of completed CSO control projects and determine the need to implement additional CSO controls (beyond those identified in this IP). In addition to post-construction monitoring completed after full IP implementation, monitoring will also occur after the North Bank WWTF is constructed and fully functional. The goals of post-construction monitoring at this phase will be to assess the effectiveness of the North Bank WWTF in reducing untreated CSOs to the Merrimack River and to support recalibration of the sewer system model. As such, post-construction monitoring undertaken at this time will include in-system flow metering. Significant operational changes will result from construction of the North Bank WWTF, and it will be necessary to recalibrate the sewer system model to more accurately represent the impact of additional CSO control projects.

Once the IP is fully implemented, receiving water quality monitoring will be performed to assess the state of the river with respect to meeting bacteria standards.

10.4 Operational Plan

Lowell is committed to effectively operate the projects and systems associated with the IP as they are built-out during the implementation period. Specific O&M plans will be developed for the proposed infrastructure during design and after regulatory approval.

10.5 Regulatory Approval

It is anticipated that regulatory approval of this IP will involve negotiations between Lowell, MassDEP, and the USEPA. It is Lowell's intention to work with regulators to implement this IP with all possible expediency to address the urgent public health and environmental protection need addressed by the projects in this IP. Regardless, Lowell recognizes that key CSO control projects, such as the North Bank WWTF, may require regulatory approval (EPA and MassDEP). It is also anticipated that construction of the North Bank WWTF will also be subject to MEPA review, with an ENF and potentially an EIR (pending MEPA review during design).

10.6 Interim Initiatives

10.6.1 CSO Discharge Validation/Additional Sewer System Characterization

While approval of the IP is being negotiated, Lowell intends to implement a systemwide program to validate estimates of CSO discharge volumes. CSO discharge volumes are currently estimated using orifice and weir equations that approximate the hydraulic behavior of upward and downward-opening diversion gates. Validating and refining this methodology for CSO discharge estimates will allow Lowell to establish a more accurate baseline against which future conditions can be compared. In addition, validating and improving the accuracy of CSO estimates will allow Lowell to better comply with requirements for reporting of CSO events. CSO discharge validation can be achieved by deploying temporary flow meters in major influent and effluent lines at each CSO station. If direct measurement of

the discharge is not feasible, then another method is to calculate the difference between influent flow and effluent flow (from the temporary meters), with the missing volume being attributed to CSO discharge. By performing this calculation at each CSO station for a variety of wet weather events, Lowell can validate its existing procedure for estimating CSO discharge volumes.

Lowell also intends to utilize the level monitors that it owns to further refine its wet weather in-line storage practices. This additional system characterization will help Lowell further optimize the sewer system and maximize wet weather storage. This will also help provide a baseline which can be used to further quantify the benefits of future CSO control projects.

10.6.2 Revised High Flow Management (HFM) Plan

As additional system improvements take place in the Recommended Plan, Lowell intends to produce a revised HFM plan that takes into account the modified operational characteristics of the system during wet weather. Lowell staff regularly meet and analyze system performance during wet weather using SCADA data collected in real time. The analysis of system performance includes a detailed examination of flow control and diversion gate positions, flow at the WWTF, CSO discharges, and more. Lowell intends to formalize many of the improvements which it has identified in an update to its existing (interim) HFM document.

The HFM plan will be revised upon completion of the ongoing clarifier upgrades and the CSO discharge validation monitoring, and a revised HFM submittal to EPA and MassDEP is planned in December 2021. The HFM plan will need to be updated again after major CSO control projects, such as the North Bank WWTF, are completed.

10.7 Other Considerations

10.7.1 Merrimack River – Regional Asset & Federal Funding

Although the IP Framework attempts to mitigate unaffordable rate increases being imposed on Lowell's most vulnerable residents, the benefits of higher levels of CSO control are not equally shared by Lowell's poorest and most vulnerable residents. Downstream river users in more affluent communities derive more benefit from additional CSO control than poverty-stricken inner-city residents in Lowell. This IP attempts to balance the needs of these residents (namely the need to maintain a safe, resilient, and consistent drinking water supply) with the need to achieve additional CSO control and protect river health; however, Lowell recognizes that by deferring spending on certain drinking water projects to complete CSO control projects, an improvement to a regional resource is being funded by vulnerable residents who can least afford rate increases and stand to benefit the least from higher levels of CSO control.

In recognition of this fact, Lowell would like to document that CSO control should be treated as regional challenge, that is deserving of regional and federal funding. If regional and federal funding were to become available, the unaffordable rate increases that will be imposed (in order to meet legally binding regulatory requirements) on Lowell's poorest residents may be mitigated. Further, federal funding would lead to more rapid implementation of CSO control projects and improved environmental protection. As

such, it is Lowell's opinion that to avoid environmental injustice, and the imposition of unaffordable rate increases on vulnerable residents who will see little benefit from additional CSO control, federal funding is required to make the high cost of CSO control more equitable.

11. Adaptive Management & Post-Construction Monitoring

In general, Lowell's Integrated Planning process has resulted in a dynamic framework that prioritizes capital improvement projects. This process was critical in the assessment of Lowell's priorities, in terms of project selection criteria, weighting and project ranking, with the goal being focused on the realization of these benefits to the community and environment. It has also resulted in an established process that is able to track benefits as the program is implemented and allow for "course correction" if needed.

In order to ensure benefits are realized, while maintaining a cost-effective approach, it is important to Lowell that adaptive management be applied on a regular basis. Inevitably, not all capital projects within the proposed plan are fully detailed from a design and construction standpoint. Furthermore, projects not yet started or those in initial study phases may result in better, more cost-effective capital projects that could produce even greater benefits than currently planned projects. As such, periodic (as-needed) review and refinement would prove beneficial to Lowell in terms of the environment and the community. To achieve this, IP selection criteria, criteria weighting, project definition & scoring, project benefits, affordability, and the implementation schedule will be re-assessed as needed. These IP elements may need to be reassessed if a new regulatory requirement were to take effect, a key infrastructure need (failure, vulnerability, etc.) develops, or some other event occurs that would require changes to the IP to ensure benefits continue to be maximized and that public health is protected.

In addition to reassessing all IP elements as needed, it is recommended that Lowell plan to reassess certain IP elements at critical milestones or events, as shown in Table 11-1.

As previously indicated, a key milestone of particular importance is completion of the Phase 3A CSO control plan and construction of the North Bank WWTF. At this stage in IP Implementation, it will be necessary to optimize operation of the North Bank WWTF and overall sewer system. This second (wet weather) treatment facility will necessitate fundamental changes to how Lowell operates its wastewater collection and treatment system. Lowell's high flow management strategy will need to be optimized to ensure benefits of the new facility are fully realized. Further opportunities for increased conveyance through other CSO stations may be discovered at this time. As such, the completion of the Phase 3A CSO control plan will serve as an important milestone to assess the effectiveness of implemented projects and employ adaptive management as the remainder of the IP as implemented.

Table 11-1: Adaptive Management and Review of IP Elements

IP Element	Milestone/Event
CSO Control Alternatives Analysis	• Phase 3A CSO Control Plan Implemented • New CSO control technology available
Affordability Metrics	• Economic recession • Federal assistance made available • Change in municipal financial capability • Phase 3A CSO Control Plan Implemented
Updated Criteria & Weighting	• Economic recession • Urgent public health concern • New regulatory requirement supporting data (ex. Clean Stream Initiative completed)
Benefits Calculation	• Economic recession • Urgent public health concern • New regulatory requirement or supporting data • Updated CSO Control Plan
IP Implementation and Schedule	• Phase 3A CSO Control Plan Implemented • Federal funding made available • Major equipment failure • Economic recession • Urgent public health concern • New regulatory requirement or supporting data • Updated CSO Control Plan • Unexpected/differing project benefits

The IP process inherently recognizes that long term planning must be an adaptive process to consistently maximize benefits and protect the environment and health and interests of the community. Table 11-1 attempts to define some of the conditions that would require the IP be adapted to meet these goals, but there may be others as well. Adaptive management will be of particular importance in Lowell as a result of the following unique considerations:

- **Economic and income disparity** is highly pronounced in Lowell. Since the end of the great recession, income growth in Lowell has been stagnant. In fact, incomes for all but Lowell's highest earners has declined over the past decade. Since there is no evidence to indicate that this trend will reverse, unaffordability of the IP may increase over time. Further, any eventual economic recession will further increase unaffordability of the IP and make the impact of rate increases more dire for much of Lowell's population. Since the IP proposed in this document already exceeds affordability thresholds for much of Lowell (without accounting for the significant impact of spending on drinking water projects), adaptive management of the IP to reduce wasteful spending and maximize benefits is crucial to protecting the interests of Lowell's most vulnerable residents.

- **Optimization of new infrastructure for CSO control** is important to maximize the benefit of each new CSO control project in an actively (dynamically) managed system. Lowell's sewer system is managed according to a High Flow Management (HFM) plan that includes a complex control strategy involving modulation of numerous flow control and CSO diversion gates based on measured system conditions (flows, levels). This HFM plan has been refined in practice over several years to best utilize existing infrastructure and maximize flow to the Duck Island WWTF, balancing flow between the North and South Bank interceptors, and maximizing inline storage. When a systemwide CSO control project, such as the North Bank WWTF, is implemented, the systemwide HFM plan must be updated and refined. The North Bank WWTF will fundamentally change how Lowell's sewer system is operated, by allowing for continuous maximization of flow from the South Bank during wet weather, and modulation of flow from the North Bank to maximize flow to the WWTF (when flow from the South Bank does not reach peak capacity) and to restrict flow when peak capacity at the WWTF has been achieved. It will require significant time, effort, and monitoring to achieve this complex new control strategy and understand the systemwide impacts of any changes. These changes have the potential to alter the predicted benefits of subsequent CSO control projects. As such, adaptive management of the CSO control plan is crucial to ensure it reflects new system conditions and predicted benefits over time.

- **Post-construction monitoring and new data** are important tools that will help inform a more accurate understanding of water quality in the Merrimack River. At present, characterization of the river's water quality relies on a limited set of data collected through a 3-phased program (Army Corps study). Lowell's ongoing Clean Stream Initiative will continue to inform a more accurate characterization of the river's water quality and help determine potential impairment due to nutrients and other pollutants. Similarly, post-construction monitoring will help inform the impact of CSO control projects. If a project were more or less beneficial to river water quality than expected, it may be necessary to adjust the weight of the criteria that informed the scores of subsequent CSO control projects.

- **Future regulatory uncertainty and requirements** may significantly impact future projects. For example, new regulations related to drinking water, such as PFAS, have the potential to appear at any time, requiring a new drinking water project to be conceived and prioritized. Nutrient limits imposed on the WWTF (e.g., nitrogen) may also require Lowell to reprioritize projects to maintain permit compliance. Long-held and industry standard viewpoints about stormwater management are also starting to shift, as there is increasing recognition of the threats posed to water quality by untreated stormwater runoff. New requirements in this area may require reassessment of the proposed projects that impact the quantity of stormwater runoff.

- **Aging infrastructure and resiliency** will likely become greater considerations in Lowell as the IP is implemented. Lowell**'s** aging water infrastructure has the potential to develop new and urgent needs unexpectedly due to a failure. In such cases, urgent projects may need to be undertaken to correct failures and mitigate the risk of further or similar failures. In addition, as regulators and the broader industry begin to recognize the importance of risk assessment and resiliency (as exemplified by the passage of AWIA) due to threats like climate change, important risk assessment and mitigation projects may need to be added to the IP.

- **Economic uncertainty, climate change, and other unknowns** have the potential to significantly impact circumstances in Lowell. An economic recession, increasingly intense rainfall, and other circumstances can drastically alter affordability and worsen existing problems, such as untreated CSO surcharges/discharges or flooding. Reprioritization of projects to reflect changed conditions may be necessary to maintain affordability and to protect public health and maximize environmental benefits.

As a result of these considerations, adaptive management of the IP and reassessment of certain IP elements as needed are critical for ensuring long term success of the IP. This framework for adaptive management ensures that the plan will remain relevant and allow Lowell to meet its CSO control commitments and protect public health and the community.

Post-construction monitoring is an essential activity that will occur after completion of Phase 3A of Lowell's CSO control. At this stage, new offline storage tanks at Douglas Road and Pevey Street will have been constructed, along with the North Bank WWTF. As previously described, these projects will have wide ranging and systemwide impacts on CSO discharges. Post-construction monitoring and measurement of remaining untreated CSO discharges will occur at this time.

After completion of Phase 3B of the CSO control plan, and full implementation of this IP, an extensive post-construction monitoring effort will be taken. The Phase 3 CSO control plan in this IP allows Lowell to achieve compliance with the CWA based on EPA's presumption approach. Regardless, after full implementation of the IP, post-construction monitoring will be important to assess compliance with the CWA and help determine if further CSO control measures are required. Although several CSO control alternatives beyond Phase 3 were assessed in this IP, these measures will be reassessed (through another update to the IP) after post-construction monitoring, if it is determined that Lowell must continue its CSO control program.

Hazen

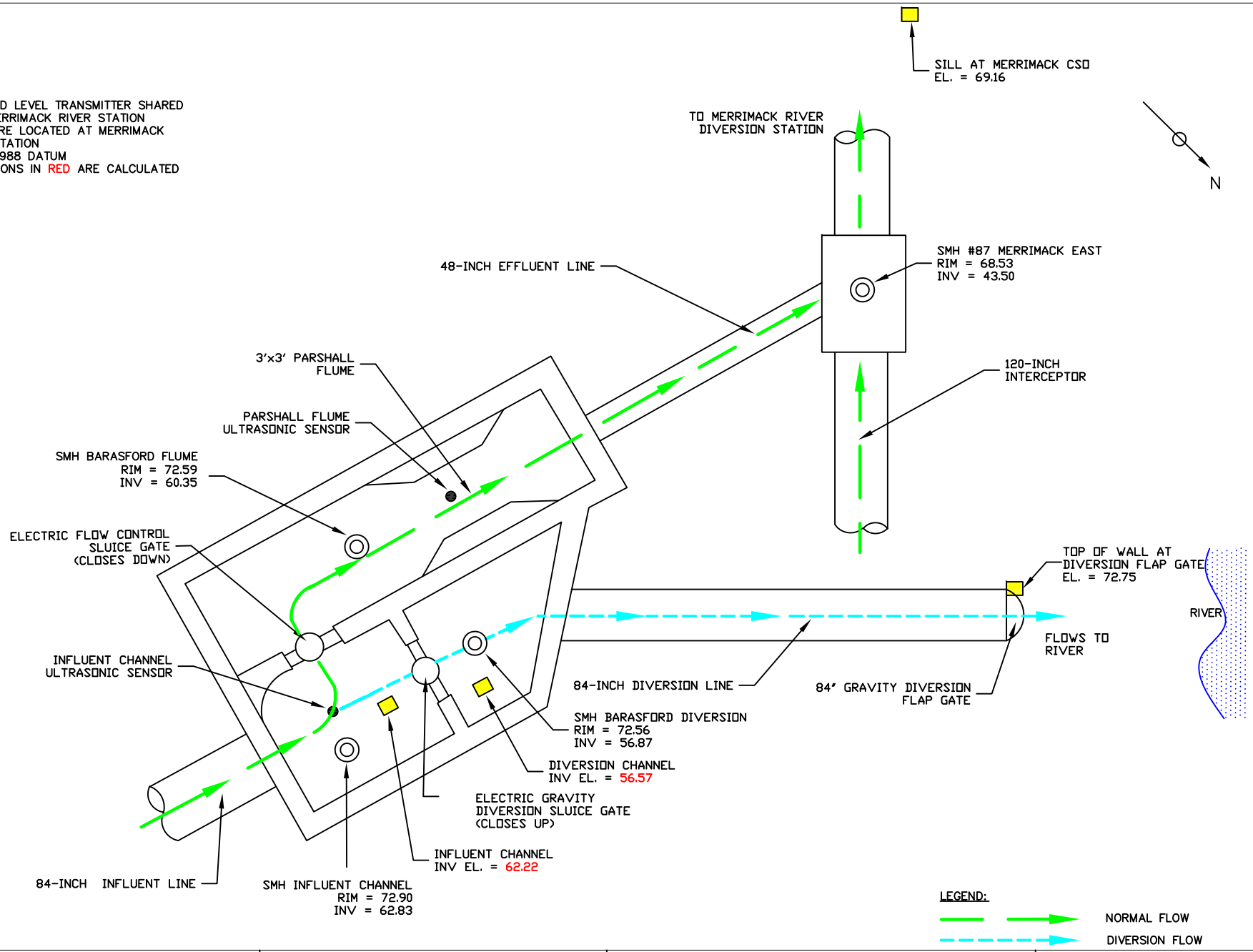
APPENDICES

Hazen

APPENDIX A

NOTES:

- PLC AND LEVEL TRANSMITTER SHARED WITH MERRIMACK RIVER STATION BOTH ARE LOCATED AT MERRIMACK RIVER STATION
- NAVD 1988 DATUM
- ELEVATIONS IN RED ARE CALCULATED



LOWELL REGIONAL WASTEWATER UTILITY

REV	DESCRIPTION	DATE
DRAFT	SUBMITTED FOR REVIEW	SEPT 9, 2009

DESIGNED BY: AF	APPROVED BY:
DRAWN BY: DP	REVIEWED BY:

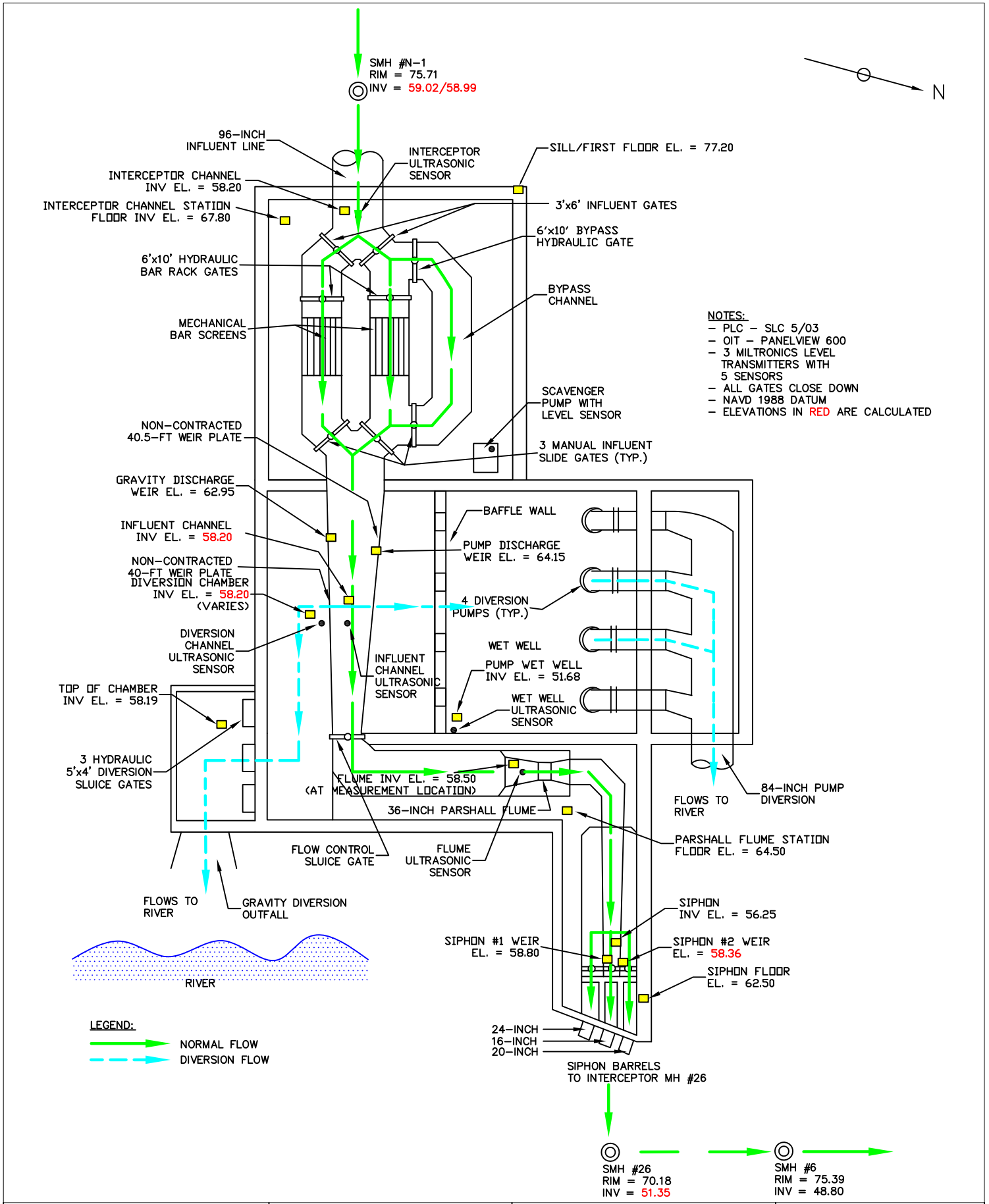
BARASFORD AVENUE DIVERSION STATION

JOB NO.:

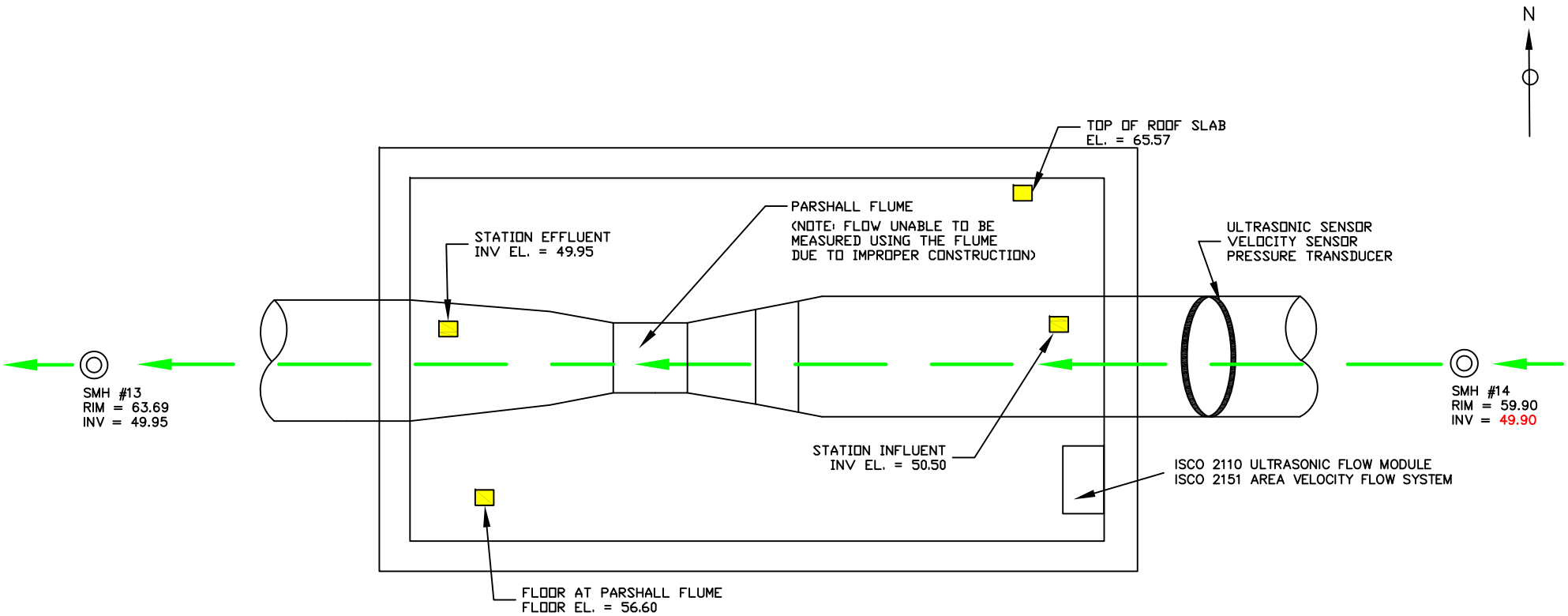
DATE: 9/9/09

SCALE: NOT TO SCALE

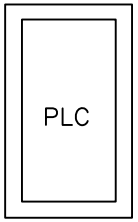
SHEET: 1 of 1



LOWELL REGIONAL WASTEWATER UTILITY	REV / DESCRIPTION / DATE		BEAVER BROOK DIVERSION STATION	JOB NO.:
	DRAFT / SUBMITTED FOR REVIEW / SEPT 9, 2009			DATE: 9/9/09
				SCALE: NOT TO SCALE
	DESIGNED BY: AF	APPROVED BY:		SHEET: 1 of 1
	DRAWN BY: DP	REVIEWED BY:		



NOTES:
- PLC LOCATED ABOVE GROUND
- PLC – SLC 5/05
- OIT – PANELVIEW 600+
- NAVD 1988 DATUM
- ELEVATIONS IN RED ARE CALCULATED



LEGEND:

NORMAL FLOW

LOWELL REGIONAL WASTEWATER UTILITY

REV	DESCRIPTION	DATE
DRAFT	SUBMITTED FOR REVIEW	SEPT 9, 2009

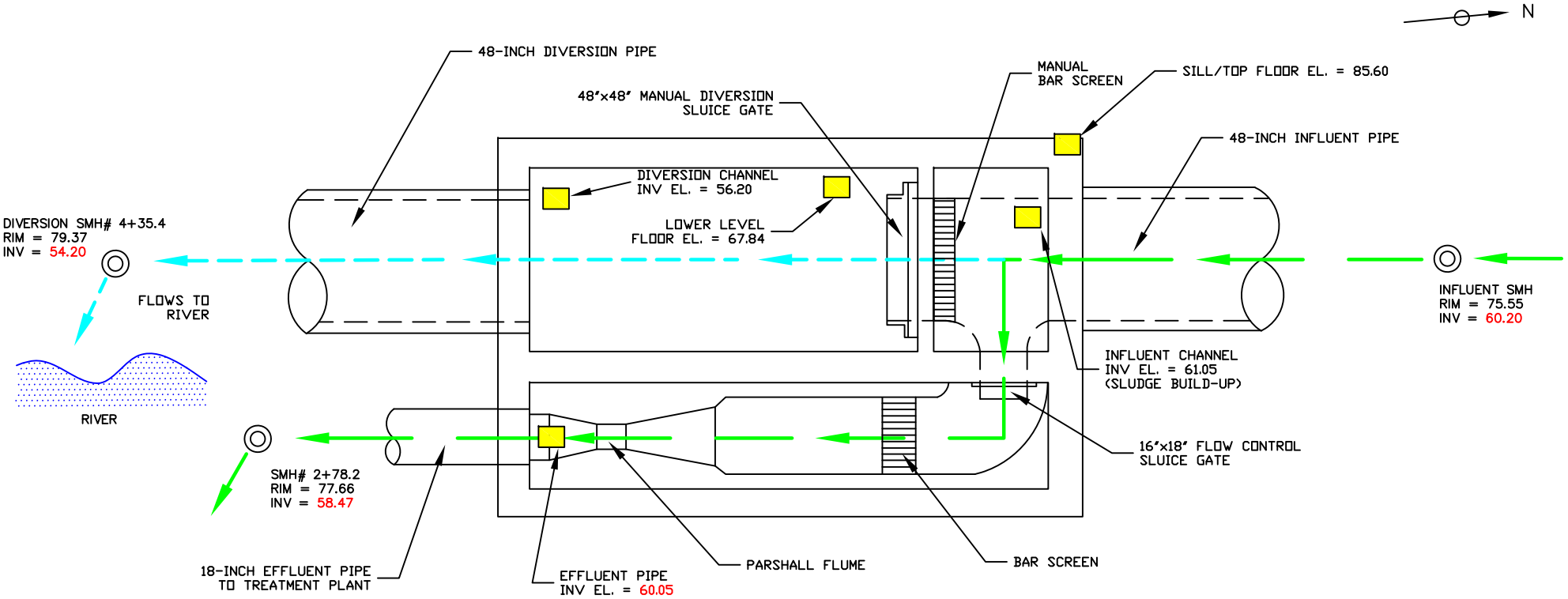
DESIGNED BY: AF	APPROVED BY:
DRAWN BY: DP	REVIEWED BY:

BURNHAM ROAD METERING STATION

JOB NO.:

DATE: 9/9/09

SCALE: NOT TO SCALE



NOTES:
- FISHER PORTER FLOW CHART
- LEVEL SENSOR
- NO PLC
- ALL GATES CLOSE DOWN
- NAVD 1988 DATUM
- ELEVATIONS IN RED ARE CALCULATED

LEGEND:

NORMAL FLOW

DIVERSION FLOW

LOWELL REGIONAL WASTEWATER UTILITY

REV	DESCRIPTION	DATE
DRAFT	SUBMITTED FOR REVIEW	SEPT 9, 2009

DESIGNED BY: AF | APPROVED BY:

DRAWN BY: DP | REVIEWED BY:

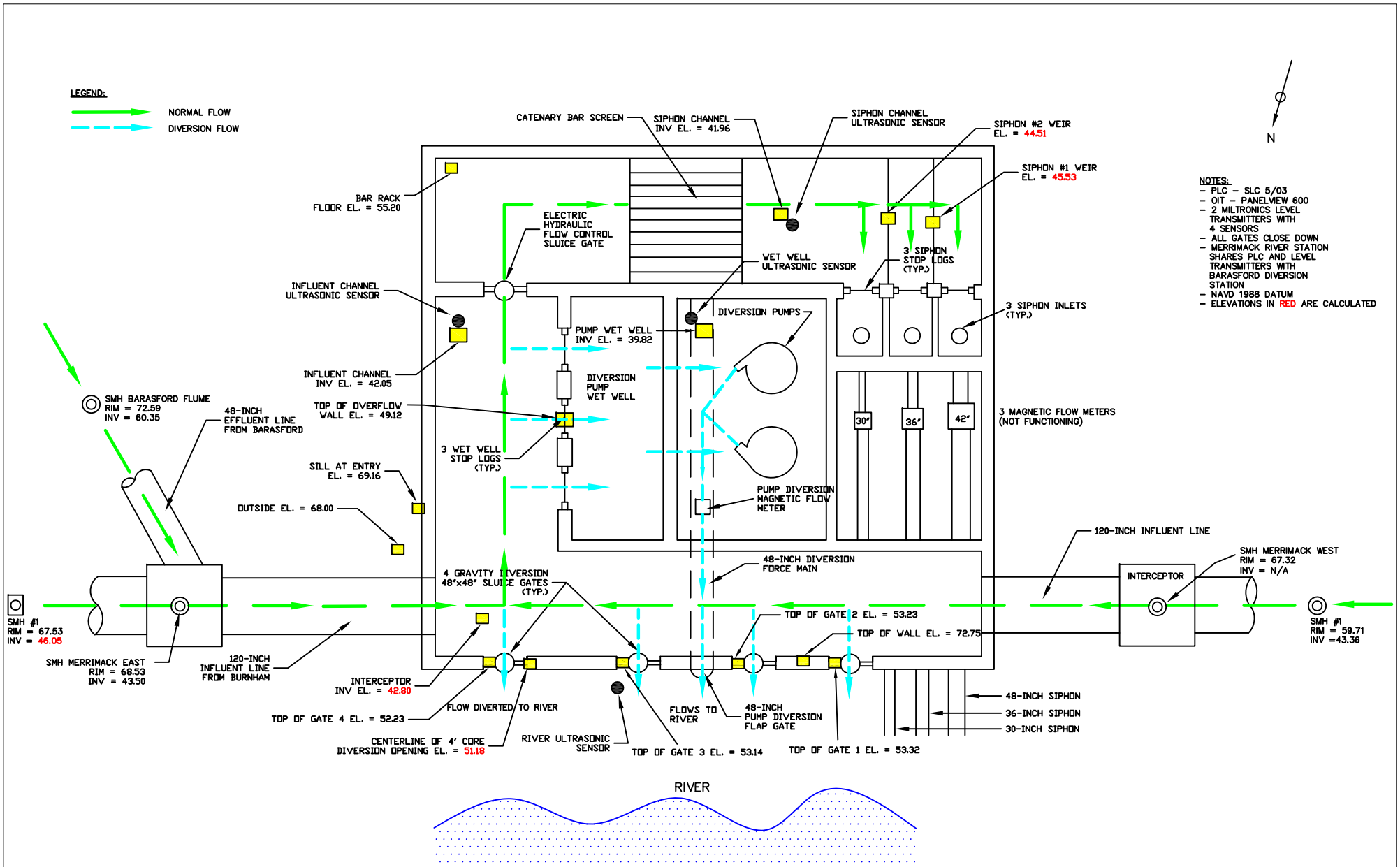
FIRST STREET DIVERSION STATION

JOB NO.:

DATE: 9/9/09

SCALE: NOT TO SCALE

SHEET: 1 of 1



NOTES:
- PLC – SLC 5/03
- OIT – PANELVIEW 600
- 2 MILTRONICS LEVEL TRANSMITTERS WITH 4 SENSORS
- ALL GATES CLOSE DOWN
- MERRIMACK RIVER STATION SHARES PLC AND LEVEL TRANSMITTERS WITH BARASFORD DIVERSION STATION
- NAVD 1988 DATUM
- ELEVATIONS IN RED ARE CALCULATED

LOWELL REGIONAL WASTEWATER UTILITY

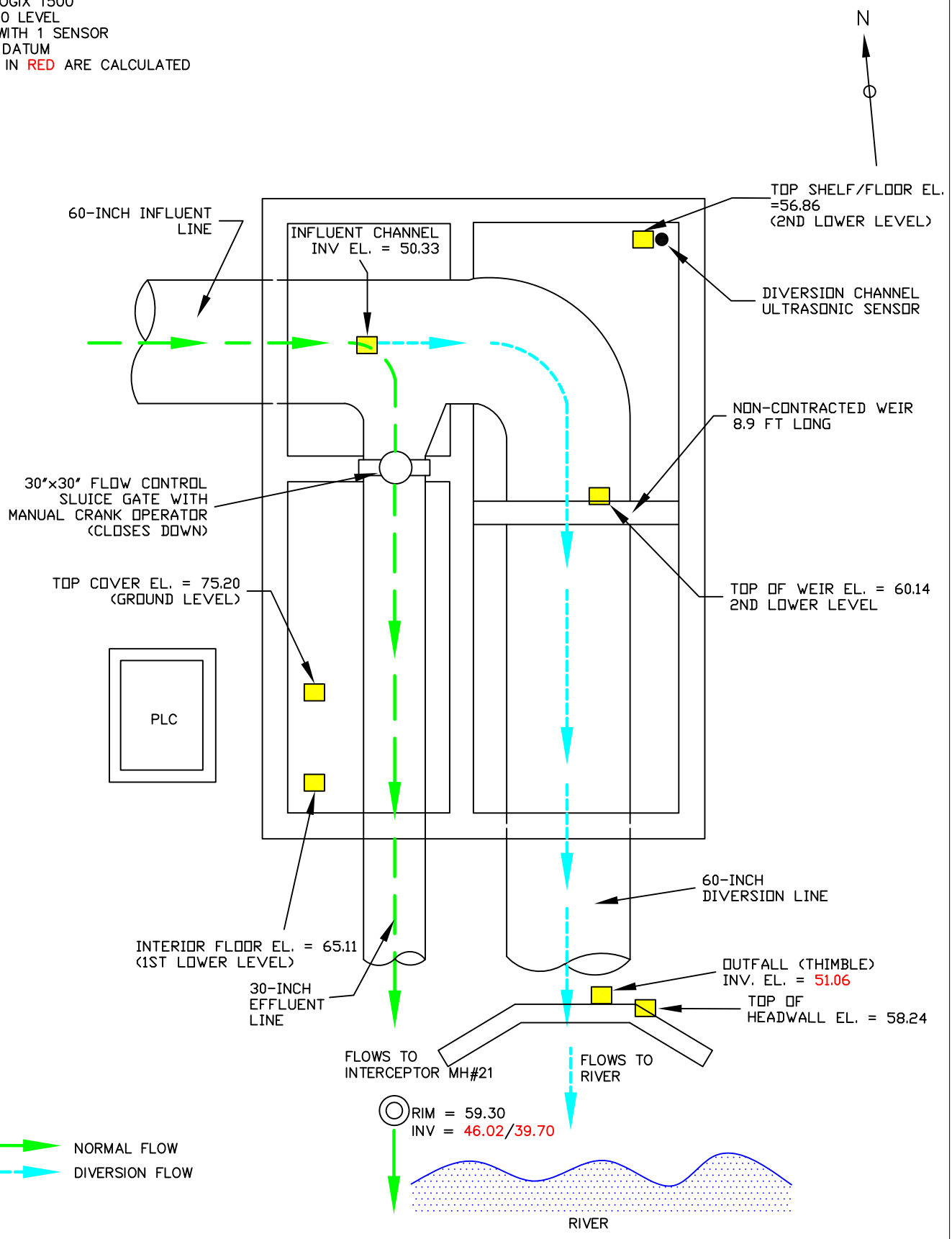
REV	DESCRIPTION	DATE
DRAFT	SUBMITTED FOR REVIEW	SEPT 9, 2009

DESIGNED BY: AF | APPROVED BY:
DRAWN BY: DP | REVIEWED BY:

MERRIMACK RIVER DIVERSION STATION

JOB NO.:
DATE: 9/9/09
SCALE: NOT TO SCALE

NOTES:
PLC LOCATED ABOVE GROUND
PLC – MICROLOGIX 1500
MILTRONICS 200 LEVEL
TRANSMITTER WITH 1 SENSOR
– NAVD 1988 DATUM
– ELEVATIONS IN RED ARE CALCULATED



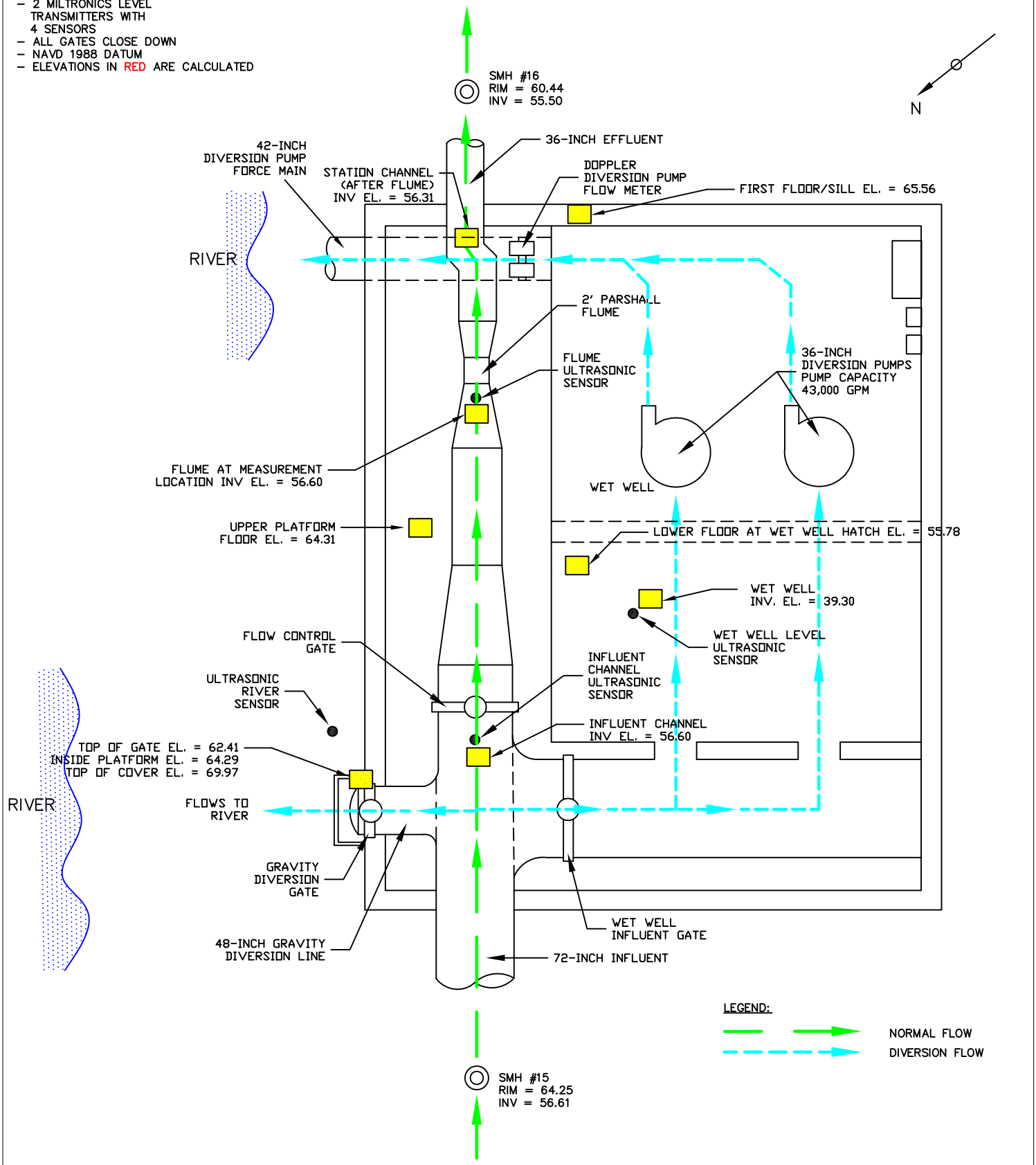
LEGEND:

NORMAL FLOW

DIVERSION FLOW

LOWELL REGIONAL WASTEWATER UTILITY	REV / DESCRIPTION / DATE		READ STREET DIVERSION STATION	JOB NO.:
	DRAFT / SUBMITTED FOR REVIEW / SEPT 9, 2009			DATE: 9/9/09
	DESIGNED BY: AF	APPROVED BY:		SCALE: NOT TO SCALE
	DRAWN BY: DP	REVIEWED BY:		SHEET: 1 of 1

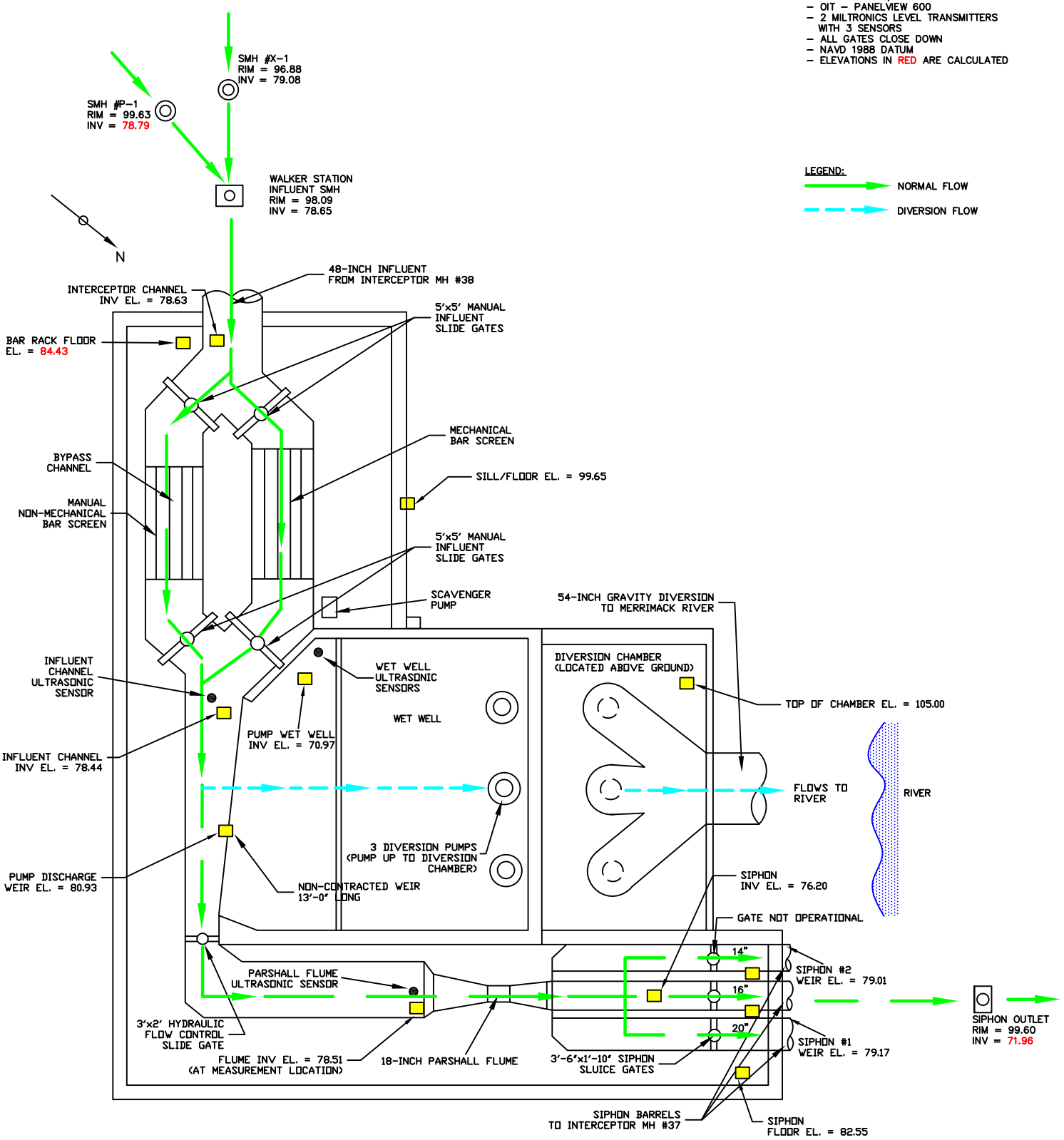
NOTES:
- PLC – SLC 5/03
- OIT – PANELVIEW 600
- 2 MILTRONICS LEVEL TRANSMITTERS WITH 4 SENSORS
- ALL GATES CLOSE DOWN
- NAVD 1988 DATUM
- ELEVATIONS IN RED ARE CALCULATED



LOWELL REGIONAL WASTEWATER UTILITY	REV / DESCRIPTION / DATE		TILDEN STREET DIVERSION STATION	JOB NO.:
	DRAFT / SUBMITTED FOR REVIEW / SEPT 9, 2009			DATE: 9/9/09
	DESIGNED BY: AF	APPROVED BY:		SCALE: NOT TO SCALE
	DRAWN BY: DP	REVIEWED BY:		SHEET: 1 of 1

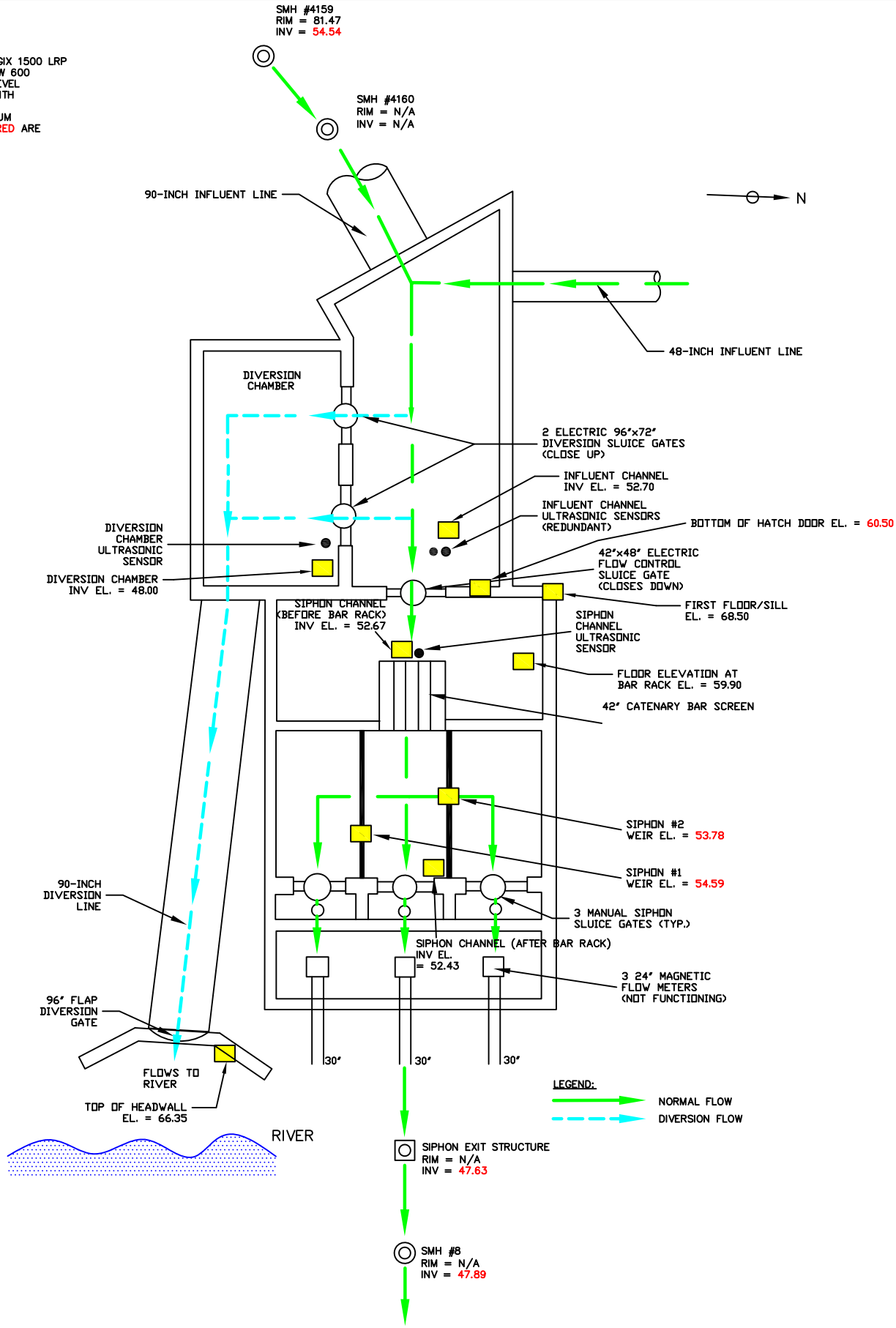
NOTES:
- PLC – SLC 5/03
- OIT – PANELVIEW 600
- 2 MILTRONICS LEVEL TRANSMITTERS WITH 3 SENSORS
- ALL GATES CLOSE DOWN
- NAVD 1988 DATUM
- ELEVATIONS IN RED ARE CALCULATED

LEGEND:
NORMAL FLOW
DIVERSION FLOW



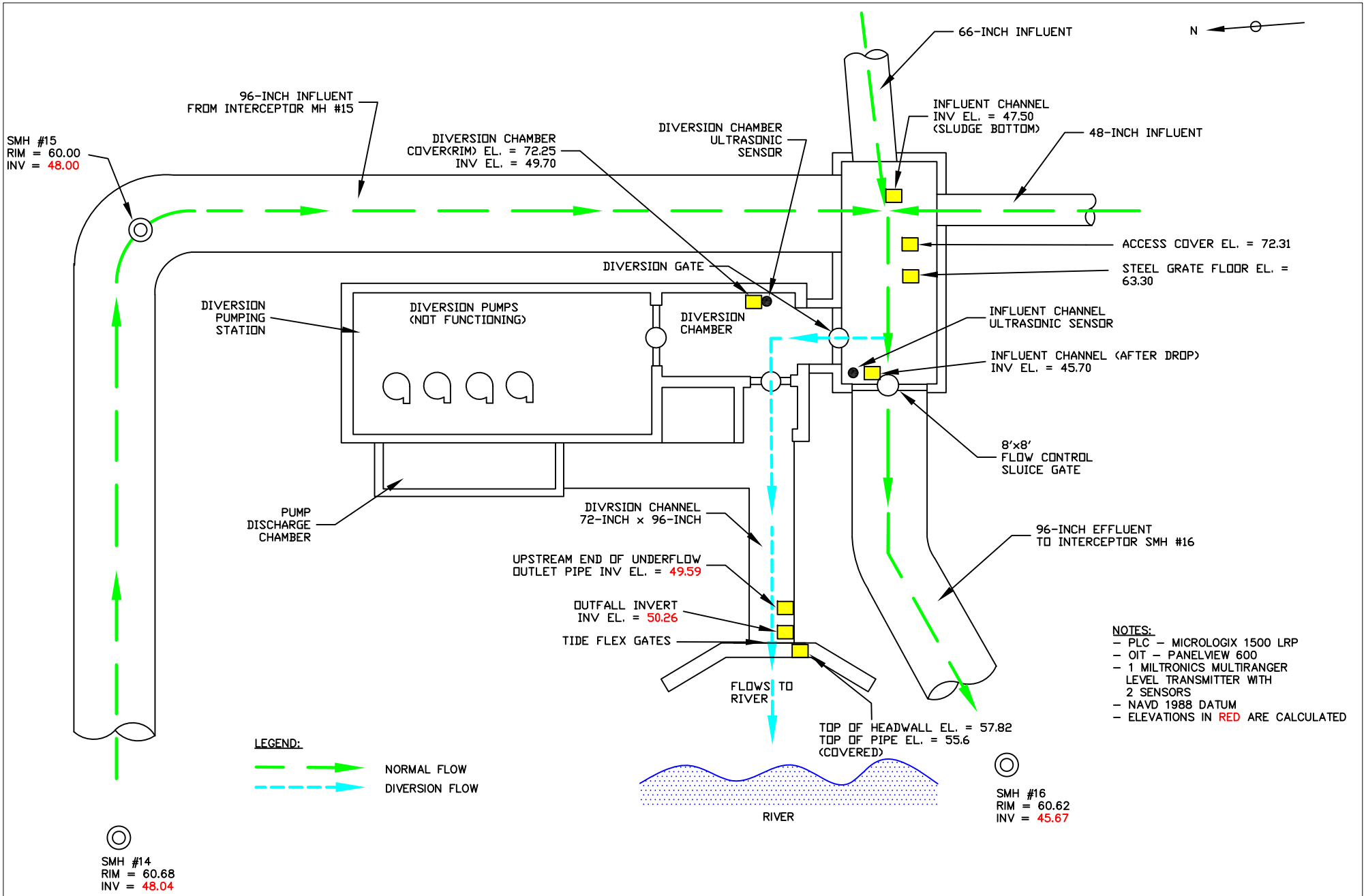
LOWELL REGIONAL WASTEWATER UTILITY	REV / DESCRIPTION / DATE		WALKER STREET DIVERSION STATION	JOB NO.:
	DRAFT / SUBMITTED FOR REVIEW / SEPT 9, 2009			DATE: 9/9/09
	DESIGNED BY: AF	APPROVED BY:		SCALE: NOT TO SCALE
	DRAWN BY: DP	REVIEWED BY:		SHEET: 1 of 1

NOTES:
- PLC – MICROLOGIX 1500 LRP
- OIT – PANELVIEW 600
- 2 MILTRONICS LEVEL TRANSMITTERS WITH 4 SENSORS
- NAVD 1988 DATUM
- ELEVATIONS IN RED ARE CALCULATED



LOWELL REGIONAL WASTEWATER UTILITY	REV	DESCRIPTION	DATE	JOB NO.:
	DRAFT	SUBMITTED FOR REVIEW	SEPT 9, 2009	DATE: 9/9/09
				SCALE: NOT TO SCALE
	DESIGNED BY: AF	APPROVED BY:		SHEET: 1 of 1
	DRAWN BY: DP	REVIEWED BY:		

WARREN STREET DIVERSION STATION



NOTES:
- PLC – MICROLOGIX 1500 LRP
- OIT – PANELVIEW 600
- 1 MILTRONICS MULTIRANGER LEVEL TRANSMITTER WITH 2 SENSORS
- NAVD 1988 DATUM
- ELEVATIONS IN RED ARE CALCULATED

LOWELL REGIONAL WASTEWATER UTILITY

REV	DESCRIPTION	DATE
DRAFT	SUBMITTED FOR REVIEW	SEPT 9, 2009

DESIGNED BY: AF	APPROVED BY:
DRAWN BY: DP	REVIEWED BY:

WEST STREET DIVERSION STATION

JOB NO.:

DATE: 9/9/09

SCALE: NOT TO SCALE

SHEET: 1 of 1

Hazen

APPENDIX B

Interim High Flow Management Plan

LTCP Phase 1A

Lowell Regional Wastewater Utility

March 1, 2011

Table of Contents

Background 1
Overview of Diversion Stations and Interceptor Storage 1
High Flow Management Program 3
Interceptor System Limitations 7
Interceptor Level Monitoring Methodology 7
Data Analysis 9
High Flow Management – Review Process 12
Benefits of High Flow Management Program 14
Conclusions 20

List of Figures

Figure 1: Map of the Lowell Interceptor System 4
Figure 2: Typical CSO Diversion Station 5
Figure 3: Interceptor Configuration Upstream of Read Diversion Station 12
Figure 4: High Flow Management Protocol 18
Figure 5: CSO Overview Screen 19

List of Tables

Table 1: LRWWU Diversion Station Summary 6
Table 2: Temporary Interceptor Level Monitoring Locations 8
Table 3: Types of Charts Created for the High Flow Management Program 9
Table 4: Storage Benefits of the High Flow Management Program 15

Appendices

Appendix A: Plan and Profile Drawings of CSO Diversion Stations
Appendix B: Example Set of Charts High Flow Management
Appendix C: Program Milestones High Flow Management
Appendix D: Review Figures High Flow Management

BACKGROUND

The Lowell Regional Wastewater Utility (LRWWU) owns and operates a combined sewer system (CSS) and the Duck Island wastewater treatment facility (WWTF). The system consists of approximately 220 miles of gravity sewers and twelve sewer pumping stations. Ten miles of large-diameter interceptors (48-inches to 120-inches in diameter), along the banks of the Merrimack and Concord Rivers, collect wastewater from the sewer system and convey it to the Duck Island WWTF. The WWTF was designed to provide secondary treatment to an average flow of 32 million gallons per day (MGD), with a short-term peak capacity of 62 MGD. Plan view of the WWTF and the LRWWU interceptor system is provided in **Figure 1**.

During wet weather conditions, a maximum flow of approximately 110 MGD is treated at the WWTF. Flow in excess of 62 MGD receives primary treatment before being bypassed around the secondary treatment system. This bypass flow is blended with secondary effluent; then the blended effluent is disinfected with chlorine and de-chlorinated with sodium hypochlorite before being discharged into the Merrimack River. Flow in excess of the WWTF wet weather treatment capacity (110 MGD) is discharged into local waterways as Combined Sewer Overflows (CSOs) at nine diversion stations. These CSO discharges relieve hydraulic surcharges in the interceptor system, preventing infrastructure and property damage and sewer back-ups into local streets and homes.

Annually, several hundred million gallons of untreated CSOs have been discharged from LRWWU's permitted CSO outfalls, depending upon rainfall conditions. LRWWU has been under a Consent Decree since 1988 to develop and implement a plan to reduce its CSO discharges to the Merrimack and Concord Rivers and to Beaver Brook. LRWWU completed a Long Term Control Plan (LTCP) for CSO mitigation in 2002 and initiated its LTCP Phase 1 Program shortly thereafter.

One priority in the LTCP program is the utilization of an existing large-diameter interceptor system to capture and store wet weather flows for later treatment at the Duck Island WWTF, rather than discharge to the local waterways. Another priority is the maximization of treatment capacity at the WWTF during wet weather events. With these priorities, LRWWU would maximize the use of its existing infrastructure so that future control facilities could be sized properly, allowing for cost-effective CSO control.

Accordingly, and in compliance with the Administrative Order dated September 2010, LRWWU has prepared this High Flow Management Plan (HFMP) to document LRWWU's progress since the development of its LTCP Phase 1 Program.

OVERVIEW OF DIVERSION STATIONS AND INTERCEPTOR SYSTEM STORAGE

The CSO diversion stations are sophisticated facilities. Several have the capability to screen flow (before downstream siphons) and to gravity discharge and/or pump CSO flow into nearby streams. All stations have multiple gates, at least one diversion gate, as well as a flow control gate that controls the flow through the station. **Figure 2** depicts a typical CSO diversion station and its features. As flow entering the station through the influent line increases during wet weather events, the level in the influent channel is measured with the ultrasonic sensor. The flow control gate and gravity diversion gate are currently programmed to open and close when certain levels in the station are reached to prevent surcharges upstream and property damage within the stations.

For many years, gates and pumps at the diversion stations were operated manually by personnel who were required to drive to each station during rain events. This meant that CSO discharges were initiated earlier and discontinued later than necessary. During this historical period (prior to 2002), there was no remote monitoring of station flows, levels or equipment status. Without this monitoring capability, it was difficult to trouble-shoot remote station problems and to understand how the interceptor system responded during storm events.

In 2002, LRWWU began work to install the initial instrumentation system to remotely operate some of its CSO diversion stations to avoid the drive and manual operation of these stations. This early work included upgrades to flow control gates to replace existing actuators that would make the gates more reliable. Gate control was established using local programmable logic controllers (PLCs) to monitor flow depths and operate the diversion gates.

In 2004, a SCADA system was implemented that improved LRWWU's ability to utilize the interceptor system for wet weather storage. The remote control of diversion gates and pumps allowed operators to instantaneously start and stop diversions based on real-time water levels at the diversion stations. Remote gate control enabled wet weather storage in the interceptors upstream of the stations, resulting in significant reduction of CSO volume and frequency. The SCADA system is also used to acquire operational data and to monitor equipment at each station. Alarms are generated at each remote station to help operators react quickly if there are any equipment failures that might otherwise go unnoticed. This avoids dry weather overflows from the stations and minimizes CSO discharges.

In 2004, as part of the Phase 1 Long Term Control Plan, the LRWWU made several improvements to the Tilden, Merrimack, and Beaver Brook diversion stations. The goal of these improvements was to increase interceptor storage and reduce CSOs at these stations. At Tilden, flow control, gravity diversion, and pump wet well gates were upgraded with continuously modulating hydraulic actuators. This allowed for more precise control of interceptor level and flow through the station. The channel walls were also increased in height by 2 feet in order to safely pass more flow through the station and maximize utilization of the 36" downstream interceptor.

The work at Merrimack station included the addition of three new circular 48" gravity diversion openings, effectively quadrupling the gravity diversion capacity. Flows from these additional gravity diversion points were controlled with new slide gates driven by continuously modulating hydraulic actuators. The flow control gate and existing gravity diversion gate were also upgraded to continuously modulating actuators. The additional diversion capacity allowed operators to maximize the use of interceptor storage capacity at Merrimack Station while maintaining the ability to divert additional flow that was conveyed from the upstream interceptor system. The continuously modulating actuators allowed for more precise control of interceptor level and flow through the station.

Major improvements were made to both the channel and gate system at the Beaver Brook diversion station. The height of both the gravity and pump diversion weirs were raised to increase flow through the station. Several gates were upgraded with modulating actuators. The station gates and pumps were also automated using PLC programming, which minimized diversions and maximized interceptor storage. Most importantly, the influent channel weirs were raised and the influent gates were automated to store wet weather flow in the upstream interceptor.

As required by the LTCP, LRWWU also looked at further refining its diversion flow measurement. In the past, diversion flow was estimated using hydrographs that were developed for each individual station. While this technique provides a good rough estimate, a more accurate measurement approach has been sought to better quantify CSOs. In 2004, LRWWU implemented direct measurement of CSOs at most diversion stations. This was a complex endeavor as the diversion stations were not originally constructed to measure CSO flow and most structures do not contain primary measuring devices.

Flow measurement was attained using Magnetic Flow meters located in the pump diversion discharge pipes and by calculating diversion flow under or over an open diversion gate. This methodology relies on the premise that flow over a gate is measured as flow over a weir, and that flow under a gate is measured as flow through an orifice. While considered more accurate than hydrographs, this method still provides a flow estimate rather than direct measurement of CSOs. LRWWU has implemented this approach at seven of its nine diversion stations. The approach requires reliable equipment, such as gate actuators, level sensors,

and PLCs. A reliable SCADA system is also needed to control the equipment, transmit the data to the WWTF, and record the details of every diversion event.

Existing diversion flow measurement methods are being evaluated to determine if there is an effective alternative to the improvised orifice and weir equations that are currently used. The configuration of the stations and equipment available makes measuring CSO diversion flow very difficult. LRWWU is investigating the use of area-velocity meters in the interceptors and diversion stations as a means to measure both diversion flows (CSOs) and through-station flows. The outcome of this effort will be addressed in a separate report.

HIGH FLOW MANAGEMENT PROGRAM

Although LRWWU was able to achieve significant improvements in wet weather operations after the implementation of SCADA and the improvements described above, the system required further optimization. The potential storage available in the interceptor system was not fully utilized and occasional system surcharging was still taking place, resulting in flooding in neighborhood streets and inside the diversion stations. Therefore, the High Flow Management (HFM) Program was initiated in October 2008 to assist LRWWU in optimizing its wet weather operations. The HFM program had the following goals:

- Monitor and characterize water levels throughout the interceptor system to gain a better understanding of how the system is affected by diversion station operation and rain intensity.
- Develop a standard operating procedure during wet weather events that maximizes and balances flows into the treatment plant while maximizing interceptor storage.
- Identify and implement operational improvements that maximize storage in the collection system and further reduce CSO frequency and volume.

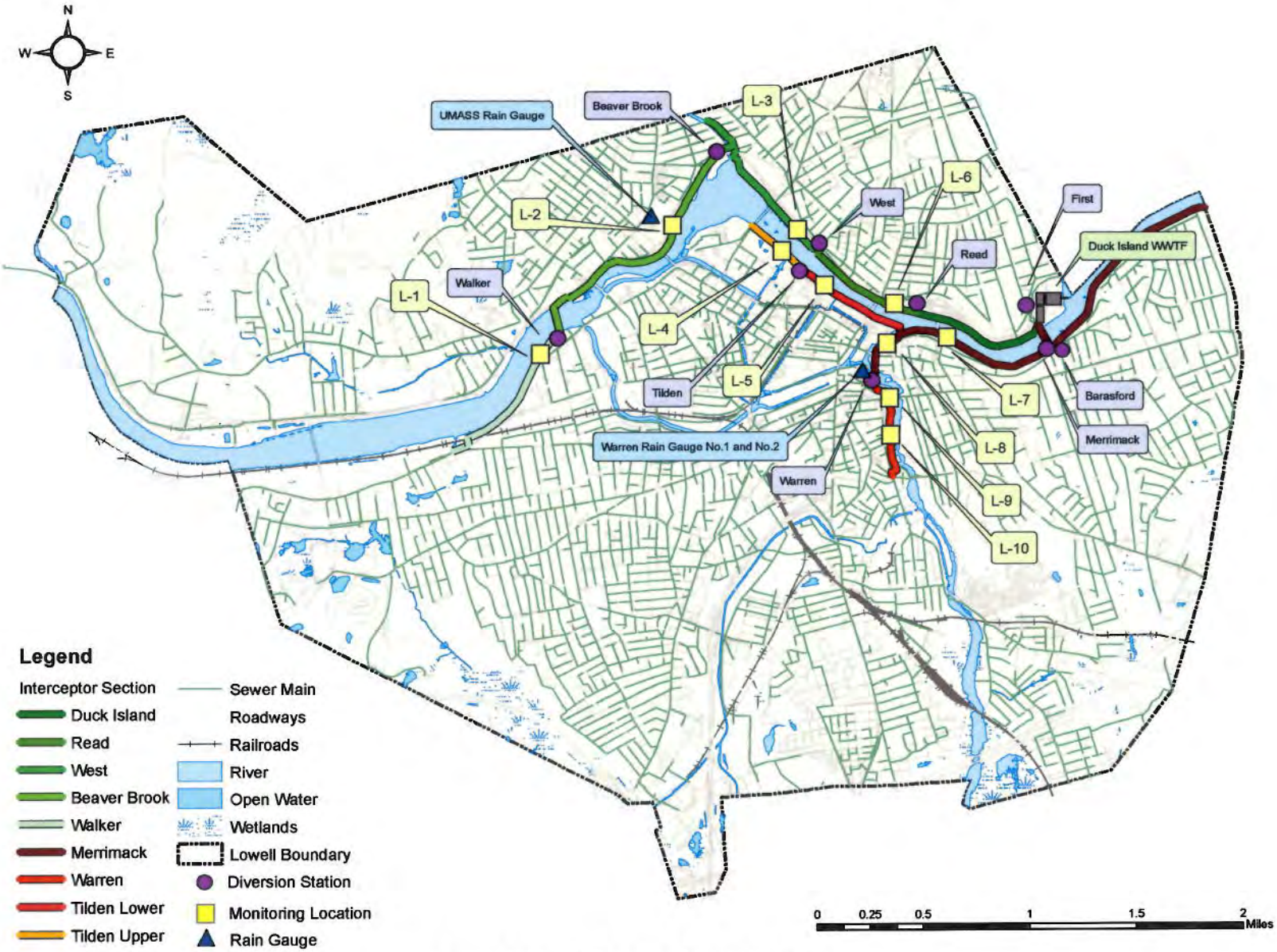


Figure 1: Map of the Lowell Interceptor System

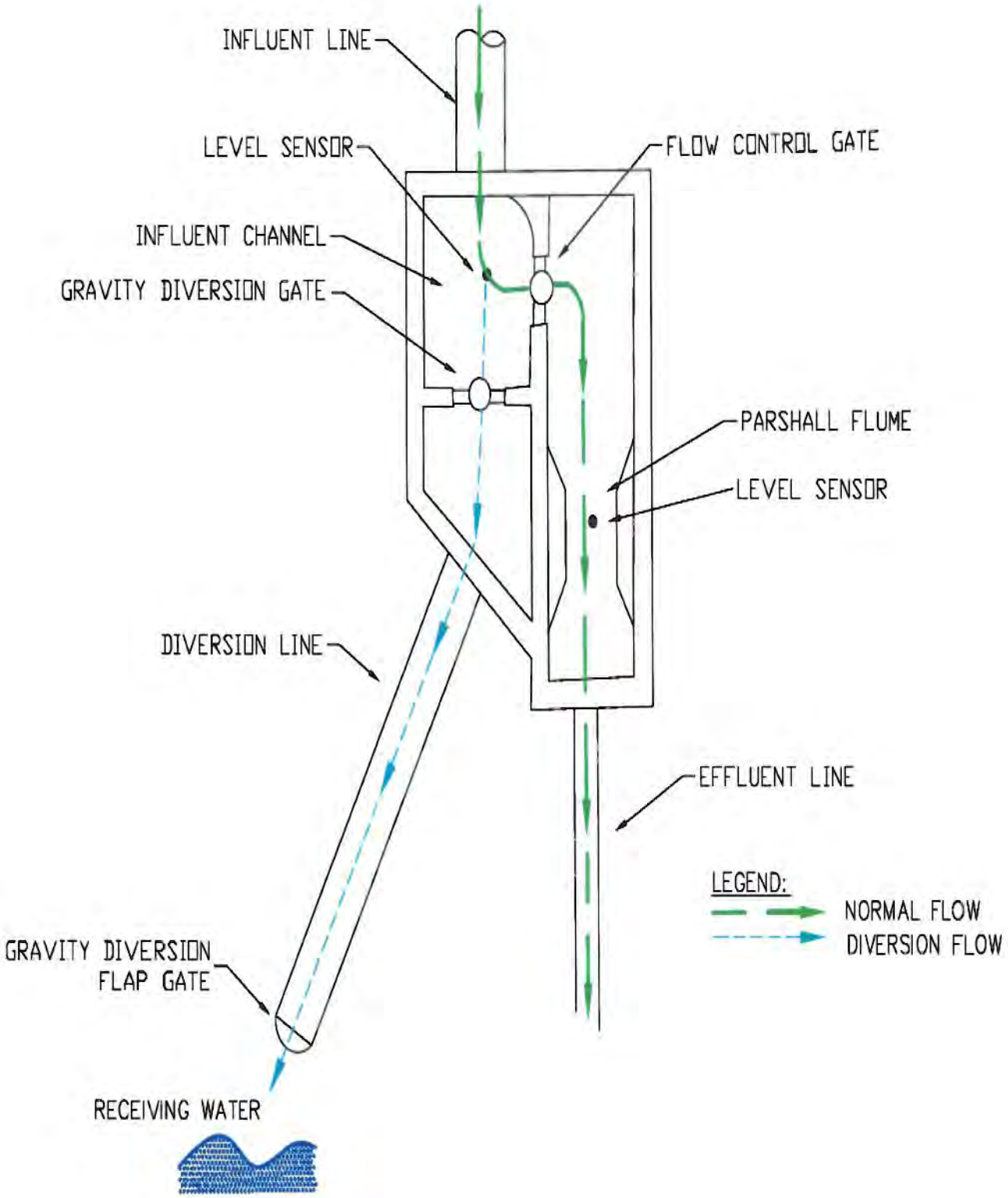


Figure 2: Typical CSO Diversion Station

Table 1: LRWWU Diversion Station Summary

Diversion Station	NPDES Outfall No.	Receiving Stream	Approximate Upstream Combined Acreage (acres)	Influent Pipe Size (inches)	Influent Capacity (MGD)	Effluent Pipe Size (inches)	Effluent Capacity (MGD)	Potential Flow Constraint (MGD)	CSO Discharge Pipe Size (inches)	Downstream Connection
North Bank Interceptor										
Beaver Brook	007	Beaver Brook	570	96	170	3 siphons (16 + 20 + 24)	25	145	Pump Diversion (84) Gravity Diversion (three 60 x 48)	North Bank Interceptor to West Station
West	008	Merrimack River	1100 (plus Dracut)	96 + 72 + 48	280	96	93	187	Gravity Diversion (96 x 72)	North Bank Interceptor to Read Station
Read	011	Merrimack River	175	60	53	30	16	37	Gravity Diversion (60)	North Bank Interceptor to WWTP
First	012	Merrimack River	90	48	37	18	3	34	Gravity Diversion (48)	WWTP
South Bank Interceptor										
Walker	002	Merrimack River	140	48	32	3 siphons (14 + 16 + 20)	8	24	Pump Diversion (54)	North Bank Interceptor to Beaver Brook Station
Tilden	027	Merrimack River	350	72	72	36	28	44	Pump Diversion (42) Gravity Diversion (48)	South Bank Interceptor to Merrimack Station
Barasford	030(1)	Merrimack River	600	84	277	48	21	256	Gravity Diversion (84)	South Bank Interceptor to Merrimack Station
Merrimack	030(2)	Merrimack River	2,941	84 + 120	204	3 siphons (30 + 36 + 48)	63	141	Pump Diversion (48) Gravity Diversion (four 48)	WWTP
Concord River Interceptor										
Warren	020	Concord River	1,626	90 + 48	348	3 siphons (30 + 30 + 30)	45	303	Gravity Diversion (90)	South Bank Interceptor to Merrimack Station

Note: Potential constraints are the difference in capacity between the upstream and downstream piping systems at each diversion station.

INTERCEPTOR SYSTEM LIMITATIONS

Despite continuous efforts to operate the interceptor system and diversion structures in a way that maximizes the flow conveyed to the WWTF and minimizes CSO discharges, wet weather events often necessitate CSO discharges before the WWTF wet weather treatment capacity is reached. Even moderate rain events contribute a significant amount of wet weather flow into the combined sewer system. This flow cannot be fully conveyed to the WWTF because of the hydraulic restrictions in the interceptor system created by the downstream interceptor capacity being only 20-30 percent of the upstream capacity. The configuration of the interceptor system is summarized in **Table 1**.

All diversion stations currently operate in a fully automatic mode based on local water levels at the station, controlled by a programmable logic controller (PLC). At the Merrimack and West stations, the diversion gates (as well as pumps at the Merrimack station) are automatically operated and the flow control gates are manually set and remotely controlled by the WWTF operator. This control method allows the operator to maximize flow to the WWTF adjusting the flow control gates at either of the two major interceptors. The Merrimack flow control gate is used to control flow into the plant from the South Bank Interceptor and the West flow control gate is used to control flow from the North Bank Interceptor. The approach that the operator takes to manage these gates has a direct effect on interceptor storage, plant flow and ultimately diversion frequency and volume.

To assist in further system characterization during wet weather conditions, plan and profile drawings of each CSO station were produced. These drawings, which include flow paths and estimated water levels, can be found in **Appendix A**. Accurate elevations in the stations and the interceptor system are important since the system is controlled based on water levels. To obtain accurate elevations in the stations and of other system components, a complete survey of the Lowell collection system was completed. One common datum was established (NAVD 1988) so that all water levels could be easily compared. Detailed drawings of the stations were a critical component of the interceptor monitoring effort described below. They were used to interpret interceptor level data and visualize what happens in the system when water level reaches critical elevations in the stations.

INTERCEPTOR LEVEL MONITORING METHODOLOGY

An interceptor level monitoring program focusing on water levels in the interceptor system during wet weather conditions was implemented to further characterize the system. The interceptor level monitoring program utilized existing level sensors in various diversion stations, as well as temporary level sensors installed and maintained by ADS Environmental Services for a period of one year, from April 2009 through April 2010. The temporary monitoring program consisted of ten monitoring locations, which were selected based on historical surcharging, interceptor depth of burial, and indications of interceptor storage capacity. Temporary interceptor monitoring locations are depicted in **Figure 1**. The primary reasons for choosing the monitoring locations are listed below in **Table 2**. During the year-long monitoring period, ADS Environmental Services collected instantaneous level data from the monitoring locations (via a cellular system and a web-based reporting site) and performed maintenance visits every six weeks to ensure that the sensors were functioning properly. ADS monitoring data was collected in 5-minute intervals and integrated with level data that was already being collected from the diversion stations through SCADA.

At the beginning of the project, there was some discussion about the best way to monitor wet weather condition in the interceptor system: flow versus level. Level monitoring was selected as the more effective approach for the following reasons:

- Level in the interceptor system shows more clearly the portion of the interceptor that is utilized and therefore is more representative of available storage capacity.
- Open-channel flow measurement in a large-diameter pipe may be impacted by turbulent flow conditions and may not be sufficiently accurate for gate control.

- Diversion station gates operate on levels; diversion level data was readily available for comparison and integration. Plotting diversion level data collected from the SCADA system with ADS level data allowed for a better evaluation of the correlation between temporary level data and level data from the diversion stations.

The temporary monitoring program also provided the ability to view real-time interceptor level data during storm events. When used in conjunction with WWTF and diversion station data, this proved to be very valuable when implementing operational changes. Being able to view the data on a real-time basis gave LRWWU personnel a more complete picture of the system and enabled them to anticipate the timing of diversions. The availability of this information contributed to several major changes to the wet weather operating strategy for the WWTF and the diversion stations. The level data was integrated with other level, flow, gate, and precipitation data being collected through SCADA to create High Flow Management Charts. Evaluating interceptor system responses to high flow conditions showed how operational changes affected storage capacity during storms. This information gave operators more understanding of the interceptor system and more confidence operating the system under high flow conditions.

Table 2: Temporary Interceptor Level Monitoring Locations

Monitoring Point	Location	Reason
L-1	Upstream of Walker	To determine the effect of Walker Station on storage capacity of the 48"inch Walker Interceptor.
L-2	Upstream of Beaver Brook	Monitor storage capacity of 84" Beaver Brook Interceptor.
L-3	Upstream of West	Monitor storage capacity of 96" West Interceptor and the effect of West Operations on CSO reduction.
L-4	Upstream of Tilden	Monitor storage capacity of 72"Tilden Upper Interceptor and to monitor effect of Tilden Operations on flooding at L-4.
L-5	Downstream of Tilden	This point in the system has had historical flooding problems. It was monitored to determine how set point changes at Tilden and Merrimack Stations affect flooding issues.
L-6	Upstream of Read	To monitor storage and evaluate the need for Interceptor control point at Read Station.
L-7	Upstream of Merrimack	Monitor storage capacity of the 120" Merrimack Interceptor.
L-8	Downstream of Warren	Evaluate if storage is maximized between Warren and Merrimack Stations.
L-9	Upstream of Warren	Converging point of 3 large diameter mains. This point was monitored to determine if it was the cause of upstream flooding issues and to monitor storage upstream of Warren Station.
L-10	Lawrence Street	Monitor the effect of Warren Station on flooding issues.

Precipitation data was also recorded and used in characterization of individual rain events as part of the HFM program. LRWWU compiles its own rain data in addition to precipitation reports obtained from UMass Lowell. Rain gage locations are shown on the system map provided in **Figure 1**. The rain gage used for the High Flow Management program is located on top of the Warren diversion station. It was chosen because of its accuracy, existing SCADA integration, and a central location in the City of Lowell that provides the most representative rainfall data for the collection system.

DATA ANALYSIS

Available flow and level data relevant to the WWTF, CSO diversion stations, and the ten new monitoring locations in the interceptor system was compiled and analyzed. Summary charts were created using new and existing data to analyze how the combined system reacts to wet weather conditions. A separate set of summary charts was produced for each event, which was defined as a day of precipitation when a diversion occurred in the interceptor system or when secondary treatment was bypassed at the WWTF. Each event data set consisted of 17 HFM charts illustrating level changes in the interceptor system as a result of changes in rainfall and system flows. The HFM charts were developed for eight of the nine CSO stations and the WWTF. No charts were developed for the First Street diversion station because this station is inoperable. An example set of charts for the January 25-26, 2010 storm event is attached in **Appendix B**. The charts were plotted for the duration of the storm event, with some events lasting several hours and others multiple days. Relevant rainfall data collected from the rain gage located at the Warren Diversion Station is depicted on the *CSO Diversion Flows and Precipitation* chart. The categories of charts that were created are described below and summarized in **Table 3**.

- Gates and Flows – these charts illustrate station flow and diversion flow in correlation with flow control and diversion gate positions.
- Levels and Flows – these charts illustrate station and interceptor levels in correlation with station flows, as well as WWTF flows.
- Gates and Levels – these charts illustrate station and interceptor levels in correlation with flow control and diversion gate positions.
- Levels – for some stations, it was necessary to create charts that only illustrate levels in the station, upstream and/or downstream interceptors, and levels at West and/or Merrimack Stations.
- System Flows and Precipitation – system charts were created to show the WWTF influent flow throughout the storm and precipitation.

Table 3: Types of Charts Created for the High Flow Management Program

Station	Flows and Gates	Levels and Flows	Levels and Gates	Levels	Upstream Interceptor Level	Flows and Precipitation
System	X					X
Barasford		X	X		X	
Beaver Brook		X	X		X	
Merrimack	X			X	X	
Read		X			X	
Tilden	X			X	X	
Walker	X	X			X	
Warren	X			X	X	
West	X	X			X	

The charts, in conjunction with the station profile drawings, were useful in developing an understanding of how each component in the combined sewer system reacts during a wet weather event and how system changes could affect the capture and storage of wet weather flow. The charts were reviewed and discussed at monthly HFM workshops. The HFM project team members were:

Aaron Fox, LRWWU Engineering Supervisor
Brandon Kelly, LRWWU Engineer
Mike Stuer, LRWWU Engineering Manager
James Drake, CDM Project Manager
Alexandra Kulinkina, Woodard & Curran Engineer
Tom Schwartz, Woodard & Curran Project Manager
Tom Kawa, LRWWU Operations Superintendent
Eric Willet, LRWWU Operations Supervisor

The charts for each wet weather event for the previous month were analyzed in detail during the HFM meetings to develop a mutual understanding of how the system responded during wet weather events. Based on the analysis and conclusions, recommended operational/procedural changes, as well as any structural improvements relevant to high flow management, were recorded in the *High Flow Management Milestones* attached in **Appendix C**. In many cases, system improvements were implemented immediately and subsequent storm data allowed the HFM project team to analyze the impacts of these improvements on wet weather operations.

The following paragraphs provide examples of how the HFM charts were used to evaluate system responses to wet weather events and the conclusions that were drawn from the analyses. The corresponding figures referenced in the analyses are included in **Appendix D**.

Observation: Correlation between water levels in the interceptor and in the stations

The summary charts consistently showed a strong correlation between the water levels in the upstream interceptor and the water levels in the diversion stations. The project team used this correlation to set open and close set points for diversion and flow control gates to maximize interceptor storage. For example, raising the diversion gate open set point as high as possible allows for maximum storage in the upstream interceptor. The consistency of the correlation between upstream interceptor levels and diversion station levels gave the project team confidence that raising set points in the stations would not create excessive system surcharging upstream. Furthermore, the automated gate control system maintained precise control of diversion gates, demonstrating that interceptor storage could be maximized safely, without flooding the stations or causing system damage. Ultimately, it was concluded that interceptor storage is safely maximized at approximately one foot below the crown of the pipe. When an influent channel reaches the one-foot-from-crown level, diversion gates are programmed to automatically open. **Figure D-1** shows an example of the correlation between the upstream interceptor level at location L-4 and the influent channel level at Tilden station. Based on this correlation, LRWWU established the Tilden diversion gate-open set point at five feet above the influent channel invert, or one foot below the influent channel crown. The Tilden gate set points were raised on November 24, 2009 (refer to *High Flow Management Milestones* in **Appendix C**).

Figure D-2 represents similar observations of the correlation between the upstream interceptor level at Location L-9 (upstream of Warren Diversion Station) and the influent channel level at the Warren diversion station. Using these observations, the diversion gate-open set point at Warren was set at 6.5 feet above the influent channel invert, or approximately 1 foot below an access way into the station. As can be seen in the charts, the influent channel level never exceeds the elevation of 6 feet above the invert (59 ft NAVD). The Warren diversion gate-open set points at were adjusted on April 5, 2010 (refer to High *Flow Management Milestones* in **Appendix C**).

Observation: WWTF flow not maximized when diversions occur

One of the objectives of the HFM program was to maximize flow to the WWTF before diverting at West and Merrimack diversion stations. The WWTF is able to treat 110 MGD of flow (including secondary bypass). In the early stages of the program, the charts indicated that diversions occurred at these two major stations before plant capacity was reached. **Figure D-3** illustrates that a diversion occurred at West diversion station

when the plant flow was at approximately 62 MGD. **Figure D-4** shows that at this particular time during the storm (approximately 1 AM), West diversion station was diverting. The flow control gate at West station was approximately 10% open during this diversion; however, the gate opening could have been increased to convey more flow to the WWTF, relieving the station and potentially avoiding a diversion. It is also evident from **Figure D-3** that a secondary bypass was not activated during this diversion, which occurs when the plant is treating approximately 60 MGD of flow.

These observations resulted in the addition of "Plant Flow Not Maximized" alarms onto the SCADA screens at Merrimack and West diversion stations. These alarms are intended to alert operators that diversions at these two stations should not occur before the plant capacity is reached. In order to increase flow to the WWTF, the operator is instructed to further open the flow control gates at West and/or Merrimack. A "Diversion Pending" alarm indicates when the water level is 6 inches below the diversion gate open set point. A "Diversion in Progress" alarm indicates that the water level has reached the set point and/or the gate opened causing a diversion. These alarms are intended to be triggered when the WWTF is operating below 110 MGD.

Observation: Storage may be available in the interceptor upstream of West CSO Diversion Station

In the past, the West diversion station was not used to control storage in the upstream North Bank Interceptor. The diversion gate was operated in a conservative manner to avoid upstream surcharging. During the evaluation process, the HFM project team realized the storage potential of a 4,500-foot segment of the 96-inch diameter North Bank Interceptor upstream of West station. To take advantage of this storage capacity, LRWWU automated remote control of the diversion gate at West. On March 29, 2009, both the diversion gate and the flow control gate were upgraded with REXA gate actuators, which allowed more flexible and responsive modulation of these two large sluice gates during storms. The automation of the diversion gate enabled safe utilization of upstream interceptor storage while preventing surcharging incidents along the interceptor. Further optimization of the station operation was achieved in May of 2009 when it was determined that the flow control gate at West Diversion Station should be partially closed at the start of storm events to maintain storage in the 96-inch diameter interceptor, while still passing wet weather flow to the WWTF. **Figure D-5** illustrates the system response when the West diversion station was operated using diversion gate modulation that maintained storage in the upstream interceptor. In this figure, prior to a diversion event, the flow control gate is at 50% open, which passes all of the wet weather flow to the WWTF. As the storm continues, the flow control gate is lowered to 10% open. In this instance, the diversion gate is adjusted very infrequently. With this way of operating the station, the upstream water level at L-3 approaches the crown of the pipe briefly and then drops to below 4 ft (53 ft NAVD) as a diversion occurs. Thus, interceptor storage is not maintained. **Figure D-6** shows better interceptor utilization, as the upstream level at L-3 is maintained between 9 and 10 feet (55 and 56 ft NAVD) throughout the storm event while a diversion occurs. In this instance, the flow control gate is kept below 10% open in anticipation of the storm and the diversion gate is modulating much more frequently.

Observation: More wet weather flow could be conveyed downstream at key diversion stations resulting in fewer diversions

Siphon channel level monitoring at Warren Diversion Station indicated that maintaining a higher siphon channel level could be accomplished without flooding the station. The project team concluded that conveying more flow downstream during a storm event reduces the volume and frequency of CSO discharges from Warren station. In the past, Warren station often diverted prematurely because the peak flow exceeded the assumed capacity of the siphons. Conveying more flow through the station was accomplished by raising the flow control gate close set point from approximately 2.5 feet below the channel crown to 1 foot below the channel crown, enabling the station to handle short-duration peak flows without CSO discharges.

Similar benefits were obtained at Tilden, Walker and Beaver Brook diversion stations. Flow through the stations was maximized by controlling the flow control gates using level in the flume located after the gate.

Originally these gates were controlled using flow measurement through the flume which proved difficult due to challenges in accuracy of flow measurement and ability to use the data to determine when maximum flow through the flume was reached. Using level measurement instead, it was easy to see that the flow through the station was maximized when the level was as high as safely possible. The flow control gate would stay open until the level at the flume approached the floor elevation. Once the gate began to close, it maintained the flume level within one foot of the station floor, the maximum flow that could pass through the station without flooding. As part of the HFM project the flume instruments were programmed to display both flow and level as opposed to only flow.

Observation: North Bank Interceptor storage between Read and West diversion stations is not fully utilized

As observed in **Figure D-7**, the level in the interceptor segment upstream of Read Diversion Station during wet weather events is only slightly higher than during average daily flows. The maximum level at the upstream L-6 monitoring location during the December 9, 2009 storm is approximately 49 feet. This means that only 3 feet of the 8-ft interceptor is utilized.

Figure 3 illustrates the configuration of the interceptor between Read and West stations. The Read Interceptor is a 3,100-foot long 96-inch interceptor with a minimal slope. At the end of this interceptor segment is a seven foot drop manhole. This makes it impossible to store in this interceptor using the plant wet well, which is downstream of the Read Interceptor. If a flow -control gate were installed at this location, the portion of the North Bank Interceptor from West station downstream to Read station could be utilized for inline storage during wet weather events. This 3,000 foot segment of 96-inch diameter pipe could be utilized for inline storage during wet weather events providing approximately 1 million gallons of additional storage.

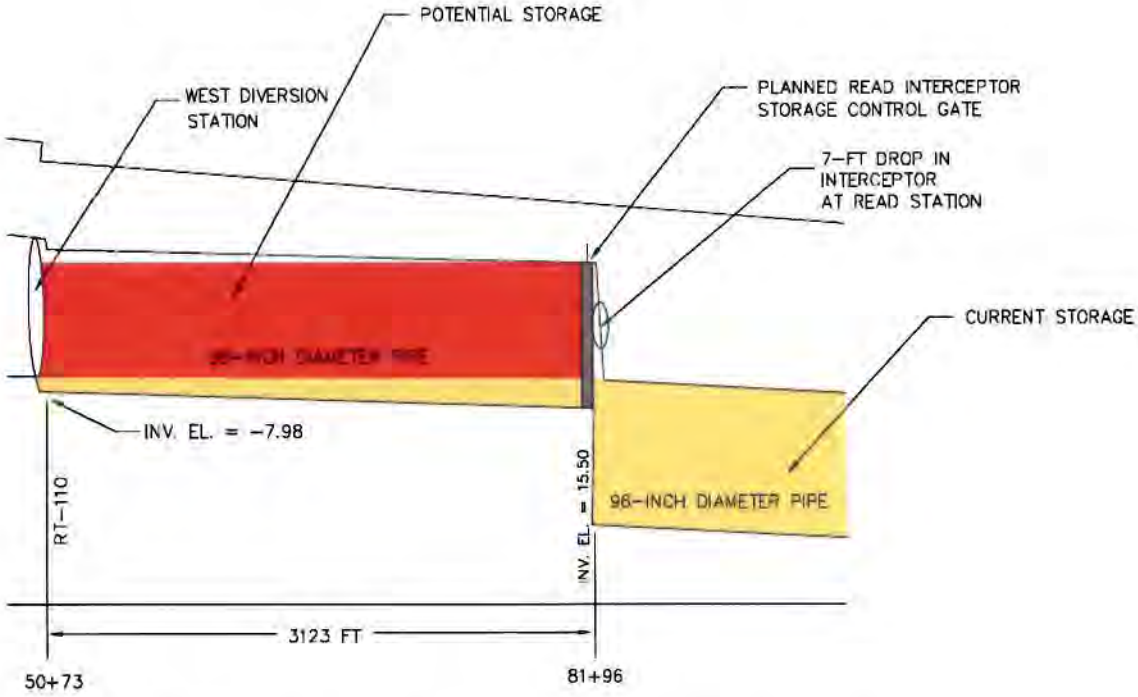


Figure 3: Interceptor Configuration Upstream of Read Diversion Station

Observation: Automation of flow control gates at West and Merrimack Diversion Stations may be more efficient than manual operation

During the December 12-13, 2010 storm event, it was observed that flows from Merrimack and West diversion stations were not well balanced. A diversion occurred at the Merrimack diversion station while storage was not maximized at West. **Figure D-8** shows that although WWTF capacity was reached, a diversion occurred at the Merrimack station at approximately 5:30 PM on December 12 while the flow control gate at West station remained at 30%. In **Figure D-9**, it is evident that the level in the West diversion station reached a maximum of only 49 feet before Merrimack station diverted. The flow control gate at West station should have been manipulated to allow for more storage. Following this event, the LRWWU staff decided to automate the flow control gates at West and Merrimack diversion stations to standardize their operation. This automation was incorporated into the standard operation procedures described below as the *High Flow Management Protocol*.

HIGH FLOW MANAGEMENT – REVIEW PROCESS

To illustrate how programmatic changes in operations affected the system's response to wet weather events, **Figures D-10** through **D-13** are described below:

Figure D-10 illustrates a storm event that occurred on May 6, 2009 in the beginning of the HFM program. During this storm, diversions occurred in the system while the WWTF flow was below 60 MGD and did not reach the bypass activation level. Because of system choke-points, it is often difficult to convey wet weather flow quickly enough to avoid these diversions. During the May 6, 2009 event, Tilden and Warren stations diverted while the WWTF flow barely reached 40 MGD. During this event, no diversions occurred at Merrimack or West diversion stations. Merrimack and West are the two stations where conveying flow to the WWTF could directly avoid a diversion.
Because of flow constrictions, passing flow through the other stations (including Tilden and Warren) has an indirect effect on local diversions. Understanding gained through the HFM program eventually led the project team to conclude that by increasing the flow through Warren and Tilden, as well as utilizing available upstream storage, CSO discharges from these two stations could have been minimized. At the time of the storm event depicted in **Figure D-10**, LRWWU plant personnel were cautious of storing upstream of Warren station because of a lack of understanding about upstream surcharging conditions. At the time, it was not known to what extent gate operations at Warren diversion station contributed to this upstream surcharging. Similar concerns existed at Tilden diversion station. Moreover, a lack of system understanding contributed to an overly conservative approach to interceptor storage in these locations.

To address the findings from the May 6 wet weather event, the following changes were made to gate controls in the system:

1. Gate-open set points for diversion gates at Warren diversion station were raised from 3 ft below the influent channel crown to 1 ft below the crown to enable additional upstream storage.
2. Gate-close set points for flow control gates at Warren diversion station were raised from 2.5 ft below the channel crown to 1 ft to allow for more flow to pass through the station downstream to Merrimack diversion station and eventually, to the Duck Island WWTF.
3. Gate-open set points for diversion gates at Tilden diversion station were raised from 1.5 ft below the influent channel crown to 1 ft below the crown to enable additional upstream storage.

As the HFM program progressed, WWTF flow during rain events increased with a higher utilization of secondary bypass. Although the LRWWU personnel had always been trying to maximize the WWTF capacity, this program made deficiencies in operations more evident and ways to increase plant capacity prior to diversions were realized and implemented. The benefits of the above changes can be observed in the October 28, 2009 event depicted in **Figure D-11** and described below. During this storm event, WWTF flow reached the bypass activation point but the bypass was immediately followed by a diversion. West station diverted when the plant flow was at 85 MGD, or before it had reached its full capacity of 110 MGD.

During this rain event, Warren diversion station did not divert. Also, WWTF flow was higher than in the past, indicating that the operators were becoming more comfortable with the operational changes to maximize flow to the WWTF before storing in the interceptor system. Although there was an improvement in wet weather operations, the same deficiency in operating the flow control gates at Merrimack and West Stations can be noted.

In response to these events, further improvements were made:

1. Development of a formal protocol to maximize wet weather flow to the WWTF (Influent Plant Flow > 110 MGD) before initiating any diversions at either Merrimack or West stations. This approach is implemented by always confirming the WWTF influent flow when a "Diversion Pending" alarm is received at Merrimack or West stations. If WWTF influent flow is less than 110 MGD, then the flow control gate at the station with the pending diversion is to be incrementally opened to increase wet weather flow to the WWTF. The WWTF influent flow rate is now displayed on the West and Merrimack SCADA control screens for quick reference.
2. The following approach was implemented to maximize interceptor storage: diversion gate-open and modulation set point values, while varying from station to station, will be the same within each individual station; diversion gate open/modulation set points are typically set one foot below the crown of the upstream pipe; diversion gate actuators capable of continuous modulation will be installed at all diversion stations.

Figure D-12 represents improved operations of the WWTF and interceptor system that only resulted in bypass activation, completely avoiding diversions on December 9, 2009. **Figure D-13** represents the most recent observation of improved operations where no diversion occurred in the system until WWTF flow reached 100 MGD. This progression of HFM charts demonstrates how maximizing interceptor storage and maximizing flow to the WWTF has reduced CSO diversions that can be avoided through these improved operations, therefore reducing the total diversion frequency and volume.

BENEFITS OF THE HIGH FLOW MANAGEMENT PROGRAM

The High Flow Management program helped LRWWU gain a much better understanding of the interceptor system and how it reacts during a storm. One of the major benefits of the HFM program was that it allowed the LRWWU staff to see a strong correlation between the interceptor levels and levels in the diversion stations. This understanding resulted in increased confidence when raising set points in the stations to maximize storage in the interceptor system. From ongoing chart review, it was determined that when setting the diversion gate-open set points, a standard of one foot below the influent channel crown would allow operators to safely maximize upstream interceptor storage. This standard was adapted at each station to maximize storage in the entire system. The storage gain in the interceptor system is summarized in **Table 4.**

A better understanding of the system and how it reacts during storms has led to major changes in wet weather operations. Several approaches were tested during the level monitoring program and the system's responses were discussed at the monthly workshops. The approach of storing in the interceptor system first in order to minimize bypass activation was tested. This approach proved less effective at reducing diversion frequency than conveying as much flow as possible to the WWTF as a first priority.

In addition to standardizing wet weather operations, the HFM program also helped to bridge the gap between the LRWWU engineering department and the operations staff. Both groups gained a better understanding of the overall system and developed an appreciation for each group's role in wet weather management. Moreover, the working relationship between the two groups was strengthened by the collaborative effort of evaluating wet weather operations. During the program, representatives of both groups participated in the workshops where data was analyzed and conclusions were reached. The entire operations staff was consulted on the changes that were made during the HFM program and the demonstrated successes and failures of the changes were discussed between all parties involved. At the conclusion of the HFM program, the results of the program, and the *High Flow Management Protocol* were

discussed with all operators so that everyone involved in wet weather operations could understand why operational changes were made, what the impact of those changes were, and how the *High Flow Management Protocol* was developed.

Table 4: Storage Benefits of the High Flow Management Program

Interceptor Name	Interceptor Diameter (ft)	Interceptor Operating Level (ft from invert)		Storage Benefit
		Before	After	
Duck Island	8	No Controlled Storage	No Controlled Storage	No Change
Read	8	No Controlled Storage	No Controlled Storage	Planned
West	8	No Controlled Storage	10	Substantial
Beaver Brook	8	8	8	No Change
Merrimack	10	8.8	9.2	Moderate
Warren	7.5	3.5	6.5	Substantial
Tilden	6	4.5	5	Moderate
Walker	4	2	4	Substantial

Operational Upgrades

Several changes in wet weather operations resulted from the HFM program including station upgrades, maximizing interceptor storage, maximizing flow through the stations (downstream to the WWTF), and changing the set points in the stations.

Station Upgrades:

- Automated the gravity diversion gate control at West diversion station and programmed the gate to maintain interceptor storage during wet weather events.
- Standardized gate actuators at all diversion stations to a model rated for continuous modulation (REXA gate actuators).
- Programmed the parshall flume sensors at Tilden, Walker and Beaver Brook diversion stations to display both flow and level. The flow control gates are now controlled using level rather than flow. Because of inaccurate flow measurement in surcharged flumes, controlling gates with level proved to be more precise and ultimately enabled conveying more flow through the station. Passing more flow through diversion stations, particularly in those stations that create system choke points, resulted in fewer and smaller CSO discharges. Level-based control also made it easier for operators to visualize station conditions, providing better indication of surcharging within the station or adjacent interceptors.
- The pump diversion weir at Walker diversion station was raised by 2 feet to increase storage upstream of the station and thus reduce diversions at this station.

Maximizing Interceptor Storage and Flow to the WWTF:

- In the past, flow control gates at Merrimack and West diversion stations were controlled manually by operators to balance flows from both interceptors (North Bank and South Bank) to the Duck Island WWTF. As a result of the HFM program, these flow control gates are now automated, ensuring that flow to the WWTF and storage in the interceptor system is maximized.
- Maximizing flow through the diversion stations, especially Beaver Brook, Tilden, and Warren, has reduced diversions. As more flow is conveyed to the WWTF in the beginning of the storm, the interceptors have available capacity for forthcoming wet weather flow.

- Adjusting diversion-gate and flow-control set points in the diversion stations maximized interceptor storage and flow through the stations. The set points were determined by monitoring water levels in the stations and in the interceptor system to make sure that maximum flow through stations and upstream interceptor storage is maintained without causing station flooding or surcharging in the interceptor system.
- To add more storage to the interceptor system, the HFM program recommended the installation of flow control gates in the North Bank Interceptor at Read diversion station. This capital improvement, with an estimated cost of $2 million, would utilize approximately 3,000 feet of a 96-inch interceptor segment between Read and West stations, resulting in an additional one million gallons of storage.

Taking all HFM program observations and system improvements into consideration, the following *High Flow Management Protocol* was adopted as the standard operating procedure for LRWWU during wet weather conditions. The *HFM Protocol* is provided below and represented graphically in **Figure 4**.

LOWELL REGIONAL WASTEWATER UTILITY

HIGH FLOW MANAGEMENT PROTOCOL

March 1, 2011

The following operational protocol is being initiated in February of 2011 and is based upon the findings of LRWWU's High Flow Management program.

- All remote gates with "Auto" functionality have been programmed to safely maximize storage and minimize CSO diversions. The remote gates and pumps are to be left in "Auto" unless otherwise notified. If the gates are not in "Auto", they must be placed in "Auto".
  - The Walker Flow Control Gate and Beaver Brook Gravity Diversion Gates are left in "Hand", because they are inoperable.
- The local weather forecast is continuously monitored to anticipate the storm arrival time, duration, and amount of potential rainfall. Until the Primary Influent Flow approaches 110 MGD, the West Flow Control Gate should be left at 20% open and the Merrimack Flow Control Gate should be left at 30% open. This is the standard position for these gates and allows for wet-weather flow to pass through the stations.
- The Primary Influent Flow at Duck Island WWTF is maximized to **110 MGD**.
  - It is important that the Primary Influent Flow is brought to 105 MGD before adjusting the Flow Control Gates at Merrimack and West.
  - Secondary Bypass is activated when Primary Influent Flow is roughly 60 MGD.
- Once the flow into the treatment plant has been maximized, the North Bank and South Bank Interceptors are utilized for wet weather storage. This is done by adjusting the Flow Control Gates at West and Merrimack.
  - The effects on the Primary Influent Flow Rate are observed and a Primary Influent Flow of 110 MGD is maintained throughout the wet weather event.
- After BOTH the Primary Influent Flow and Interceptor Storage have been maximized, the West and Merrimack Diversion Structures will initiate CSO diversions if interceptor levels rise above the gate-open set points at these locations.
  - The other Diversion Stations divert automatically based on local conditions at these stations.
- The Merrimack and West Flow Control Gates are continually adjusted throughout the storm event in order to first maintain maximum flow to the treatment plant and then maintain maximum storage within the interceptors.

- The Merrimack Flow Control Gate is adjusted in 5% increments, with a 5-minute observation time between adjustments. The West Flow Control Gate is adjusted in 2% increments, with a 10-minute observation time between adjustments.
- Once the Primary Influent Flow is maximized, storage must be maintained in both interceptors throughout the storm event.
- When the Plant Influent Flow Rate drops BELOW 110 MGD, the interceptor levels at Merrimack and West are compared and the Flow Control Gate associated with the HIGHER interceptor level is OPENED. The adjustment will be done in prescribed increments (see above bullet).
- When the Plant Influent Flow Rate rises ABOVE 110 MGD, the interceptor levels at Merrimack and West are compared and the Flow Control Gate associated with the LOWER interceptor level is CLOSED. The adjustment will be done in prescribed increments (see above bullet).

- The maximum Primary Influent Flow of 110 MGD must be maintained until the interceptors have returned to normal levels and all CSO diversions have ceased.
- Immediately following a secondary bypass or a CSO Diversion, all parties listed on the Downstream Notification List, including the EPA, DEP, and downstream water users and fisheries, are contacted.
- The Diversion / Bypass Log and the Head Operator's Log are updated with diversion data throughout the rain event.

CSO Overview Screen

To support the *HFM Protocol*, a CSO Overview Screen was developed for the SCADA system and implemented. The layout of the screen is shown in **Figure 5**. The screen was designed to provide the operators with an overview of the diversion stations, the interceptor system and the WWTF. This overview screen proved to be invaluable during wet weather events. A graphical representation of the system helps the operator quickly assess the current system conditions, reducing time spent reading text or deciphering numeric values during stressful conditions. The CSO Overview Screen acts as a simplified navigation tool, allowing operators to move from one screen to another by clicking on different areas of the screen. In addition to its usefulness during wet weather events, the CSO Overview Screen also helps infrequent users gain a basic understanding of the interceptor system.

Lowell Regional Wastewater Utility

High Flow Management Protocol

March 1, 2011

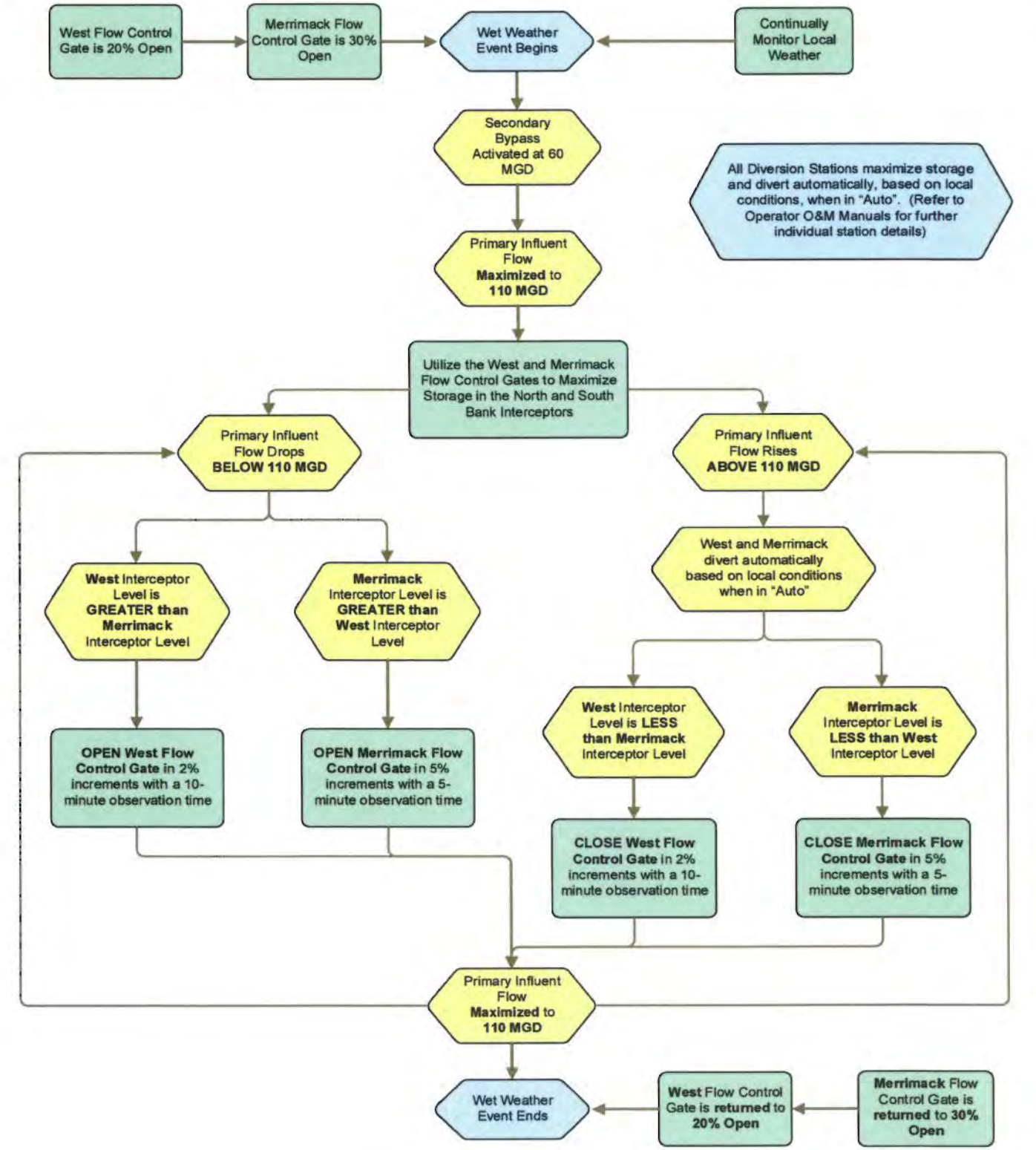


Figure 4: High Flow Management Protocol

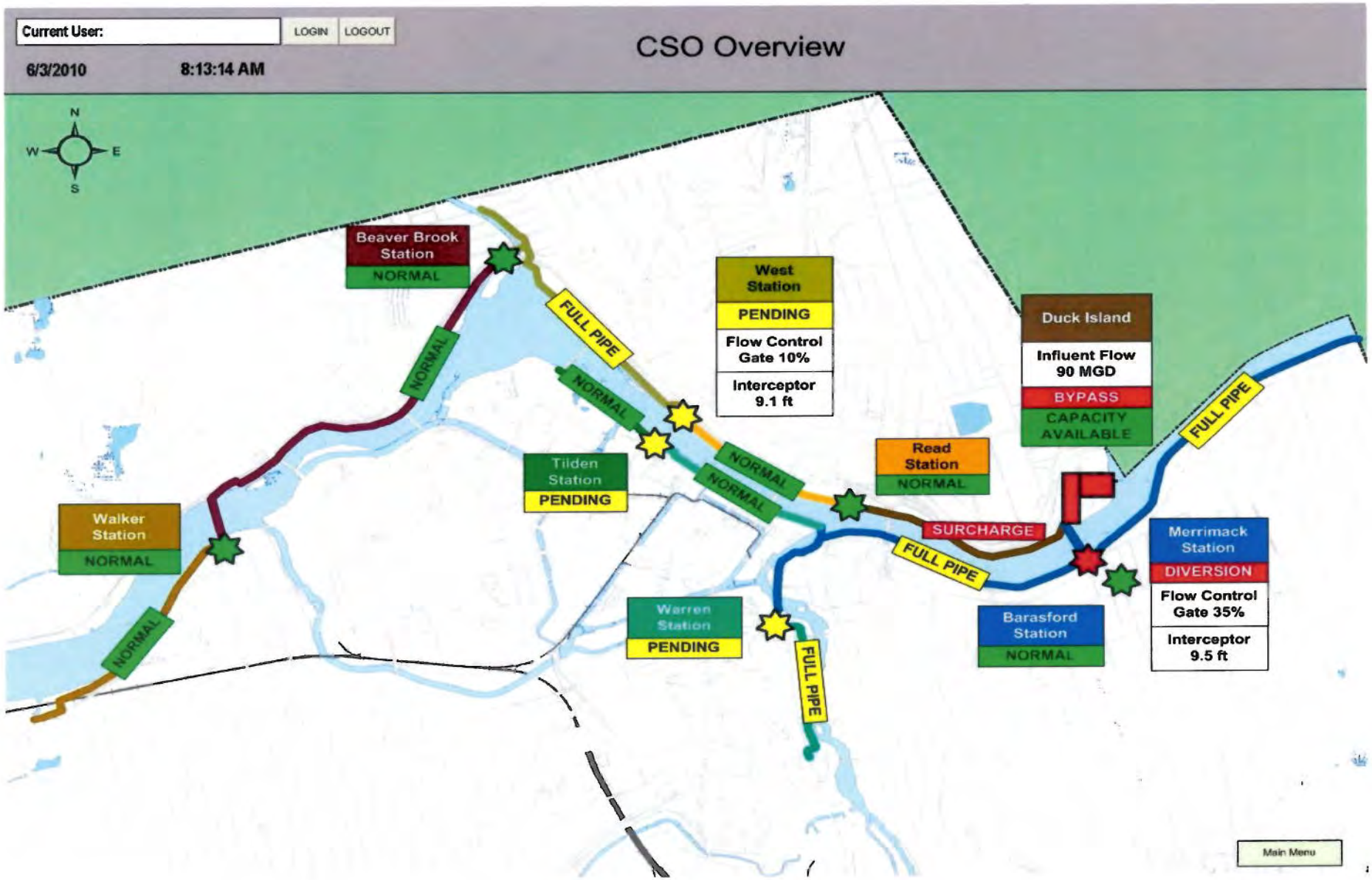


Figure 5: CSO Overview Screen

CONCLUSIONS

High Flow Management Cultural Shift: As the HFM program progressed, it brought about a shift in the way plant personnel approached controlling the remote diversion structures. The HFM program consisted of monthly team meetings, daily assessments of system responses to wet-weather conditions, HFM chart review, familiarization of the entire project team with the interceptor system, development of written HFM protocol, and periodic operator meetings to update them on changes to wet-weather operations. This meticulous evaluation approach, which involved the LRWWU engineering and operations staff as well as engineering consultants, has changed the culture of wet weather operations at LRWWU. The increased system understanding and involvement of the entire project team in decision making and implementation of operational standards has re-shaped the mindset from a "take-no-chances" approach to a "safe storage" approach that balances CSO minimization and property protection.

Evolution of Storage-Bypass-Diversion Philosophy: In the initial stages of the HFM program, the project team considered the approach of maximizing storage first, then initiating bypass when necessary and then diverting as a last resort. This is referred to as the storage-bypass-diversion approach, which intended to minimize unnecessary secondary bypass during less severe storms. After this approach was tested during several storms, it was concluded that it is not effective for the following reasons: stations upstream of the WWTF are more likely to divert when the interceptor is full; while storing, less flow reaches the WWTF so the maximum treatment capacity may not be reached. This operational approach often resulted in diversions in the system while the WWTF was operating under peak capacity, an undesirable outcome.

Through the program, the project team began realizing that a bypass-storage-diversion approach provides a more consistent way of operating the system, independently of the severity of the rain event. This approach involved first maximizing flow through the WWTF including secondary bypass, before initiating storage in the interceptor. This change in mentality took some time because the focus of the operations and engineering staff has always been on maximizing storage <u>and</u> avoiding bypass as much as possible. The hesitancy to change the approach was exacerbated by the difficulty of balancing flows between the North and South Bank Interceptors by means of the flow control gates at West and Merrimack.

The HFM program enabled the project team to test different operational approaches and observe how the system reacted. After evaluating many different storms, the project team agreed that maximizing storage as a first priority is too complex and maximizing flow to the WWTF provides the most consistent results considering varying conditions and multiple operators. The most important characteristics of the bypass-storage-diversion approach are its simplicity and the ability to avoid diversions while the WWTF flow is not maximized. This approach optimizes the treatment capacity of the WWTF and maintains available storage in the interceptor system for subsequent wet weather flows resulting from prolonged storm events.

Benefits of Gate Modulation: During HFM meetings, it was concluded that continuous gate modulation allows for more precise control of station flow and interceptor level. Based on this conclusion, the old diversion and flow control electric gate actuators were replaced with REXA gate actuators rated for continuous modulation. This change was implemented at West, Barasford, Merrimack, Tilden, Warren, and Walker (planned). Being able to maintain exact levels in the interceptor and stations enabled the minimization of CSOs by holding maximum storage levels.

System-Wide Gate Control Set Point Adjustments: Throughout the HFM program, gate set points were adjusted to either maximize flow through the station or maximize storage in the interceptor system. In the beginning of the program, it was uncertain which set points safely optimized system operation. As the program progressed, additional observations increased the confidence of all parties involved to push the system further than was previously acceptable. The diversion gate set points were raised to control the interceptor level within one foot below the crown, which resulted in increased storage upstream of most stations. The flow control gate set points were also raised to maximize flow through the stations.

At Warren Diversion Station, the flow through the station was controlled to within one foot of the station floor. The Barasford flow control gate, which is manipulated based on Merrimack Interceptor level, was maximized to remain open as long as the Merrimack Interceptor was not on the verge of diverting. At Walker, Beaver Brook and Tilden, it was decided that programming the flow control gates based on flume level rather than flume flow would be a more accurate and reliable way to maximize flow through the stations. This change enabled the flow through these stations to be brought within one foot of the lowest point in the station floor.

Progression of Gate Control at West and Merrimack Stations: Like the other stations, West and Merrimack diversion stations were manually operated until 2002. When the benefits of automated gate control were realized, the Merrimack diversion gates, along with others, were automated. Through the HFM Program, the opportunity for additional interceptor storage upstream of West Station was identified. In 2009, as part of this HFM program, the diversion gate at West Station was also automated. Before this time, the West diversion gate was operated as either fully open or fully closed. With this improvement, both stations would divert automatically when the diversion set points were reached. This strategy provided the operators with a "safety net" that promoted storage without causing damage from surcharging. It also allowed the operators to concentrate on manipulating the flow control gates and maximizing the flow to the WWTF.

The next challenge that the HFM program addressed was balancing the flows received at the Duck Island WWTF from the North and South Bank interceptors. The preference had always been to store at Merrimack Station rather than at West because of uncertainty with the impacts of manipulating the West Station flow control gate. Because of this uncertainty, storage at West was not utilized in the past. As part of this program, the HFM protocol emphasizes a balanced use of both Merrimack and West to control flow to the WWTF and maximize interceptor storage in both the North Bank and South Bank interceptors. This led to optimization of interceptor storage and overall minimization of CSOs from both stations.

The ultimate protocol for balancing flows from both interceptors and minimizing diversions from West and Merrimack was developed through the HFM program. As a result of this program, automated control of the flow control gates at Merrimack and West has been implemented to further optimize the storage upstream of both stations. The gates are now programmed to balance flows to the WWTF from each station while maintaining the maximum plant flow of 110 MGD. The result is a HFM protocol that completely utilizes the existing collection system during wet weather conditions.

Opportunities for Additional Interceptor Storage: Many improvements were made during the HFM program to optimize interceptor system storage. These improvements, described above, were augmented by changes to Walker Station, where the diversion weir was raised by two feet. The raised weir has resulted in more upstream storage and minimization of diversions at Walker. The weir extension was installed in a temporary manner to ensure that the adjustment did not result in upstream flooding. Because the temporary weir has proved to be effective, a permanent steel weir extension is planned. REXA actuators are also being considered at Walker station to enable gate modulation of the flow control gate.

In addition to implementing enhanced interceptor storage throughout the system, the HFM Program identified an important opportunity to significantly increase interceptor storage in one location. This opportunity is the installation of flow control structures in the North Bank Interceptor at Read Station. Currently, there is no flow control at Read, where a seven-foot elevation drop leaves more than 3,000 feet of 96-inch diameter pipe nearly empty during wet weather events. LRWWU is currently planning a three-phase project at Read Station, with storage being implemented first, followed by a flood pumping station and a wet weather treatment facility in subsequent phases. An additional one million gallons of interceptor storage is targeted, which is the basis for constructing a storage-pumping-diversion-treatment facility at this site. The anticipated completion date of the interceptor storage phase of this project is March 2012. When the Read Station Interceptor Storage project is completed, LRWWU will be fully utilizing its entire interceptor system for wet weather storage. Full utilization of the existing infrastructure will ensure a cost-effective LTCP, allowing for maximum benefit of future investments to eliminate CSOs.

Evaluation of WWTF Treatment Capacity: The HFM program is not only seeking to optimize wet-weather storage in the interceptor system, but also striving to fully utilize the treatment capacity of the Duck Island WWTF. In order to do this, a capacity study is being undertaken to quantify peak capacities for both primary and secondary treatment processes. Much work has been already done to evaluate treatment capacities; however, in order to properly quantify these capacities, it is necessary for LRWWU to collect more data.

Recent changes to the treatment processes and the flow measurement devices at the WWTF have rendered past data insufficient. LRWWU is seeking additional time to compile new data that better characterizes the treatment processes that are being upgraded. In September 2012, LRWWU will submit a Final High Flow Management Plan (HFMP) that will include a complete evaluation of WWTF treatment capacities and a review of the North Bank Interceptor Storage Project at Read Station. Any new information that revises this Interim HFMP will also be included in the Final HFMP submittal.

High Flow Management Program (Revised)

This document is an excerpt from Lowell Water's 2018 Annual Clean Water Report

Lowell Water's High Flow Management program (HFM) has been developed in order to maximize the treatment and storage of wet-weather flows with existing infrastructure prior to investing in planning and construction of new infrastructure. This program's conceptual groundwork lies in the Nine Minimum Controls (Appendix E of Lowell's NPDES wastewater permit), wherein it is explicitly stated that Lowell should maximize flow to the treatment plant through utilization of excess primary treatment capacity and maximization of the existing collection system for in-line storage. Accordingly, and as described above, Lowell has invested heavily in developing this program over the past 17 years.

This section of the report provides a detailed presentation of the current HFM protocol as practiced in 2018.

1.1.1 HFM Protocol

Lowell Water developed and implemented a Supervisory Control and Data Acquisition (SCADA) network, which allows operators to remotely control and monitor gates, valves, and pumps directly from the Operations Center at Duck Island. In addition to equipment at Duck Island, remote monitoring and control was enabled at all eight active CSO diversion stations along the interceptor system. Lowell Water has developed automated wet-weather protocols implemented through algorithms in the human-machine-interface (HMI) programming package RSLogix provided by Rockwell Automation.

The current protocol is implemented as a combination of reactions taken to increase or decrease flow to Duck Island and to accordingly increase or decrease flow through collection system structures in response to the network of level and flow sensors in the collection system and at Duck Island. These reactions are predominantly automated through control rules established in SCADA, but are continually reviewed and assessed by head operators throughout any given event. At any time, operators may change the automated system response based on their professional experience in order to avoid undesirable outcomes or to increase throughput at the plant when conditions allow.

Simply expressed, the HFM protocol follows the logic:

1. Maximize flow to the Duck Island treatment facility
2. Maximize use of available storage in the collection system's interceptors upstream of CSO diversion stations
3. Prevent sewer surcharging by diverting flow through CSO stations

With a bit more detail, the North Bank and South Bank interceptors are controlled primarily by gates at the North Bank Flow Control Station and at Merrimack Station (on the South Bank). These gates are kept open to levels that do not restrict flow under normal (dry) conditions. Upon the start of a wet-weather event, these gates are adjusted to allow free gravity flow to the facility until the biological treatment

system has reached maximum capacity (this is a variable range dependent on process performance and external factors, but generally lies within 60-75 MGD).

Upon maximization of flow to the biological treatment system, the high-flow treatment line is opened to allow excess primary treatment capacity to be conveyed to the blending well at the outlet of the secondary clarifiers. The hydraulic capacity at Duck Island is currently restricted to an instantaneous peak flow rate of 120 MGD, and an average hourly flow rate of 105 MGD. Flows in excess of this upper limit are not allowed, and result in the control gates modulating to maintain the maximum flow rate. As these gates modulate, levels in the interceptor rise until they are within one foot of the interceptor crown. Upon crossing this threshold, excess flows are diverted through CSO stations to prevent sewer surcharging.

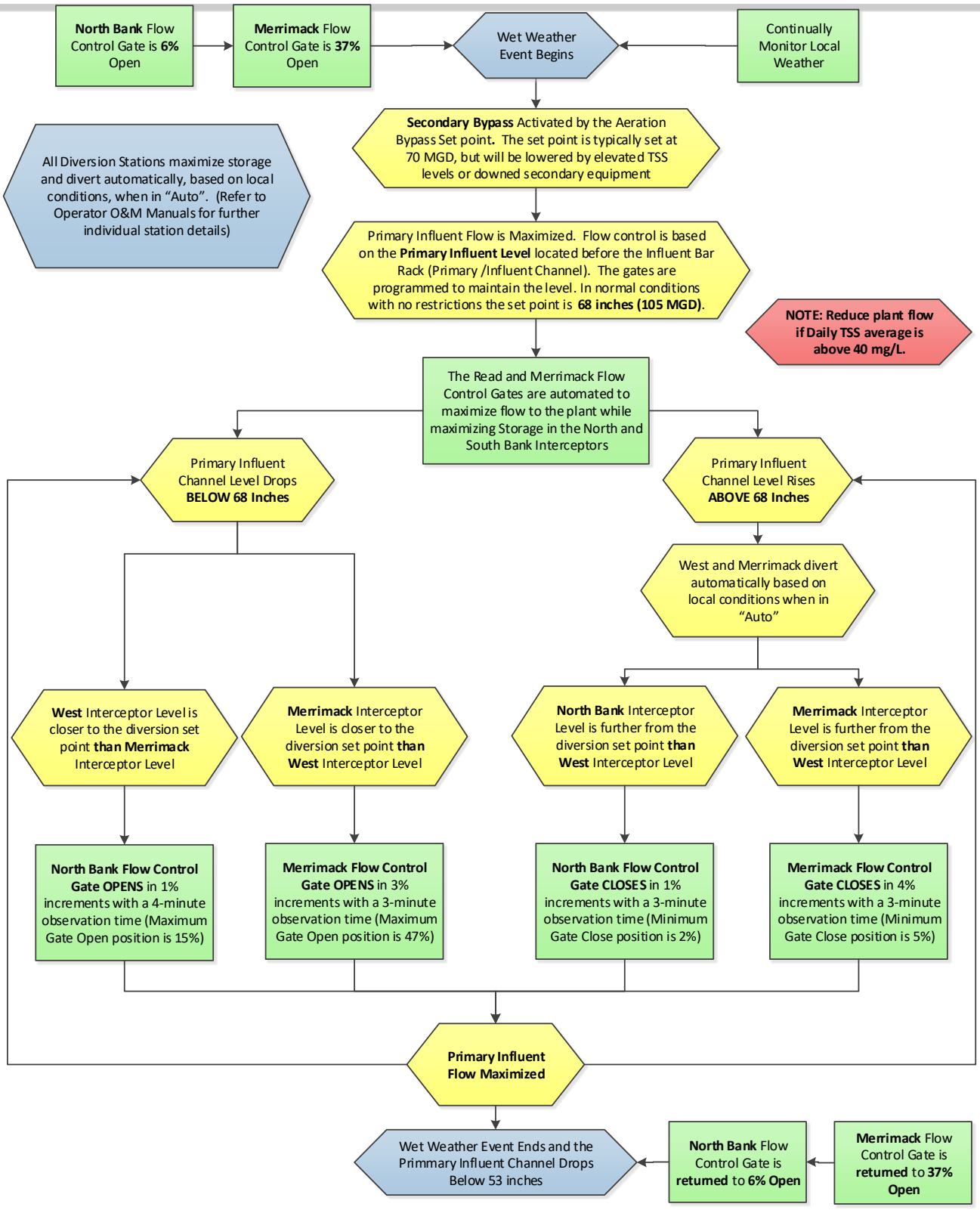
At present, chlorine pumps are installed for manual dosing of the high-flow treatment line to allow for additional disinfection of the primary effluent. This primary effluent is blended with secondary effluent at the blending well, and then enters the chlorine contact chambers prior to discharge at the Duck Island outfall. High-flow treatment continues in this manner until the plant-influent flow rate falls below the biological treatment capacity, whereupon the high-flow line is closed.

As this process occurs, total suspended solids (TSS) meters continuously record the quality of primary and secondary effluent. SCADA calculates a mass balance to forecast effluent TSS concentrations, and displays this information to the operators. If TSS concentrations are forecasted to exceed allowable secondary-treatment levels, flow to the plant is reduced and the collection system responds by modulating its gates to increase storage and, if necessary, discharge at CSO stations.

Figure 1, below, provides a visual representation of the HFM protocol, as followed at present.

Automated High Flow Management Protocol

December 23, 2019



1.1.2 HFM Improvement Actions in 2018

The following actions have been undertaken to inform improvements to the HFM program in 2018.

High Flow Treatment Chlorine Dosing Automation

In 2018, Lowell Water staff conducted sampling of chlorinated high-flows at the end of the high-flow treatment line and through the chlorine contact chamber to support automation of high-flow chlorine dosing. Results suggested that development of an automated chlorine dosing rate based on the total residual chlorine (TRC) probe at the front of the chlorine contact chambers may be beneficial to ensure optimal dosing by modulating the chlorine-pump speed to maintain a constant residual chlorine level at that point. In 2019, these results will be assessed further to develop SCADA control algorithms relating pump speed and chlorine dosage to improve reliability and efficiency of disinfection and de-chlorination.

High Flow Management Plan Update

Lowell Water engineering staff began a station-by-station review of measurements taken at CSO stations that factor into HFM automation protocols. These measurements were originally developed in 2009-2011 by Lowell staff and CDM, during the initial design of the HFM program. After eight years of active management experience, a comprehensive revision to the 2011 HFM Plan is due. Several measurements are considered during this review process, including: structure elevations; river stage elevations; level sensor settings; gate opening ranges; SCADA flow calculations and control algorithms; and flow meter validation.

Among the issues identified and corrected in 2018 (and most significant among them all), the Warren Station CSO calculation was found to be incorrect, in that one of the two diversion gates was not accurately represented in the flow calculation employed in SCADA. This resulted in revision of that algorithm to accurately calculate the flow through this station, and a subsequent revision of flow measurements at Warren during CSOs that activated the gate in error. This error is discussed in more detail in Section 2.5, of Lowell Water's 2018 Annual Clean Water Report and the revised CSO volumes are included in the annual CSO volume report presented in Section 2.4.

As this review process continues in 2019, the HFM plan will be revised and updated to reflect the current system state, which has changed significantly over the years. Submission of the revised HFM plan to EPA and MassDEP will be included as part of the Integrated Planning schedule.

1.1.3 HFM Meetings

Central to the HFM program is a recurring bi-weekly meeting at which Lowell Water staff from the Operations, Maintenance and Engineering divisions convene with the Executive Director to discuss recent high-flow events and assess performance of those events. Recurring action items include review of gate positions, system levels and flows, and precipitation records to assess opportunities for improvement; review of plant discharge sampling data to ensure that treatment levels meet permit limits; status updates on SCADA improvements and previously identified opportunities for improvement.

1.1.4 Public Notification and Reporting

Lowell has increased the speed of distribution and audience receiving notifications about CSO discharges in 2018. Public concerns over CSO discharges to the Merrimack River, in particular, have grown significantly since 2017. Lowell has responded by providing near real-time notification of CSO discharges to interested parties via emails sent by Operations staff as they occur. Detailed reports of each CSO event and High-Flow Treatment performance are sent to all parties after proper validation of instrument and communication records within ten days of the end of a high-flow or CSO event. Lowell has also designed more 'readable' notification reports in response to concerns presented by downstream community representatives that standard reporting formats were difficult to understand.

Lowell engineering staff have been actively involved in communication and collaboration with special interest groups like the Massachusetts Coalition for Water Resources Stewardship, Massachusetts Rivers Alliance, the Merrimack River Watershed Council, and others to identify the primary objectives of public notifications that may be delivered in a timeframe manageable from a utility perspective while still meaningful to the general public. Lowell will continue to engage in this public outreach project through 2019 and onward to ensure that the public understands the frequency, cause and effect of CSO discharges in the Merrimack River.

Hazen

APPENDIX C

Lowell, MA

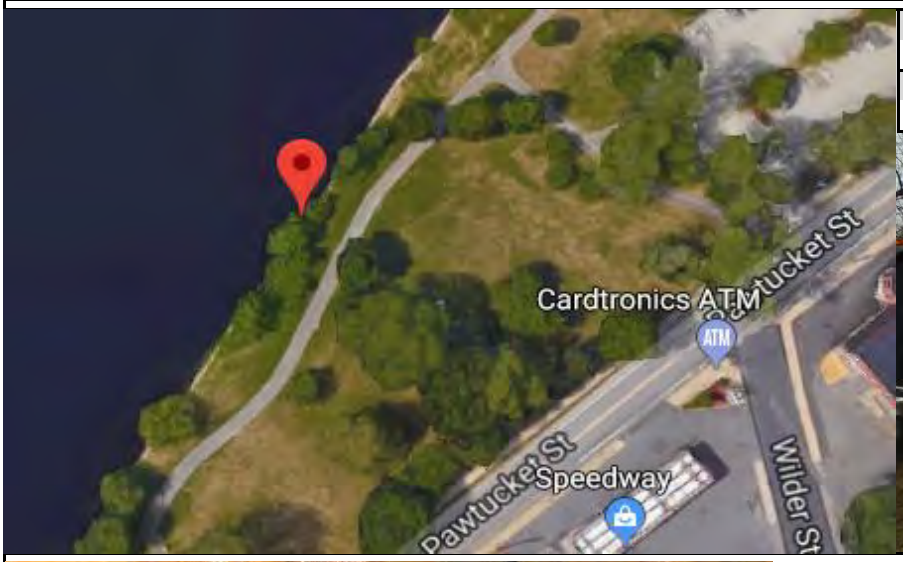
Flow Monitoring Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB1

Site Address / Location:	Off Of 579 Pawtucket Street, Lowell, MA (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive (On Walking Path)	Pipe Size (H x W)	Pipe Shape
		47.75" X 48.00"	Elliptical



Manhole #	System Characteristics
N/A	Other
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Wednesday, April 04, 2018	Doppler Standard Ring and Crank
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
11:35:00 AM	47.75" X 48.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
11.5	36.25"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.25	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Choppy	

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
16'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

*I.P. 107.80.27.188 *Serial Number: 30080

*Coordinates: N 42.64544 W 071.33543

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB2

Site Address / Location:	90 Varnum Ave (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		35.13" X 36.00"	Elliptical

Manhole #	System Characteristics
N/A	Industrial
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Monday, May 07, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
12:06:00 PM	35.13" X 36.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
10.5	24.63"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
4.13	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Choppy	

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
35'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
PVC	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

I.P. 166.219,174.64 *Sernial Number: 61900 *Coordinates: N 42.649013 W 071.333465

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB2alt

Site Address / Location:	90 Varnum Ave (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		35.13" X 36.00"	Elliptical

Manhole #	System Characteristics
N/A	Industrial
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Monday, May 7, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
12:06:00 PM	35.13" X 36.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
10.5	24.63"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
4.13	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:
Fast & Choppy

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
35'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
PVC	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

I.P. 166.219,174.64 *Serial Number: 61900 *Coordinates:
N 42.649013 W 071.333465

Boston, MA

Flow Monitoring
Site Installation Report

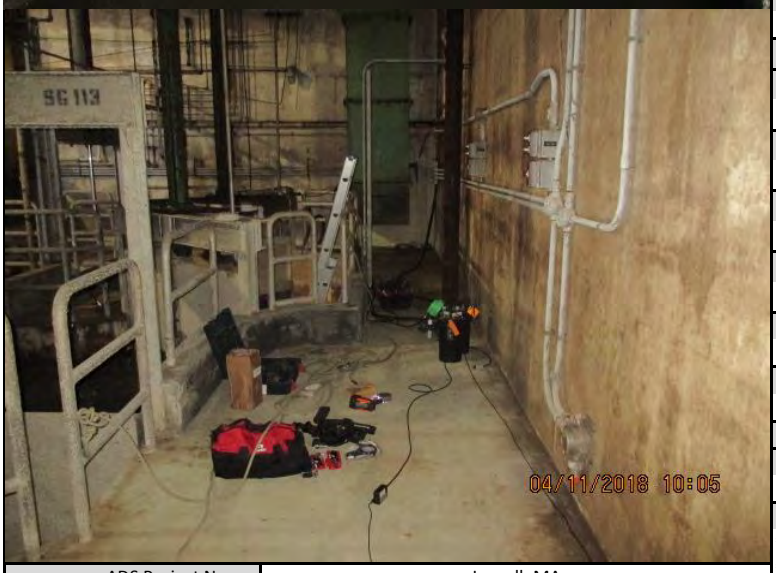
ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB3

Site Address / Location:	Martin Street Pump Station (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive/Located in Building	Pipe Size (H x W)	Pipe Shape
		96.00" X 95.63"	Elliptical

Manhole #	System Characteristics
N/A	Industrial
Access	Traffic
Drive	None



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Wednesday, April 11, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Building - Contact Client
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
9:59:00 AM	96.00" X 95.63"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
23.5	72.5
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.24	N/A
Silt (in)	Silt Type
2.5	Sandy

Hydraulic Comments:
Slow & Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
N/A	Pump Station
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
N/A	N/A
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Building

Additional Site Info. / Comments:

*I.P. 166.219.174.52 *Serial Number: 21765
*Coordinates: N 42.659311 W 071.319416 *Physical Offset: 7.5"

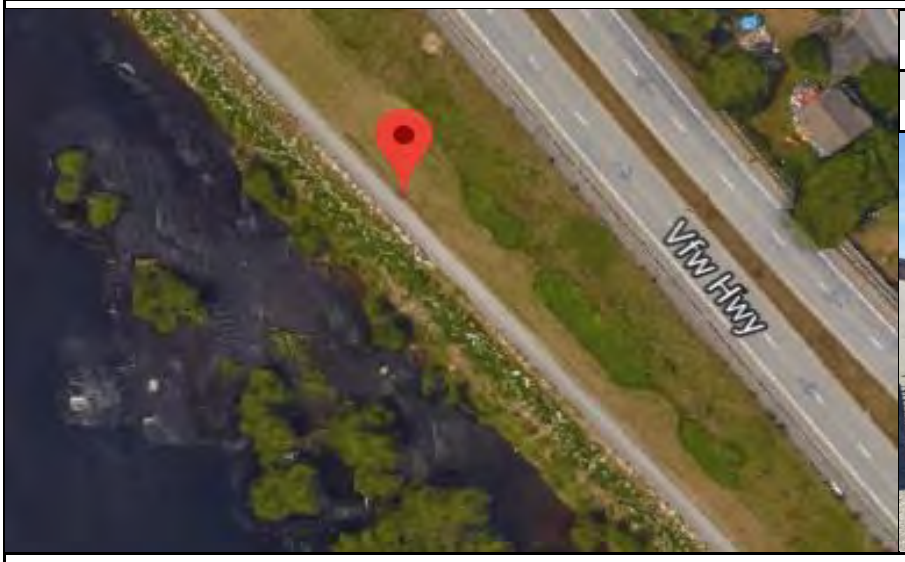
Lowell, MA

Flow Monitoring Site Installation Report

Site I.D.

Lowell_NB4

Site Address / Location:	Bike Path on the North Bank of the Merrimack River (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		96.25" X 96.5"	Circular



Manhole #	System Characteristics
N/A	Other
Access	Traffic
Drive	Light

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Monday, April 09, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
12:38:00 PM	96.25" X 96.5"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
25.00"	71.25"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.87"	N/A
Silt (in)	Silt Type
4.0"	Sandy
Hydraulic Comments:	
Slow & Smooth	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
10'	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.17.113 *Serial Number: 22038

*Coordinates: N 42654011 W 071.312720 *Physical Offset: 7.0"

Lowell, MA

Flow Monitoring
Site Installation Report

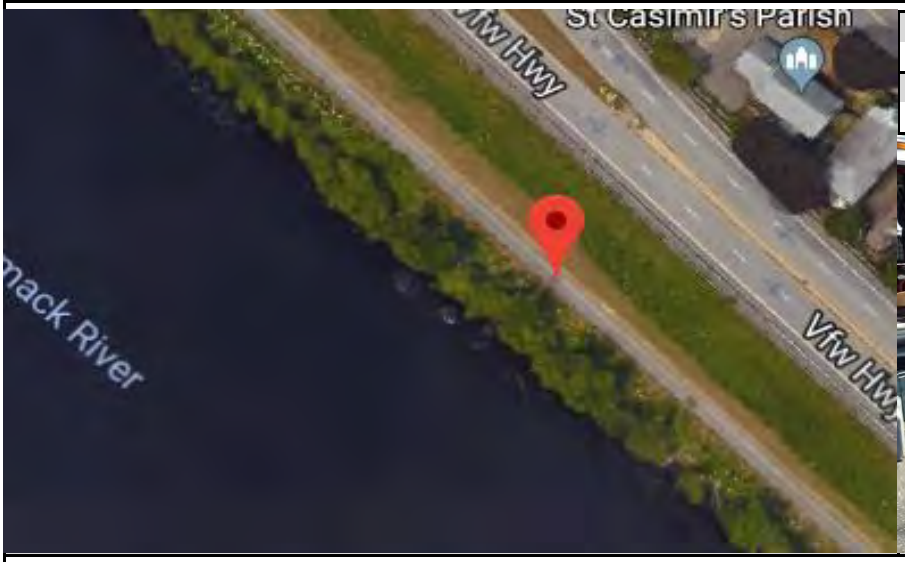
ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB5

Site Address / Location:	Bike Path on theNorth Bank of the Merrimack River (see Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		96.25" X 95.00"	Elliptical

Manhole #	System Characteristics
N/A	Other
Access	Traffic
Drive	None



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Monday, April 09, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
2:50:00 PM	96.25" X 95.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
22.13"	74.12"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.48	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:
Slow & Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
13'	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.16.135 *Serial Number: 21710
*Coordinates: N 42. 650952 W 071.308939

Lowell, MA

Flow Monitoring Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB6

Site Address / Location:	Hall Street East @ River Place (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		35.75" X 35.75"	Circular

Manhole #	System Characteristics
N/A	Other
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Tuesday, April 10, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
9:19:00 AM	35.75" X 35.75"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
12.5	23.25
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.19	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Smooth	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
16	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.25.235 * Serial Number: 21565 *Coordinates: N 42.646977 W 071.303591

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB6alt

Site Address / Location:	Hall Street East @ River Place (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		35.75" X 35.75"	Circular

Manhole #	System Characteristics
N/A	Other
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Tuesday, April 10, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
9:19:00 AM	35.75" X 35.75"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
12.5	23.25
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.19	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Smooth	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
16	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.25.235 * Serial Number: 21565
*Coordinates: N 42.646977 W 071.303591

Lowell, MA

Flow Monitoring Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB7

Site Address / Location:	Walking Path Located Off VFW Highway (See Coordinates)	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		96.00" X 96.00"	Circular

Manhole #	System Characteristics
N/A	Other
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.324

Installation Information

Installation Date:	Installation Type:
Friday, April 06, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
2:29:00 PM	96.00" X 96.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
22.00"	74.00"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.25"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.72	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Smooth	

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
17.00"	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

*I.P. 166.219.48.191 *Serial Number: 61891

*Coordinates: N 42.64555 W 071.292231

Lowell, MA

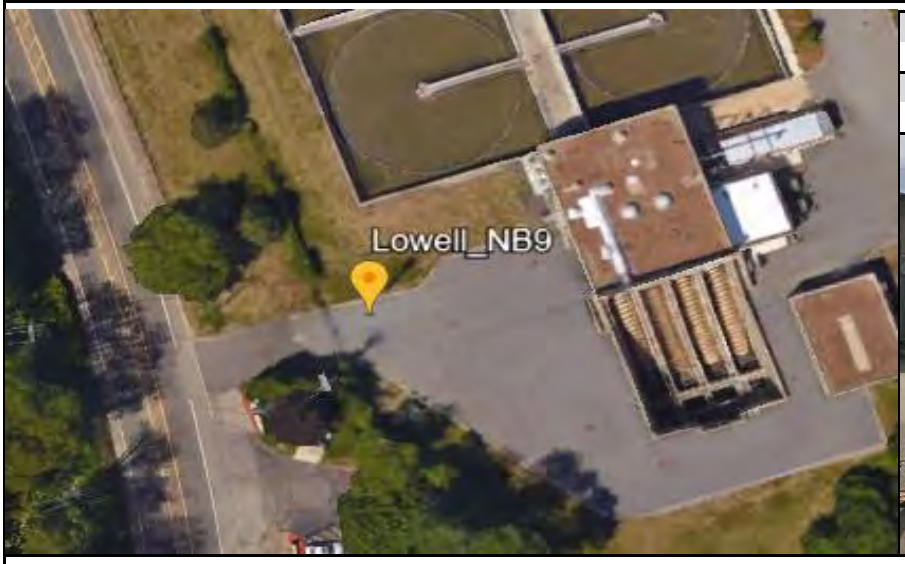
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB9

Site Address / Location:	Duck Island WWTP, Lowell, MA (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		18.00" X 18.00"	Circular



Manhole #	System Characteristics
N/A	Industrial
Access	Traffic
Drive	Light

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Wednesday, May 30, 2018	Doppler Standard Ring and Crank
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
9:27:00 AM	18.00" X 18.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
4.50"	13.50"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
0.65	N/A
Silt (in)	Silt Type
0	N?A
Hydraulic Comments:	
Slow & Slighty Turbulent due to Drop Connection	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
N/A	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
Yes, Inside	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 166.219.19.163 *Serial Number: 61816 *Coordinates: N 42.6471 W 071.2904

Lowell, MA 18

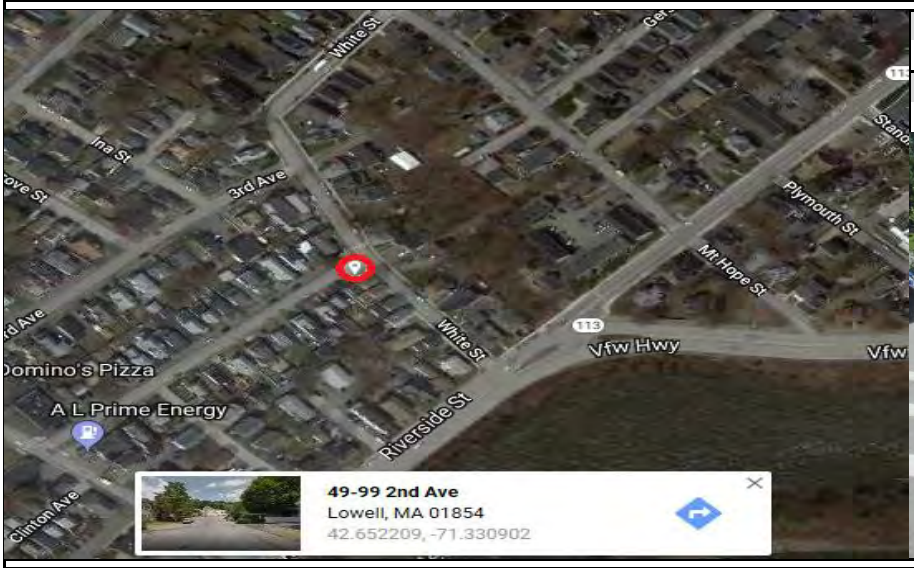
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

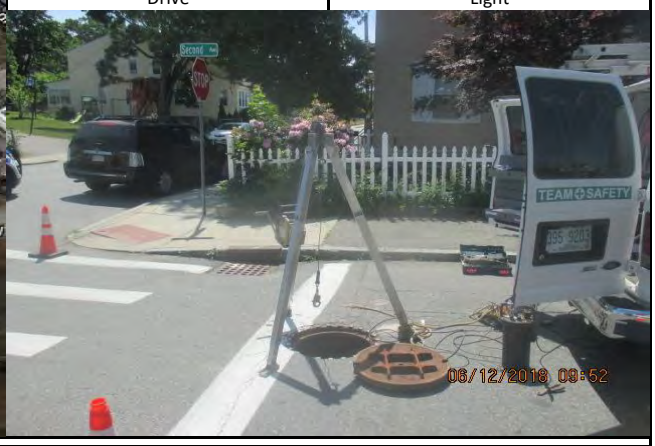
Site I.D.

Lowell_NB10

Site Address / Location:	Second Ave @ White St.	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:		Pipe Size (H x W)	Pipe Shape
		62 x 64	Elliptical



Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Drive	Light



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Tuesday, June 12, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
10:57:00 AM	62 x 64
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
6.38	55.62
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
0	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:
Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
13	CSO Flow Divider
Manhole Material:	Manhole Condition:
Brick	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Brick	Fair

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

S/N: 52269 I/P: 166.219.170.122

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

SB1

Site Address / Location:	End of Martin Luther King Jr. Way. Up path from Tilden CSO pump station (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	On bike path between Merrimack river and Western canal	Pipe Size (H x W)	Pipe Shape
		72 x 72	Circular

Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Drive	Light

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Thursday, April 5, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
1:50:00 AM	72 x 72
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
13.38	58.62
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.25"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.65	N/A
Silt (in)	Silt Type
4.5"	N/A

Hydraulic Comments:
Slow & Choppy

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
10	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Manhole Pick / Vent Hole

Additional Site Info. / Comments:

*I/P: 107.80.25.89 *S/N: 31090
*Coordinates: N 42.651541 W 071.312648 *Physical Offset: 8.13"

Lowell, MA

Flow Monitoring Site Installation Report

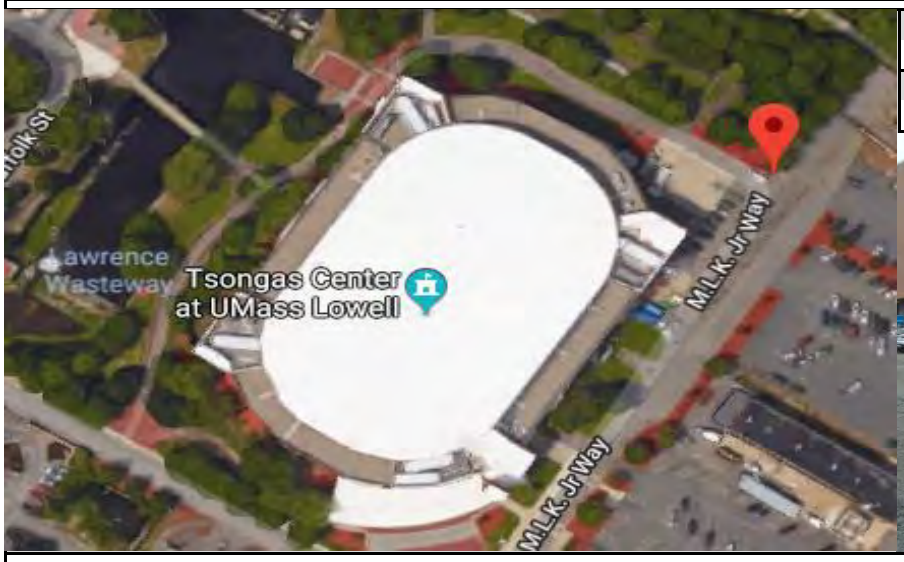
ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB2

Site Address / Location:	Behind Tsongas Arena, Lowell, MA (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		36.00" X 36.00"	Circular

Manhole #	System Characteristics
N/A	Commercial
Access	Traffic
Drive	Light



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Wednesday, April 04, 2018	Doppler Standard Ring and Crank
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
4:01:00 PM	36.00" X 36.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
8.5"	27.5"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.31	N/A
Silt (in)	Silt Type
2	Sandy
Hydraulic Comments:	
Fast & Choppy	

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
10'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
Yes, Inside	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P 166.219.48.326 *Serial Number:20867
*Coordinates: N 42.65062 W 071.31213 *Physical Offset: 2.0" *Sensor is on a wedge

Lowell, MA

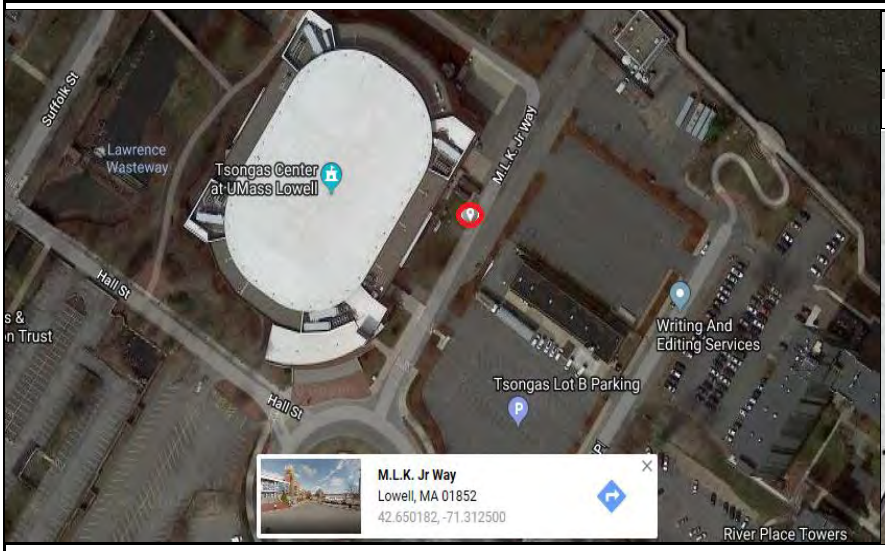
Flow Monitoring
Site Installation Report

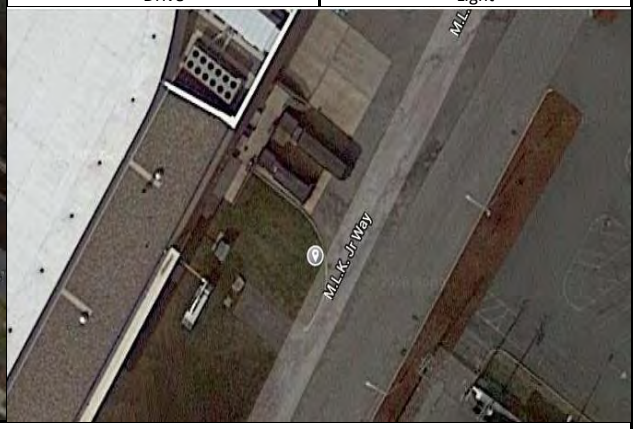
ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell SB2-A

Site Address / Location:	Martin Luther King JR. Way	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Manhole in grass	Pipe Size (H x W)	Pipe Shape
		36 x 36	Circular
		Manhole #	System Characteristics
		N/A	Commercial
		Access	Traffic
		Drive	Light





Installation Information	
Installation Date:	Installation Type:
Wednesday, May 23, 2018	Doppler Standard Ring and Crank
Monitoring Location (Sensors):	Monitor Location:
Downstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
5:06:00 PM	36 x 36
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
3.75	32.25
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.50"
Peak Velocity (fps)	Velocity Sensor Offset (in)
7.5	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast, Choppy	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
10	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Concrete	Fair
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete
Additional Site Info. / Comments:	
S/N: 20867 I/P: 166.219.48.195	

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Lowell, MA

Flow Monitoring
Site Installation Report

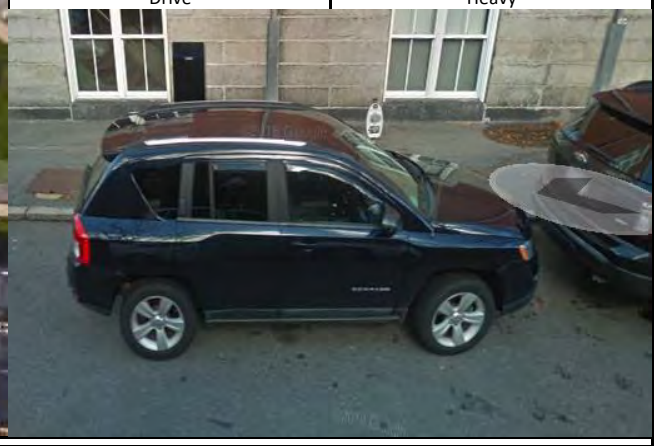
ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB3

Site Address / Location:	41 Hurd Street, Lowell, MA (In front of Lowell District Court)	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		47.00" X 32.00"	Elliptical

Manhole #	System Characteristics
N/A	Commercial
Access	Traffic
Drive	Heavy



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Friday, April 6, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
9:28:00 AM	47.00" X 32.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
3.75	43.25"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
4.97	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:
Fast & Turbulent

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
15'	Common Trench
Manhole Material:	Manhole Condition:
Brick	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Brick	Fair

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

I.P. 166.219.18.196 *Serial Number: 52533
*Coordinates: N 42.642849 W 071.307209 *Police Detail Needed

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB4

Site Address / Location:	151 Warren Street, Lowell,MA	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		90.00" X 90.00"	Circular

Manhole #	System Characteristics
N/A	Commercial
Access	Traffic
Drive	Heavy

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Friday, April 06, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
11:29:00 AM	90.00" X 90.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
15.50"	74.50"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
4.19	
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Turbulent	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
26'	CSO Flow Divider
Manhole Material:	Manhole Condition:
Brick	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Brick	Fair
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 166.219.48.218 *Serial Number: 60809
*Coordinates: N 42.642056 W 071.304526

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB5

Site Address / Location:	East Merrimack Street In Front of Lowell Auditorium (See coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		72.00" X 72.00"	Circular

Manhole #	System Characteristics
N/A	Commercial
Access	Traffic
Drive	Medium

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Wednesday, April 11, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
1:45:00 PM	72.00" X 72.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
12.75"	59.25"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
5.08	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:
Fast & Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
15'	Common Trench
Manhole Material:	Manhole Condition:
RCP	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vault	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
RCP	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 166.219.170.138 *Serial Number: 30460 *Coordinates: N 42.644913 W 071.305023 *MH has different platform levels

Lowell, MA

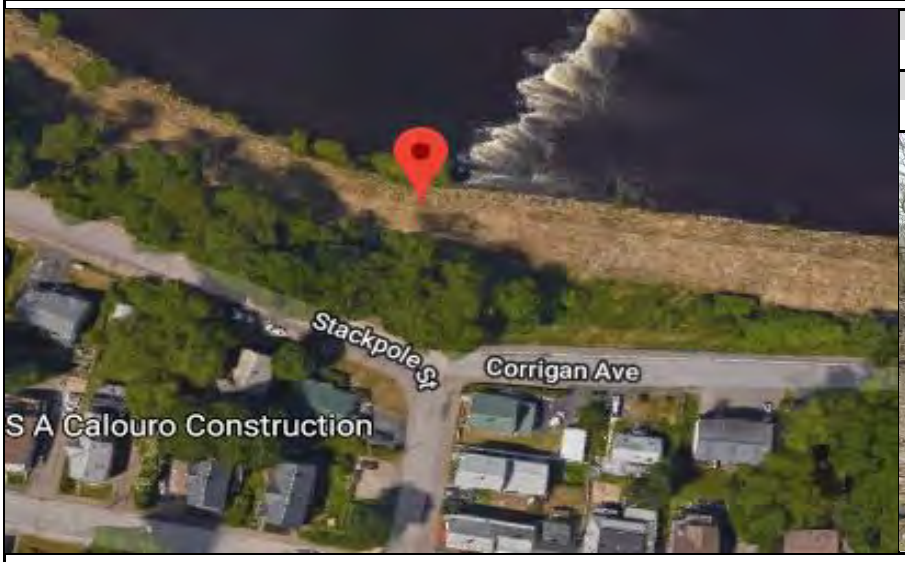
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB6

Site Address / Location:	Stackhole Street @ Corrigan Ave (Over the Bank, See Coordinates)	Monitor Series	Location Type
			Temporary
Site Access:	Drive/Walk	Pipe Size (H x W)	Pipe Shape
		120.00" X 120.00"	Circular



Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Walk (Residential)	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Tuesday, April 10, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
2:14:00 PM	120.00" X 120.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
23.50"	96.50"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.9	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Smooth	

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
16.00'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

*I.P. 107.80.26.42 *Serial Number: 22085
*Coordinates: N 42.644013 W 071.293874

Lowell, MA

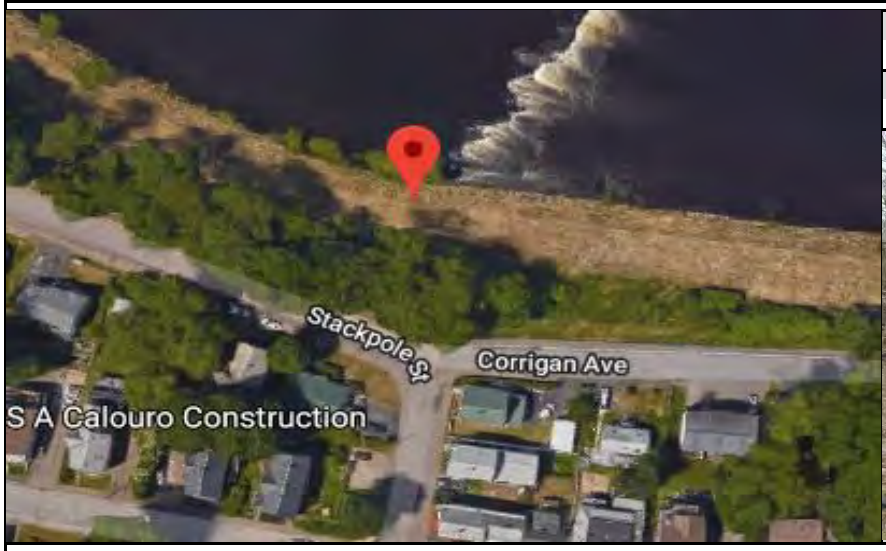
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB6

Site Address / Location:	Stackhole Street @ Corrigan Ave (Over the Bank, See Coordinates)	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive/Walk	Pipe Size (H x W)	Pipe Shape
		120.00" X 120.00"	Circular



Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Walk (Residential)	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Wednesday, May 23, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Downstream 10-15 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
3:45:00 PM	120.00" X 120.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
21.75	98.25
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.25"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.75	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Smooth	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
16.00'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

*I.P. 107.80.26.42 *Serial Number: 22085
*Coordinates: N 42.644013 W 071.293874

Lowell, MA

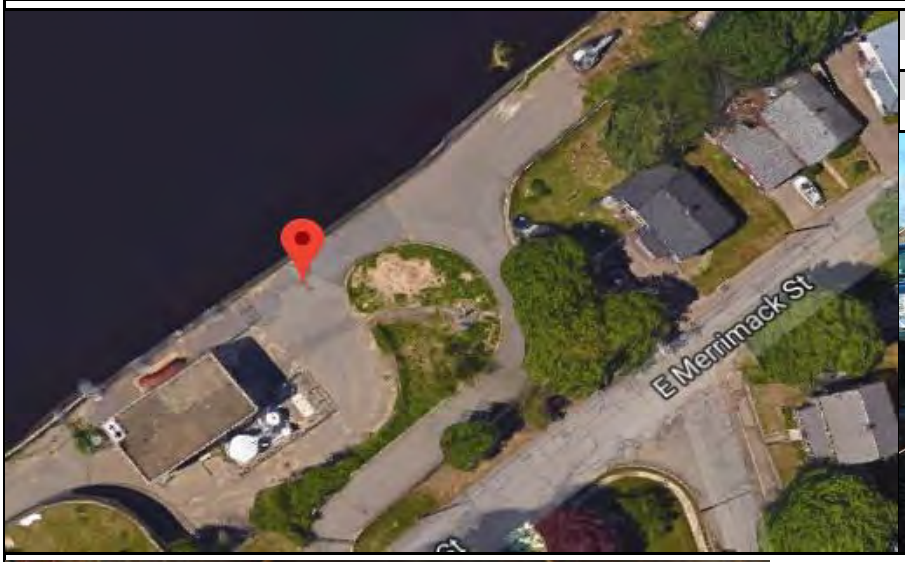
Flow Monitoring Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB7

Site Address / Location:	Merrimack CSO Station off Merrimack Street, Lowell, MA (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		84.00" X 84.00"	Circular



Manhole #	System Characteristics
N/A	Industrial
Access	Traffic
Drive	Light

ADS Project Name:	Lowell,MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Thursday, April 05, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
4:24:00 PM	84.00" X 84.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
8.00"	76.00"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
3.3	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Smooth	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
13'	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

*I.P. 10.4.2.90 *Serial Number: 40461

*Coordinates: N 42.645360 W 071.288630

Lowell, MA

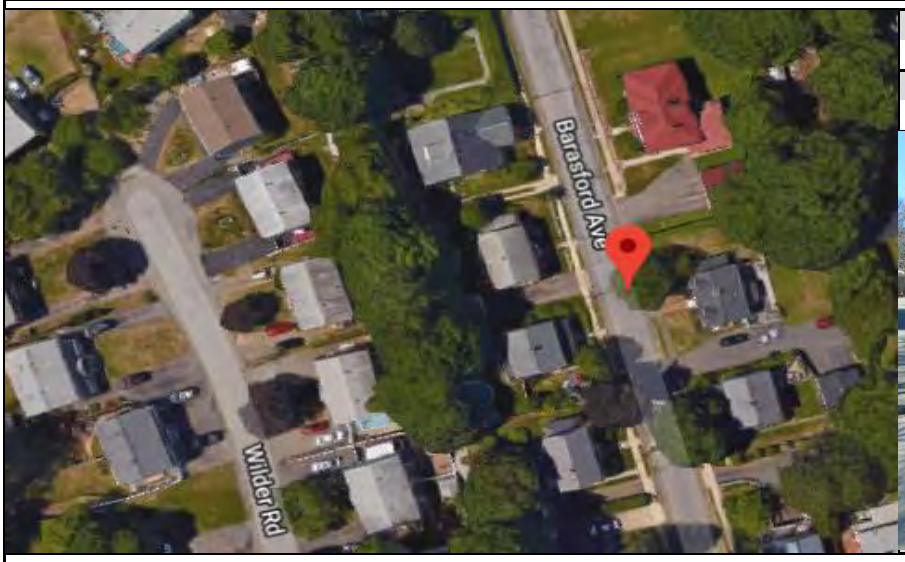
Flow Monitoring Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB8

Site Address / Location:	15 Barasford Ave, Lowell, MA	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		60.00" X 60.00"	Circular



Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Drive	Medium

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Thursday, April 05, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
11:12:00 AM	60.00" X 60.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
4.88	55.12
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
5.5	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:

Fast & Choppy

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
19'	Common Trench
Manhole Material:	Manhole Condition:
Brick	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Brick	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.27.162 *Serial Number: 20265 *Coordinates: N 42.644168 W 071.287633

Lowell, MA

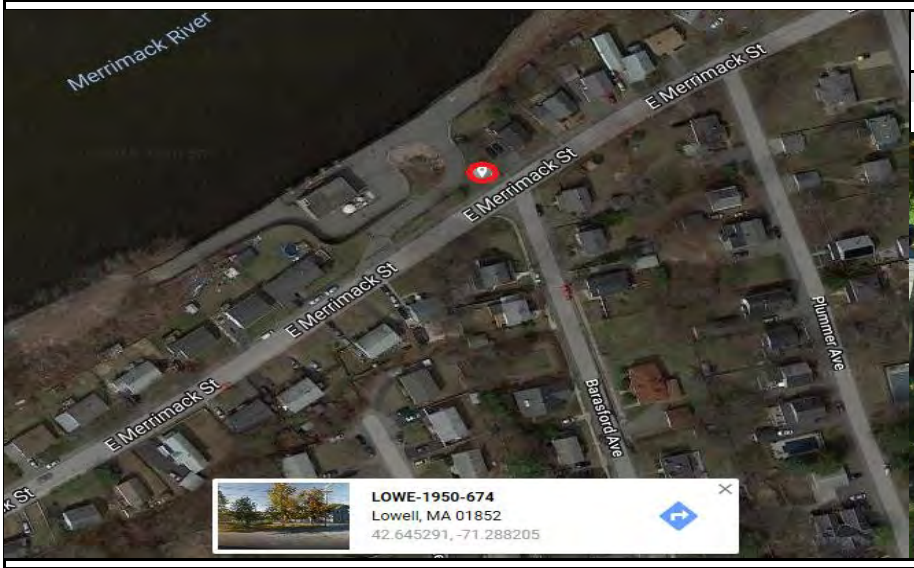
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

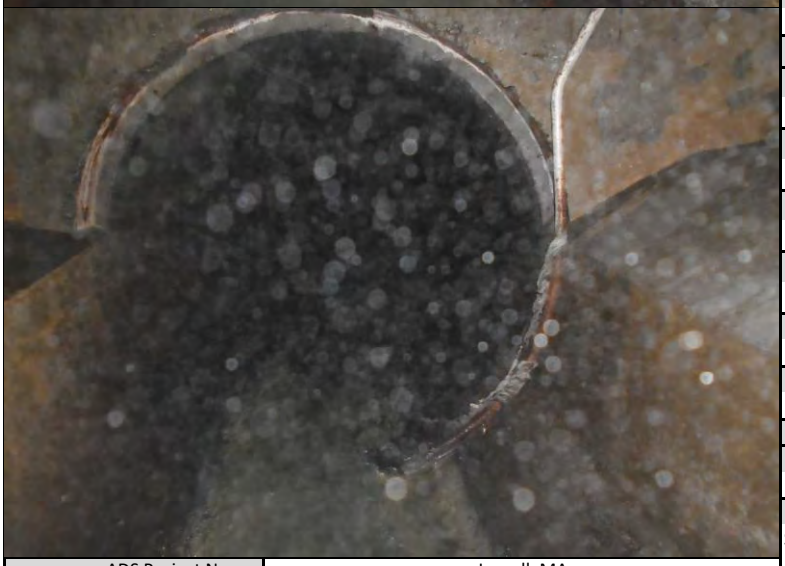
Site I.D.

Lowell_SB8-A

Site Address / Location:	East Merrimack St @ Barasford Ave	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Site in grass	Pipe Size (H x W)	Pipe Shape
		61.75 x 60.5	Elliptical



Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Drive	Medium



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Wednesday, May 23, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4), Smart Depth (CS5)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
	61.75 x 60.5
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
8.75	53
Downlooker Physical Offset (in)	Measurement Confidence (in)
2	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.9	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Smooth	

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
14	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Poor
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Brick	Poor

Communication Information:

Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

S/N: 52592 I/P: 107.80.27.162

Lowell, MA

Flow Monitoring Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB9

Site Address / Location:	21 George Street, Lowell, MA (See Coordinates)	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive (Police Detail Required)	Pipe Size (H x W)	Pipe Shape
		29.75" X 20.88"	Elliptical

Manhole #	System Characteristics
N/A	Commercial
Access	Traffic
Drive	Medium

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Monday, May 7, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
2:11:00 PM	29.75" X 20.88"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
4.50"	25.25"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.12	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:

Slow & Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
20'	Common Trench
Manhole Material:	Manhole Condition:
Brick	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Brick	Fair

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.16.134 *Serial Number: 61983 *Coordinates: N 42.642336 W 071.306290 Physical Offset: 2.13

Lowell, MA

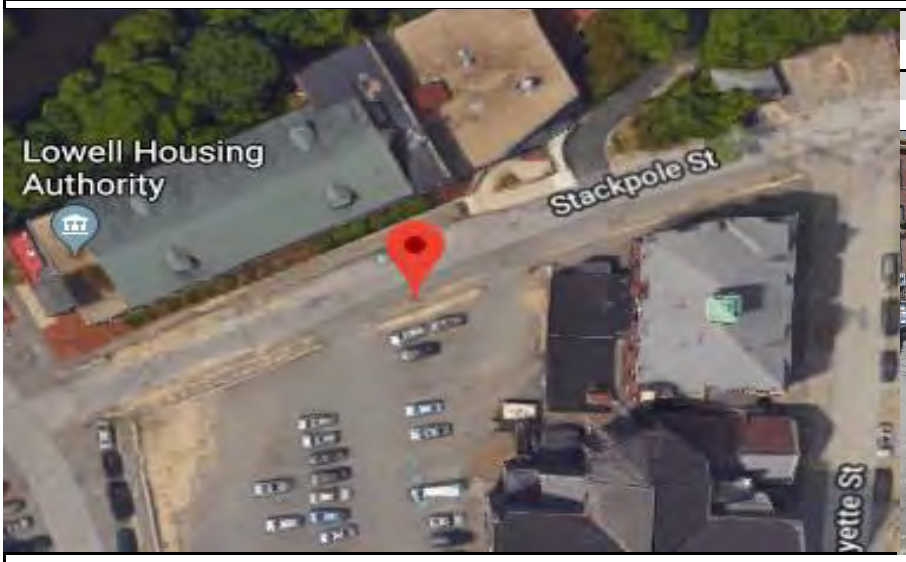
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

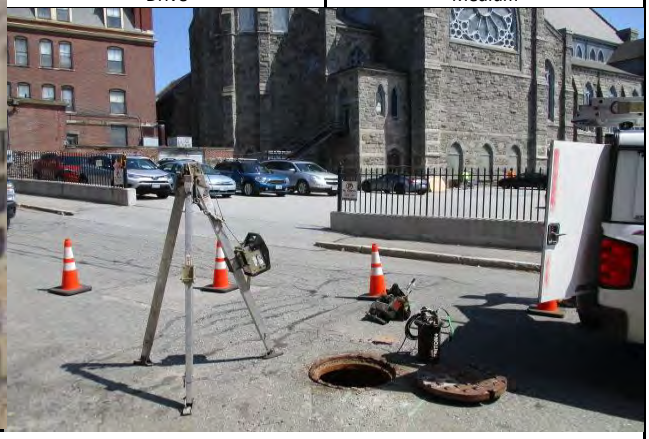
Site I.D.

Lowell_SB10

Site Address / Location:	Stackpole Road Near Church (See Coordinates)	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		24.00" X 24.00"	Circular



Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Drive	Medium



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Tuesday, May 08, 2018	Doppler Standard Ring and Crank
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
2:12:00 PM	24.00" X 24.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
1.25"	22.75"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
3.93	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Choppy	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
12'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Offset
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.23.10 *Serial Number: 61818
*Coordinates: N 42.6457 W 071.3032 *Reverse Install

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB11

Site Address / Location:	Hall Street East @ River Place (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		35.75" X 35.75"	Circular

Manhole #	System Characteristics
SMH-003247	Other
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Tuesday, April 10, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
9:19:00 AM	35.75" X 35.75"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
12.5	23.25
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.19	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Smooth	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
16	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.25.235 * Serial Number: 21565
*Coordinates: N 42.646977 W 071.303591

Lowell, MA

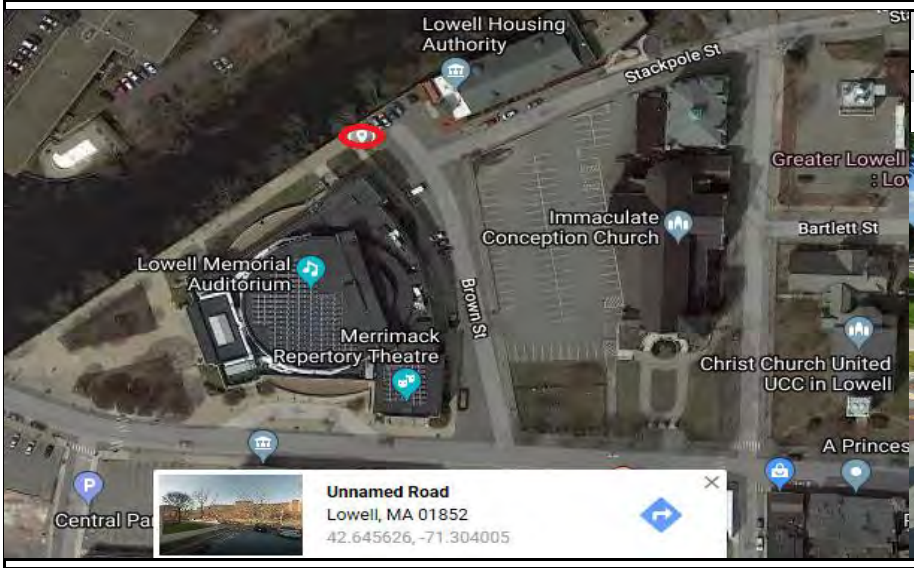
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

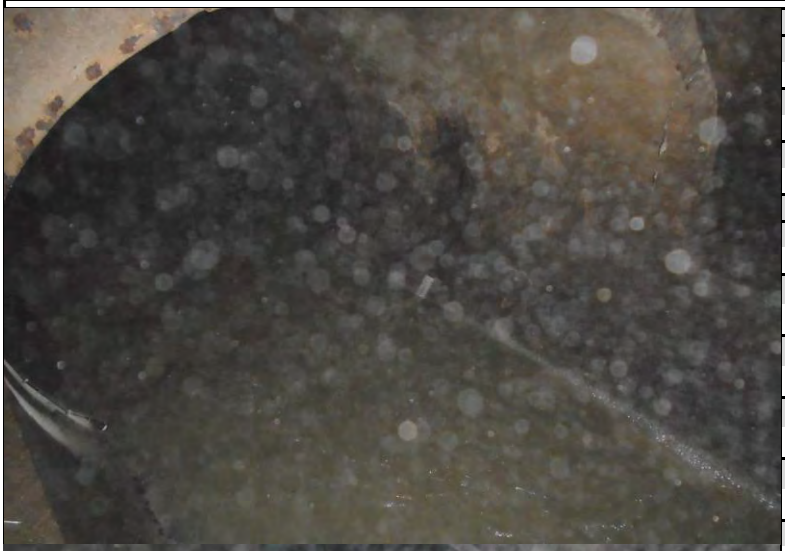
Site I.D.

Lowell_SB12

Site Address / Location:	Stackpole St. @ Brown St.	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		96 x 96	Circular



Manhole #	System Characteristics
N/A	Residential
Access	**Traffic**
Drive	Light



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Wednesday, May 23, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
10:07:00 AM	96 x 96
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
18.25	77.75
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.25"
Peak Velocity (fps)	Velocity Sensor Offset (in)
3.63	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:
Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
15	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

S/N: 52335 I/P: 166.219.172.128

Lowell, MA

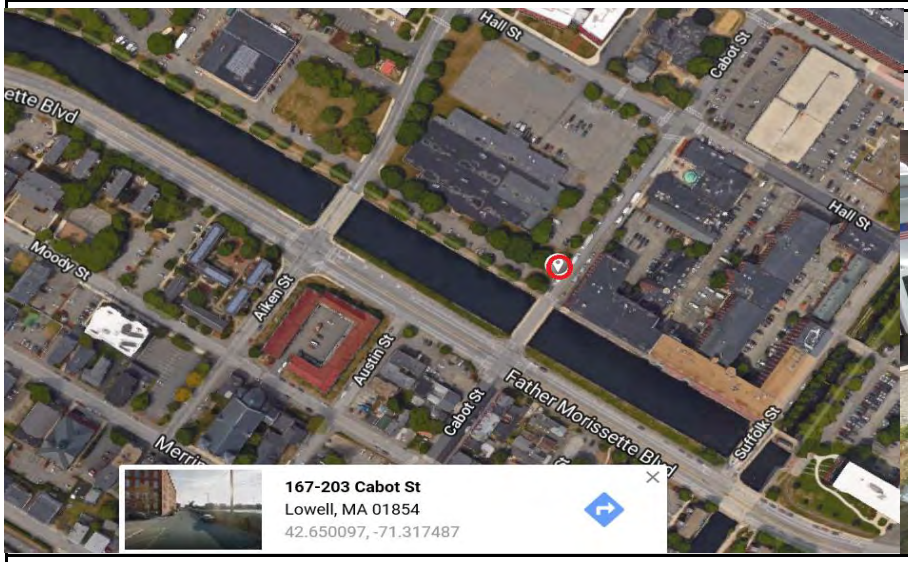
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB13

Site Address / Location:	Cabot st	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Site Located Between Soccer Field and	Pipe Size (H x W)	Pipe Shape
		39 x 39	Circular
		Manhole #	System Characteristics
		N/A	Commercial
		Access	Traffic
		Drive	None



ADS Project Name:	Lowell, MA
ADS Project Number:	

Installation Information

Installation Date:	Installation Type:
Monday, July 16, 2018	Doppler Standard Ring and Crank
Monitoring Location (Sensors):	Monitor Location:
Downstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
1:58:00 PM	39 x 39
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
4	35
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.25"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.75	N/A
Silt (in)	Silt Type
N/A	N/A

Hydraulic Comments:
Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
35	Common Trench
Manhole Material:	Manhole Condition:
Brick	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Cast Iron Pipe	Fair

Communication Information:

Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

S/N: 61878 I/P: 107.80.26.32

Lowell, MA

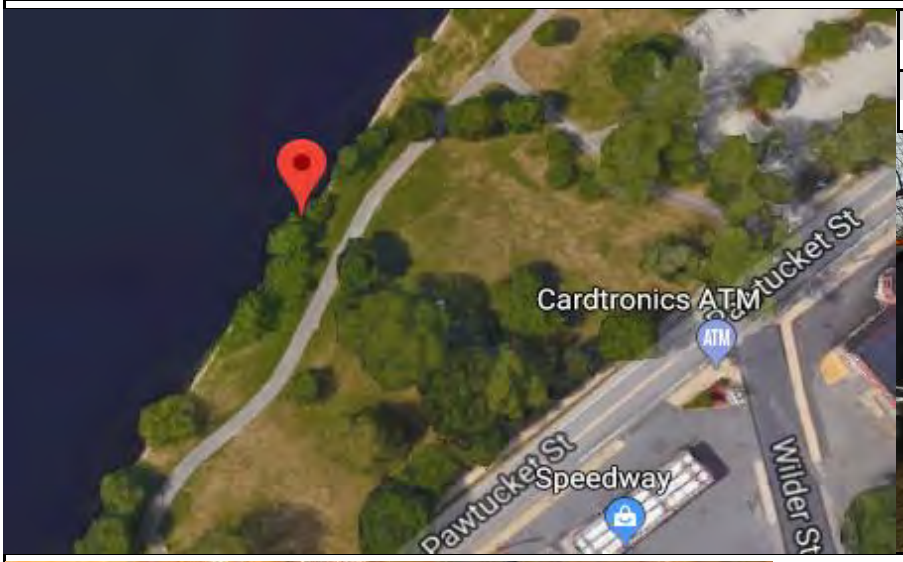
Flow Monitoring Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB1

Site Address / Location:	Off Of 579 Pawtucket Street, Lowell, MA (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive (On Walking Path)	Pipe Size (H x W)	Pipe Shape
		47.75" X 48.00"	Elliptical



Manhole #	System Characteristics
N/A	Other
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Wednesday, April 04, 2018	Doppler Standard Ring and Crank
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
11:35:00 AM	47.75" X 48.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
11.5	36.25"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.25	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Choppy	

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
16'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

*I.P. 107.80.27.188 *Serial Number: 30080

*Coordinates: N 42.64544 W 071.33543

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB2

Site Address / Location:	90 Varnum Ave (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		35.13" X 36.00"	Elliptical

Manhole #	System Characteristics
N/A	Industrial
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Monday, May 07, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
12:06:00 PM	35.13" X 36.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
10.5	24.63"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
4.13	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Choppy	

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
35'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
PVC	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

I.P. 166.219,174.64 *Sernial Number: 61900 *Coordinates: N 42.649013 W 071.333465

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB2alt

Site Address / Location:	90 Varnum Ave (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		35.13" X 36.00"	Elliptical

Manhole #	System Characteristics
N/A	Industrial
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Monday, May 7, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
12:06:00 PM	35.13" X 36.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
10.5	24.63"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
4.13	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:
Fast & Choppy

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
35'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
PVC	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

I.P. 166.219,174.64 *Serial Number: 61900 *Coordinates:
N 42.649013 W 071.333465

Boston, MA

Flow Monitoring
Site Installation Report

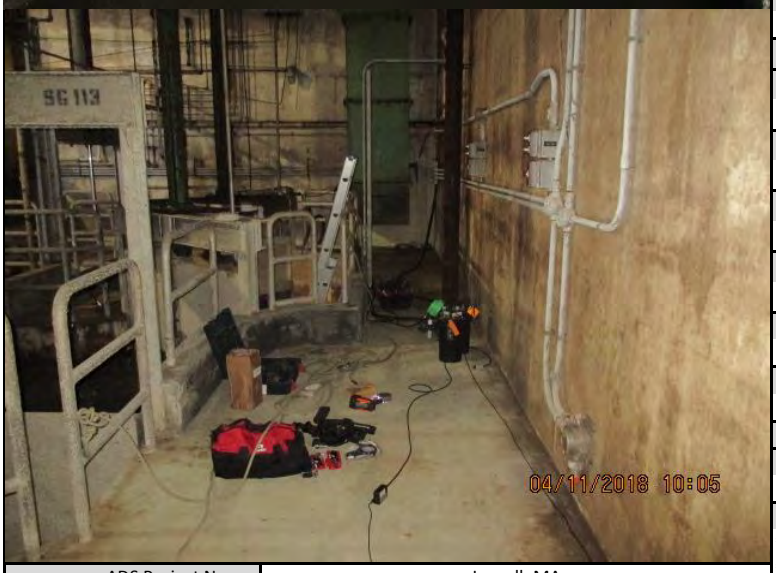
ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB3

Site Address / Location:	Martin Street Pump Station (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive/Located in Building	Pipe Size (H x W)	Pipe Shape
		96.00" X 95.63"	Elliptical

Manhole #	System Characteristics
N/A	Industrial
Access	Traffic
Drive	None



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Wednesday, April 11, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Building - Contact Client
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
9:59:00 AM	96.00" X 95.63"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
23.5	72.5
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.24	N/A
Silt (in)	Silt Type
2.5	Sandy

Hydraulic Comments:
Slow & Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
N/A	Pump Station
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
N/A	N/A
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Building

Additional Site Info. / Comments:

*I.P. 166.219.174.52 *Serial Number: 21765
*Coordinates: N 42.659311 W 071.319416 *Physical Offset: 7.5"

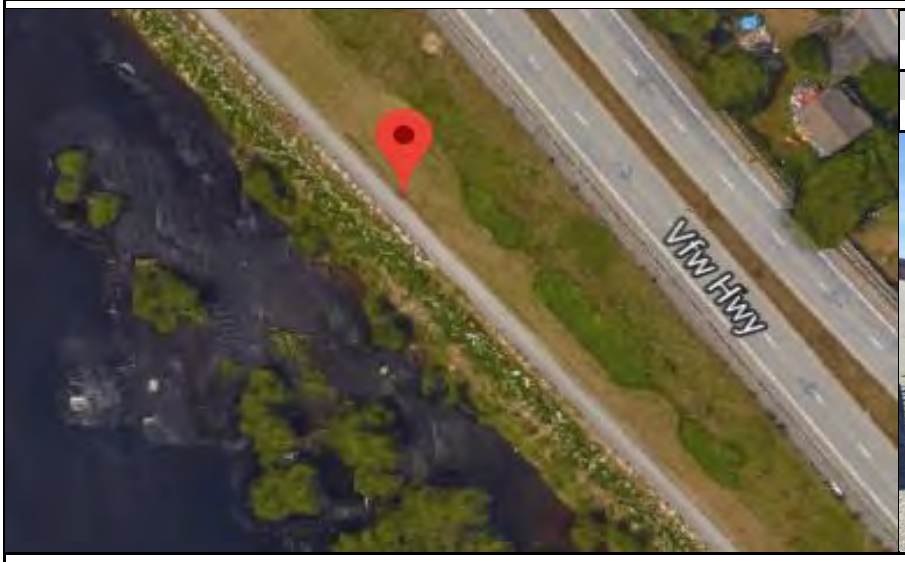
Lowell, MA

Flow Monitoring Site Installation Report

Site I.D.

Lowell_NB4

Site Address / Location:	Bike Path on the North Bank of the Merrimack River (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		96.25" X 96.5"	Circular



Manhole #	System Characteristics
N/A	Other
Access	Traffic
Drive	Light

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Monday, April 09, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
12:38:00 PM	96.25" X 96.5"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
25.00"	71.25"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.87"	N/A
Silt (in)	Silt Type
4.0"	Sandy
Hydraulic Comments:	
Slow & Smooth	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
10'	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.17.113 *Serial Number: 22038

*Coordinates: N 42654011 W 071.312720 *Physical Offset: 7.0"

Lowell, MA

Flow Monitoring
Site Installation Report

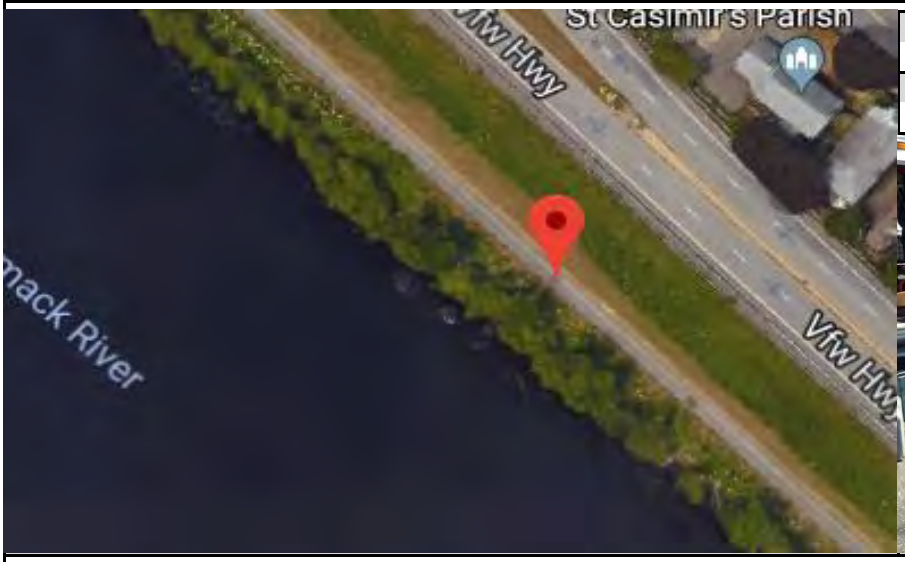
ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB5

Site Address / Location:	Bike Path on theNorth Bank of the Merrimack River (see Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		96.25" X 95.00"	Elliptical

Manhole #	System Characteristics
N/A	Other
Access	Traffic
Drive	None



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Monday, April 09, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
2:50:00 PM	96.25" X 95.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
22.13"	74.12"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.48	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:
Slow & Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
13'	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.16.135 *Serial Number: 21710
*Coordinates: N 42. 650952 W 071.308939

Lowell, MA

Flow Monitoring Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB6

Site Address / Location:	Hall Street East @ River Place (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		35.75" X 35.75"	Circular

Manhole #	System Characteristics
N/A	Other
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Tuesday, April 10, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
9:19:00 AM	35.75" X 35.75"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
12.5	23.25
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.19	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Smooth	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
16	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.25.235 * Serial Number: 21565 *Coordinates: N 42.646977 W 071.303591

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB6alt

Site Address / Location:	Hall Street East @ River Place (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		35.75" X 35.75"	Circular

Manhole #	System Characteristics
N/A	Other
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Tuesday, April 10, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
9:19:00 AM	35.75" X 35.75"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
12.5	23.25
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.19	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Smooth	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
16	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.25.235 * Serial Number: 21565
*Coordinates: N 42.646977 W 071.303591

Lowell, MA

Flow Monitoring Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB7

Site Address / Location:	Walking Path Located Off VFW Highway (See Coordinates)	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		96.00" X 96.00"	Circular

Manhole #	System Characteristics
N/A	Other
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.324

Installation Information

Installation Date:	Installation Type:
Friday, April 06, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
2:29:00 PM	96.00" X 96.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
22.00"	74.00"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.25"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.72	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Smooth	

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
17.00"	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

*I.P. 166.219.48.191 *Serial Number: 61891

*Coordinates: N 42.64555 W 071.292231

Lowell, MA

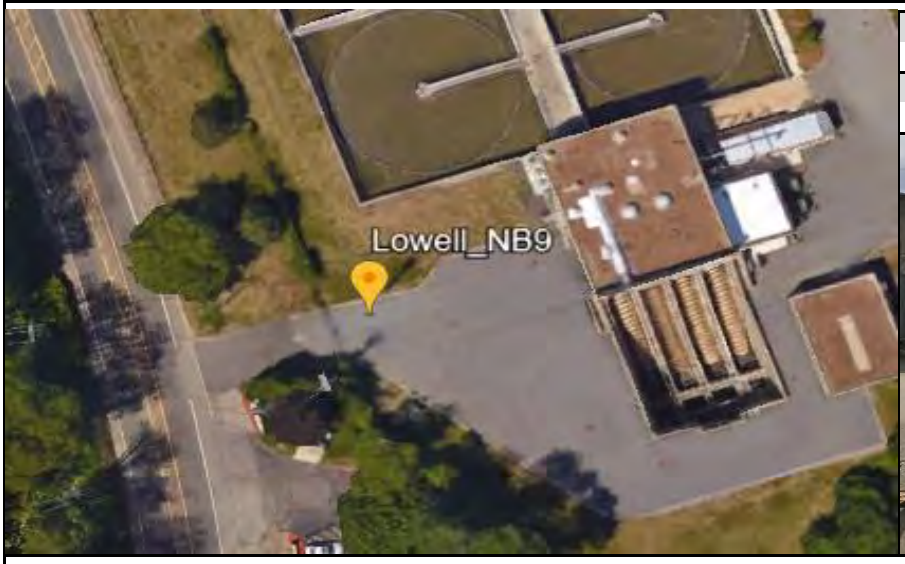
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_NB9

Site Address / Location:	Duck Island WWTP, Lowell, MA (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		18.00" X 18.00"	Circular



Manhole #	System Characteristics
N/A	Industrial
Access	Traffic
Drive	Light

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Wednesday, May 30, 2018	Doppler Standard Ring and Crank
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
9:27:00 AM	18.00" X 18.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
4.50"	13.50"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
0.65	N/A
Silt (in)	Silt Type
0	N?A
Hydraulic Comments:	
Slow & Slighty Turbulent due to Drop Connection	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
N/A	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
Yes, Inside	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 166.219.19.163 *Serial Number: 61816 *Coordinates: N 42.6471 W 071.2904

Lowell, MA 18

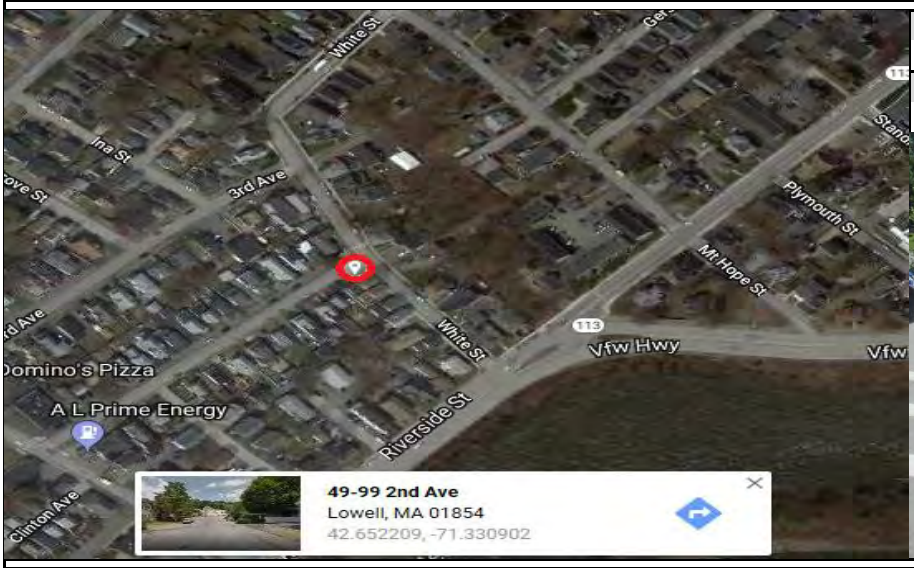
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

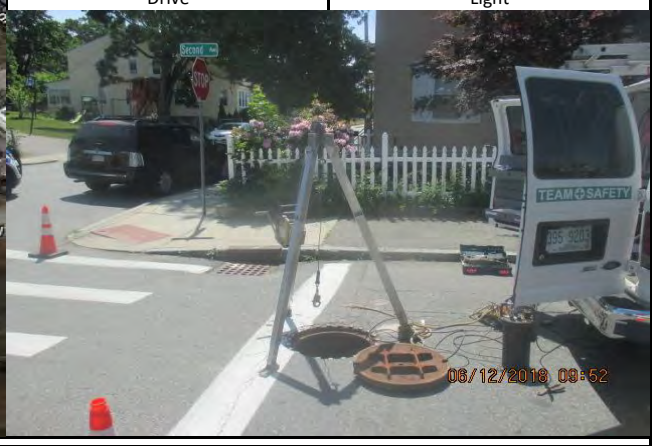
Site I.D.

Lowell_NB10

Site Address / Location:	Second Ave @ White St.	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:		Pipe Size (H x W)	Pipe Shape
		62 x 64	Elliptical



Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Drive	Light



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Tuesday, June 12, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
10:57:00 AM	62 x 64
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
6.38	55.62
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
0	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:
Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
13	CSO Flow Divider
Manhole Material:	Manhole Condition:
Brick	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Brick	Fair

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

S/N: 52269 I/P: 166.219.170.122

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

SB1

Site Address / Location:	End of Martin Luther King Jr. Way. Up path from Tilden CSO pump station (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	On bike path between Merrimack river and Western canal	Pipe Size (H x W)	Pipe Shape
		72 x 72	Circular

Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Drive	Light

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Thursday, April 5, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
1:50:00 AM	72 x 72
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
13.38	58.62
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.25"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.65	N/A
Silt (in)	Silt Type
4.5"	N/A

Hydraulic Comments:
Slow & Choppy

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
10	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Manhole Pick / Vent Hole

Additional Site Info. / Comments:

*I/P: 107.80.25.89 *S/N: 31090
*Coordinates: N 42.651541 W 071.312648 *Physical Offset: 8.13"

Lowell, MA

Flow Monitoring Site Installation Report

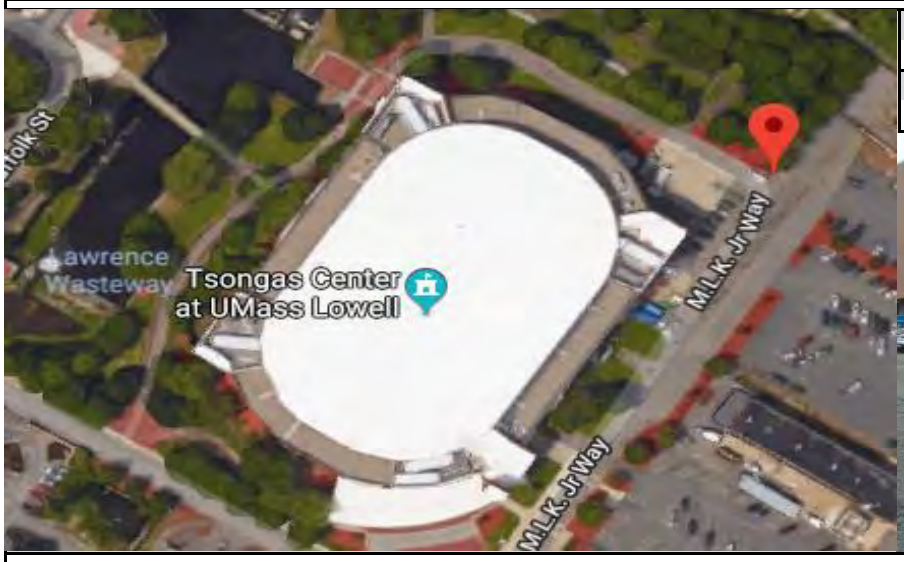
ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB2

Site Address / Location:	Behind Tsongas Arena, Lowell, MA (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		36.00" X 36.00"	Circular

Manhole #	System Characteristics
N/A	Commercial
Access	Traffic
Drive	Light



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Wednesday, April 04, 2018	Doppler Standard Ring and Crank
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
4:01:00 PM	36.00" X 36.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
8.5"	27.5"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.31	N/A
Silt (in)	Silt Type
2	Sandy
Hydraulic Comments:	
Fast & Choppy	

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
10'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
Yes, Inside	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P 166.219.48.326 *Serial Number:20867
*Coordinates: N 42.65062 W 071.31213 *Physical Offset: 2.0" *Sensor is on a wedge

Lowell, MA

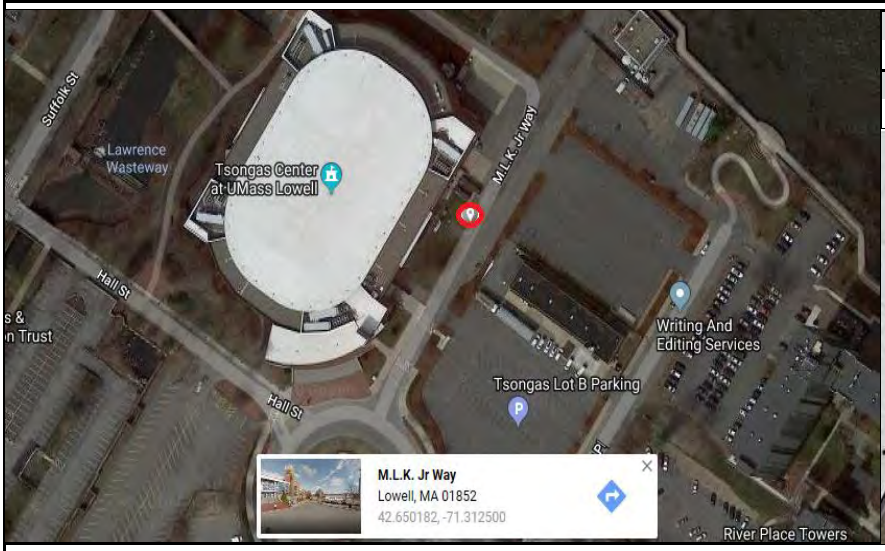
Flow Monitoring
Site Installation Report

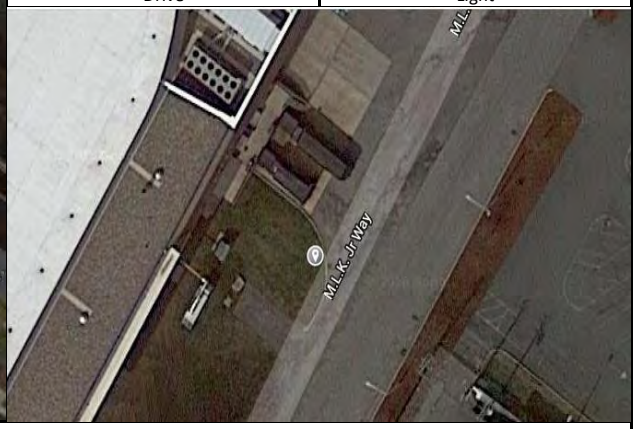
ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell SB2-A

Site Address / Location:	Martin Luther King JR. Way	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Manhole in grass	Pipe Size (H x W)	Pipe Shape
		36 x 36	Circular
		Manhole #	System Characteristics
		N/A	Commercial
		Access	Traffic
		Drive	Light





Installation Information	
Installation Date:	Installation Type:
Wednesday, May 23, 2018	Doppler Standard Ring and Crank
Monitoring Location (Sensors):	Monitor Location:
Downstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
5:06:00 PM	36 x 36
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
3.75	32.25
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.50"
Peak Velocity (fps)	Velocity Sensor Offset (in)
7.5	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast, Choppy	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
10	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Concrete	Fair
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete
Additional Site Info. / Comments:	
S/N: 20867 I/P: 166.219.48.195	

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Lowell, MA

Flow Monitoring
Site Installation Report

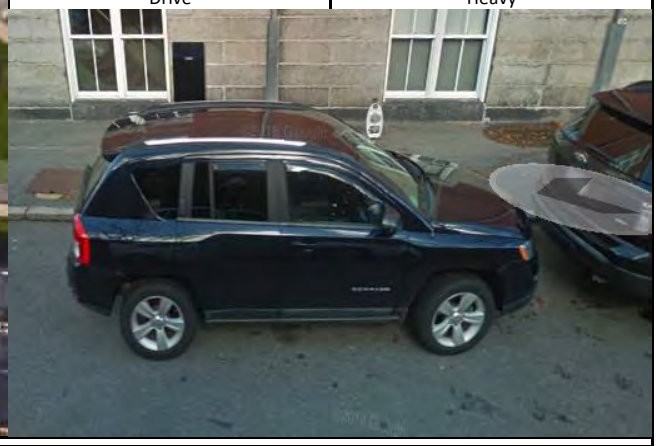
ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB3

Site Address / Location:	41 Hurd Street, Lowell, MA (In front of Lowell District Court)	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		47.00" X 32.00"	Elliptical

Manhole #	System Characteristics
N/A	Commercial
Access	Traffic
Drive	Heavy



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Friday, April 6, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
9:28:00 AM	47.00" X 32.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
3.75	43.25"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
4.97	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:
Fast & Turbulent

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
15'	Common Trench
Manhole Material:	Manhole Condition:
Brick	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Brick	Fair

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

I.P. 166.219.18.196 *Serial Number: 52533
*Coordinates: N 42.642849 W 071.307209 *Police Detail Needed

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB4

Site Address / Location:	151 Warren Street, Lowell,MA	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		90.00" X 90.00"	Circular

Manhole #	System Characteristics
N/A	Commercial
Access	Traffic
Drive	Heavy

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Friday, April 06, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
11:29:00 AM	90.00" X 90.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
15.50"	74.50"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
4.19	
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Turbulent	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
26'	CSO Flow Divider
Manhole Material:	Manhole Condition:
Brick	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Brick	Fair
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 166.219.48.218 *Serial Number: 60809
*Coordinates: N 42.642056 W 071.304526

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB5

Site Address / Location:	East Merrimack Street In Front of Lowell Auditorium (See coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		72.00" X 72.00"	Circular

Manhole #	System Characteristics
N/A	Commercial
Access	Traffic
Drive	Medium

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Wednesday, April 11, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
1:45:00 PM	72.00" X 72.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
12.75"	59.25"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
5.08	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:
Fast & Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
15'	Common Trench
Manhole Material:	Manhole Condition:
RCP	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vault	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
RCP	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 166.219.170.138 *Serial Number: 30460 *Coordinates: N 42.644913 W 071.305023 *MH has different platform levels

Lowell, MA

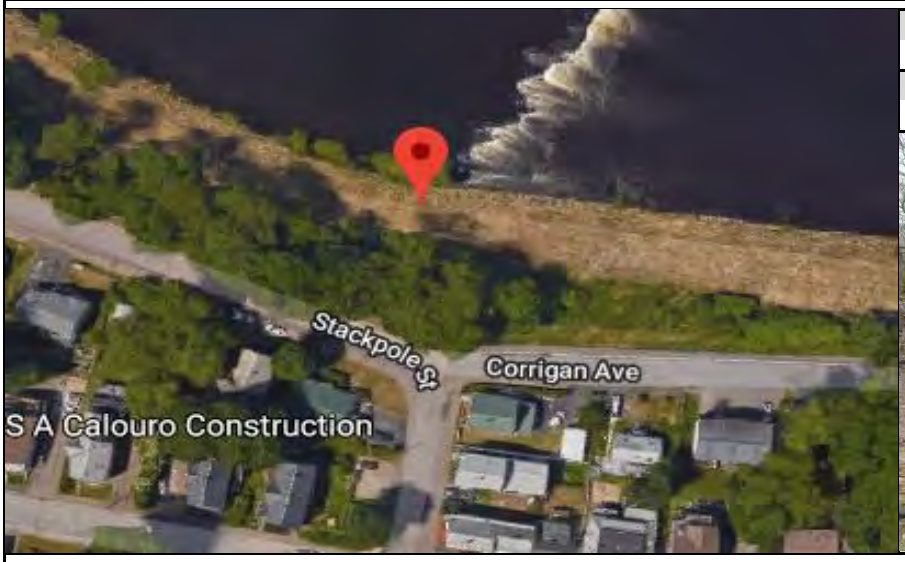
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB6

Site Address / Location:	Stackhole Street @ Corrigan Ave (Over the Bank, See Coordinates)	Monitor Series	Location Type
			Temporary
Site Access:	Drive/Walk	Pipe Size (H x W)	Pipe Shape
		120.00" X 120.00"	Circular



Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Walk (Residential)	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Tuesday, April 10, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
2:14:00 PM	120.00" X 120.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
23.50"	96.50"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.9	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Smooth	

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
16.00'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

*I.P. 107.80.26.42 *Serial Number: 22085
*Coordinates: N 42.644013 W 071.293874

Lowell, MA

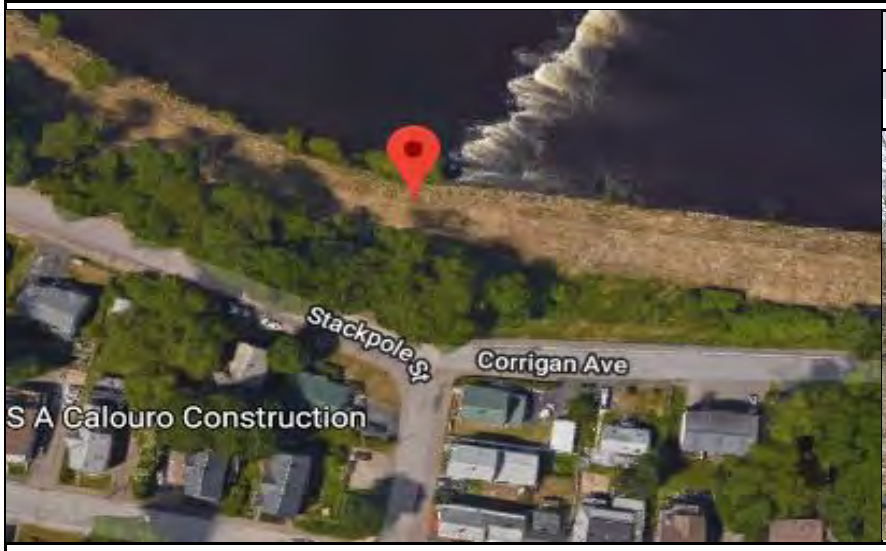
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB6

Site Address / Location:	Stackhole Street @ Corrigan Ave (Over the Bank, See Coordinates)	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive/Walk	Pipe Size (H x W)	Pipe Shape
		120.00" X 120.00"	Circular



Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Walk (Residential)	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Wednesday, May 23, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Downstream 10-15 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
3:45:00 PM	120.00" X 120.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
21.75	98.25
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.25"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.75	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Smooth	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
16.00'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

*I.P. 107.80.26.42 *Serial Number: 22085
*Coordinates: N 42.644013 W 071.293874

Lowell, MA

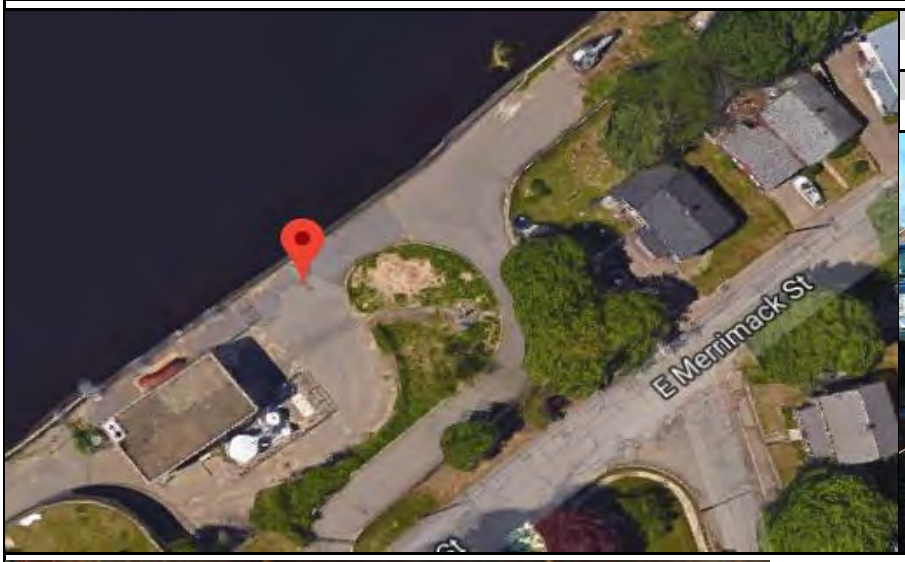
Flow Monitoring Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB7

Site Address / Location:	Merrimack CSO Station off Merrimack Street, Lowell, MA (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		84.00" X 84.00"	Circular



Manhole #	System Characteristics
N/A	Industrial
Access	Traffic
Drive	Light

ADS Project Name:	Lowell,MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Thursday, April 05, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
4:24:00 PM	84.00" X 84.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
8.00"	76.00"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
3.3	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Smooth	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
13'	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

*I.P. 10.4.2.90 *Serial Number: 40461

*Coordinates: N 42.645360 W 071.288630

Lowell, MA

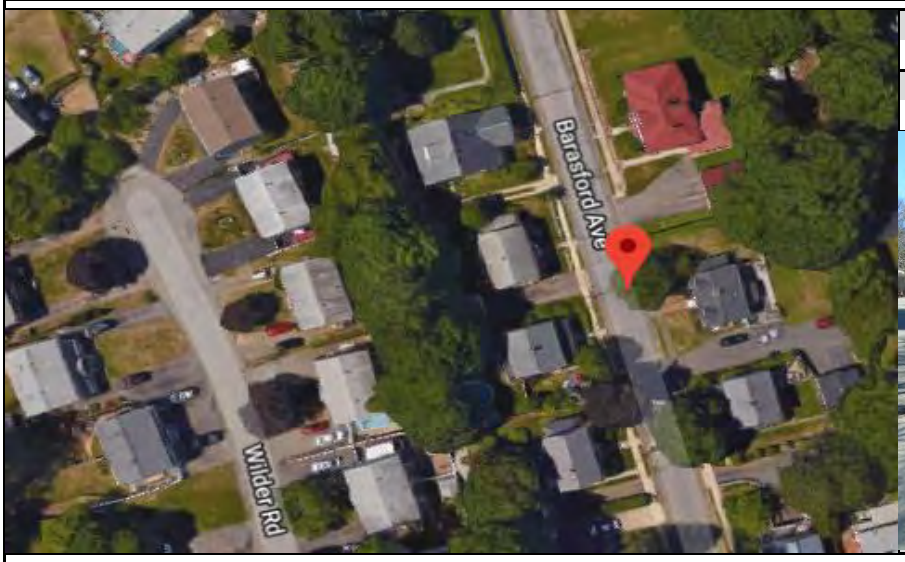
Flow Monitoring Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB8

Site Address / Location:	15 Barasford Ave, Lowell, MA	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		60.00" X 60.00"	Circular



Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Drive	Medium

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Thursday, April 05, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
11:12:00 AM	60.00" X 60.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
4.88	55.12
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
5.5	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:

Fast & Choppy

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
19'	Common Trench
Manhole Material:	Manhole Condition:
Brick	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Brick	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.27.162 *Serial Number: 20265 *Coordinates: N 42.644168 W 071.287633

Lowell, MA

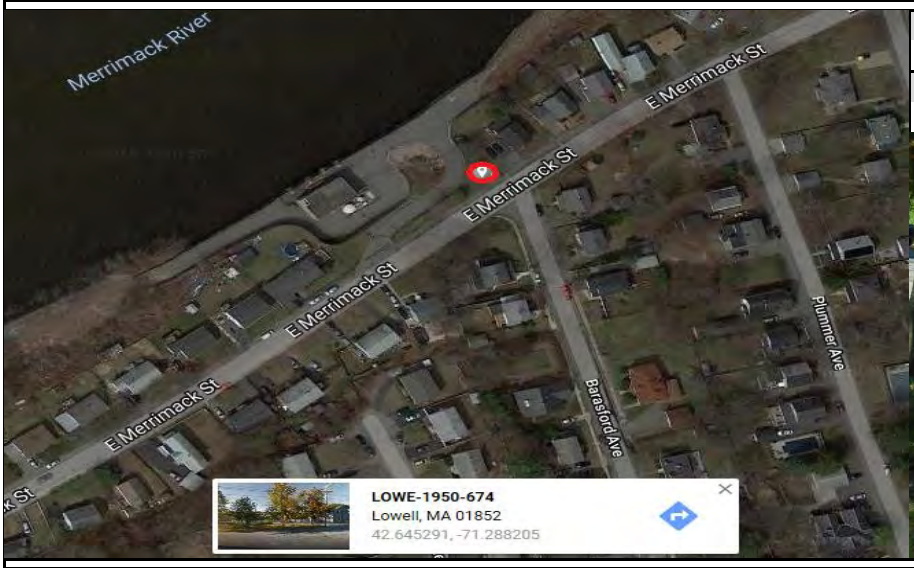
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

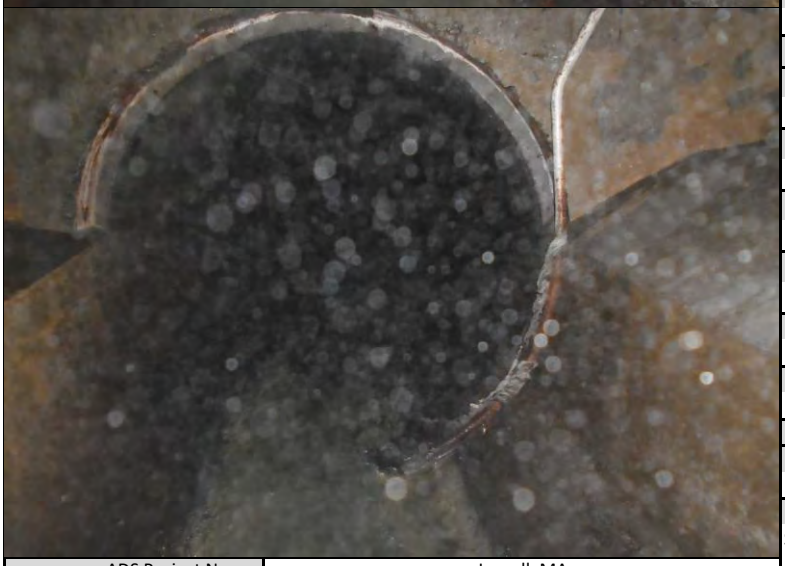
Site I.D.

Lowell_SB8-A

Site Address / Location:	East Merrimack St @ Barasford Ave	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Site in grass	Pipe Size (H x W)	Pipe Shape
		61.75 x 60.5	Elliptical



Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Drive	Medium



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Wednesday, May 23, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4), Smart Depth (CS5)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
	61.75 x 60.5
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
8.75	53
Downlooker Physical Offset (in)	Measurement Confidence (in)
2	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.9	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Smooth	

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
14	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Poor
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Brick	Poor

Communication Information:

Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

S/N: 52592 I/P: 107.80.27.162

Lowell, MA

Flow Monitoring Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB9

Site Address / Location:	21 George Street, Lowell, MA (See Coordinates)	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive (Police Detail Required)	Pipe Size (H x W)	Pipe Shape
		29.75" X 20.88"	Elliptical

Manhole #	System Characteristics
N/A	Commercial
Access	Traffic
Drive	Medium

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Monday, May 7, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
2:11:00 PM	29.75" X 20.88"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
4.50"	25.25"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
1.12	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:

Slow & Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
20'	Common Trench
Manhole Material:	Manhole Condition:
Brick	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Brick	Fair

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.16.134 *Serial Number: 61983 *Coordinates: N 42.642336 W 071.306290 Physical Offset: 2.13

Lowell, MA

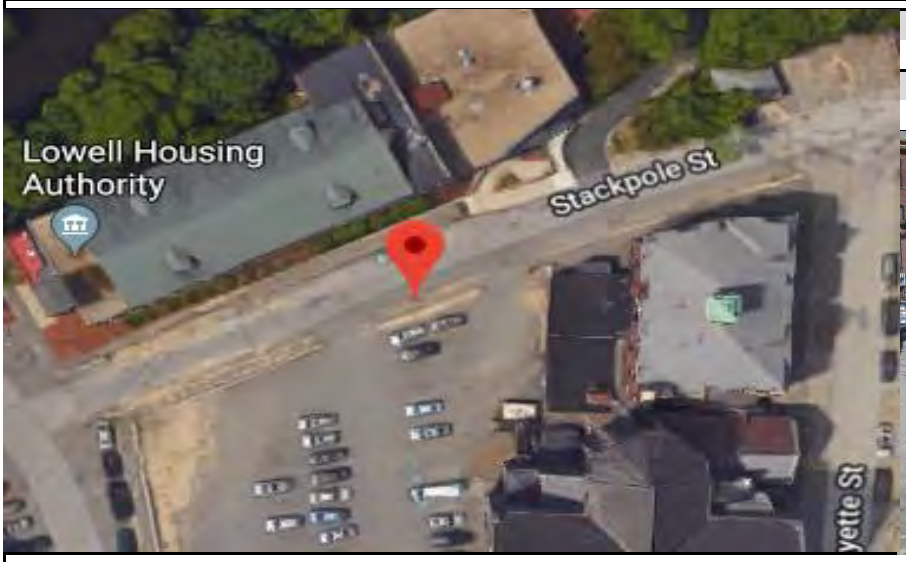
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

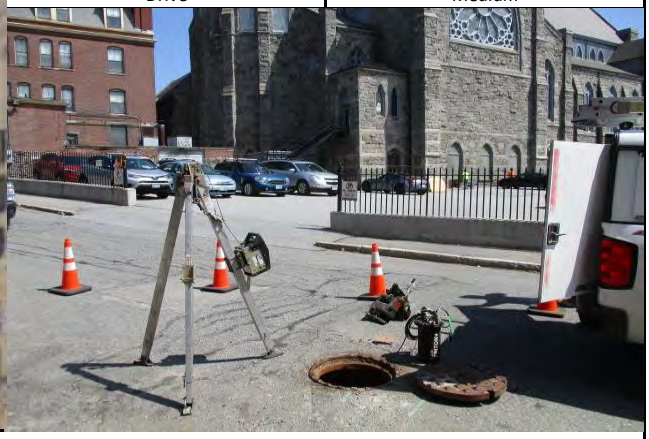
Site I.D.

Lowell_SB10

Site Address / Location:	Stackpole Road Near Church (See Coordinates)	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		24.00" X 24.00"	Circular



Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Drive	Medium



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Tuesday, May 08, 2018	Doppler Standard Ring and Crank
Monitoring Location (Sensors):	Monitor Location:
Upstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
2:12:00 PM	24.00" X 24.00"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
1.25"	22.75"
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
3.93	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Choppy	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
12'	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Offset
Active Drop Connections	Air Quality:
No	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.23.10 *Serial Number: 61818
*Coordinates: N 42.6457 W 071.3032 *Reverse Install

Lowell, MA

Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB11

Site Address / Location:	Hall Street East @ River Place (See Coordinates)	Monitor Series	Location Type
		Triton	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		35.75" X 35.75"	Circular

Manhole #	System Characteristics
SMH-003247	Other
Access	Traffic
Drive	None

ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information	
Installation Date:	Installation Type:
Tuesday, April 10, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 - 15 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
9:19:00 AM	35.75" X 35.75"
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
12.5	23.25
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.38"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.19	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Fast & Smooth	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
16	CSO Flow Divider
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Unbolted	Normal
Active Drop Connections	Air Quality:
	Safe To Enter
Pipe Material	Pipe Condition:
Concrete	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

*I.P. 107.80.25.235 * Serial Number: 21565
*Coordinates: N 42.646977 W 071.303591

Lowell, MA

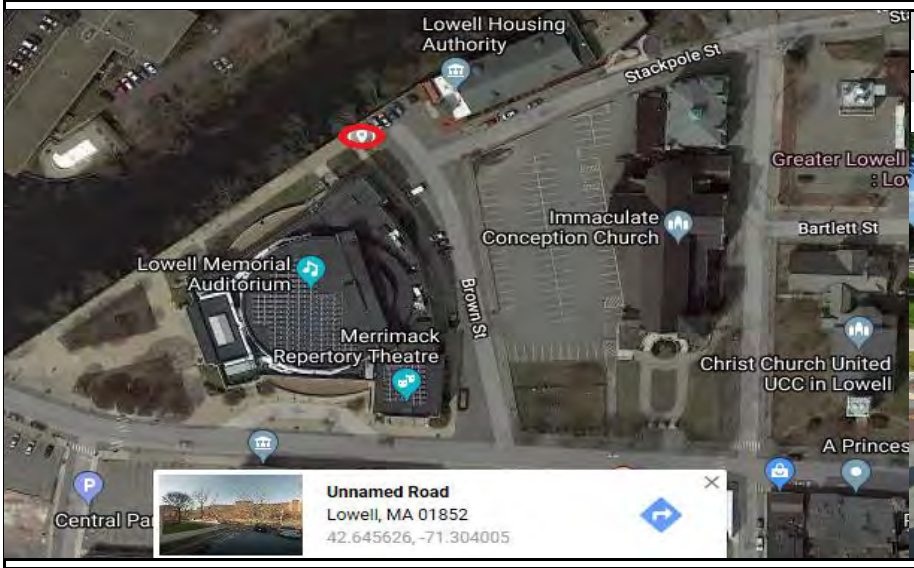
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

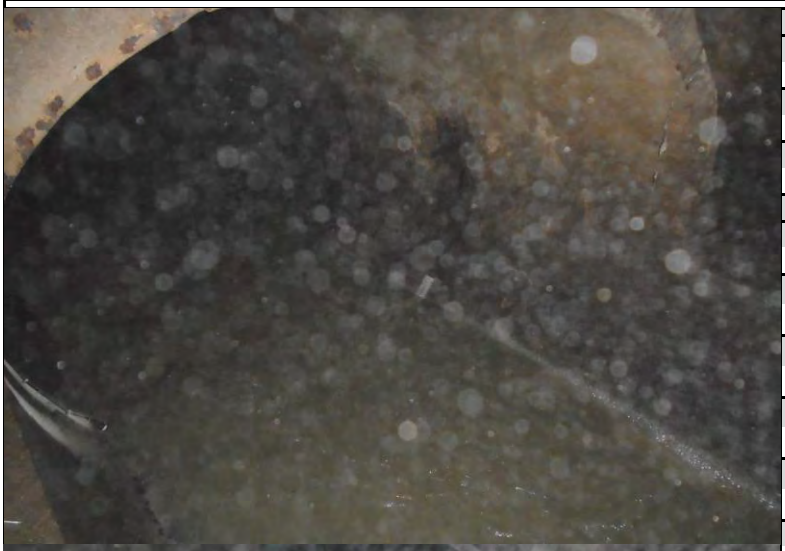
Site I.D.

Lowell_SB12

Site Address / Location:	Stackpole St. @ Brown St.	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Drive	Pipe Size (H x W)	Pipe Shape
		96 x 96	Circular



Manhole #	System Characteristics
N/A	Residential
Access	**Traffic**
Drive	Light



ADS Project Name:	Lowell, MA
ADS Project Number:	32565.11.325

Installation Information

Installation Date:	Installation Type:
Wednesday, May 23, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Upstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
10:07:00 AM	96 x 96
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
18.25	77.75
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.25"
Peak Velocity (fps)	Velocity Sensor Offset (in)
3.63	N/A
Silt (in)	Silt Type
0	N/A

Hydraulic Comments:
Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
15	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Concrete	Good

Communication Information:

Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete

Additional Site Info. / Comments:

S/N: 52335 I/P: 166.219.172.128

Lowell, MA

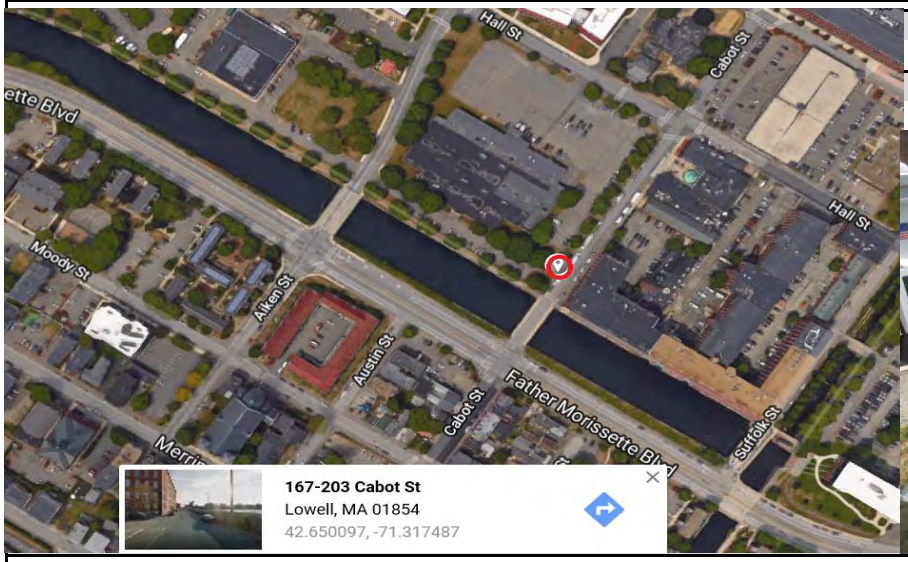
Flow Monitoring
Site Installation Report

ADS ENVIRONMENTAL SERVICES®

Site I.D.

Lowell_SB13

Site Address / Location:	Cabot st	Monitor Series	Location Type
		TRITON+	Temporary
Site Access:	Site Located Between Soccer Field and	Pipe Size (H x W)	Pipe Shape
		39 x 39	Circular
		Manhole #	System Characteristics
		N/A	Commercial
		Access	Traffic
		Drive	None



ADS Project Name:	Lowell, MA
ADS Project Number:	

Installation Information

Installation Date:	Installation Type:
Monday, July 16, 2018	Doppler Standard Ring and Crank
Monitoring Location (Sensors):	Monitor Location:
Downstream 5-10 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi

Installation Confirmation:

Confirmation Time:	Pipe Size (HxW)
1:58:00 PM	39 x 39
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
4	35
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.25"
Peak Velocity (fps)	Velocity Sensor Offset (in)
2.75	N/A
Silt (in)	Silt Type
N/A	N/A

Hydraulic Comments:
Smooth

Manhole / Pipe Information:

Manhole Depth (Approx. FT):	Manhole Configuration
35	Common Trench
Manhole Material:	Manhole Condition:
Brick	Fair
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Vented	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Cast Iron Pipe	Fair

Communication Information:

Communication Type	Antenna Location
Wireless	Grass (buried)

Additional Site Info. / Comments:

S/N: 61878 I/P: 107.80.26.32

Hazen

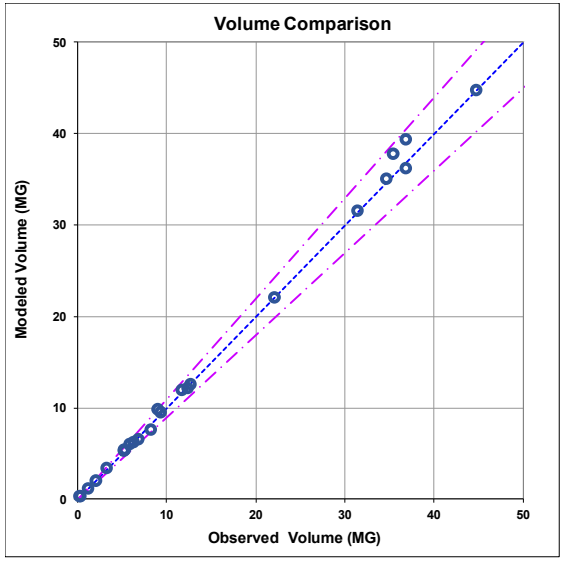
APPENDIX D

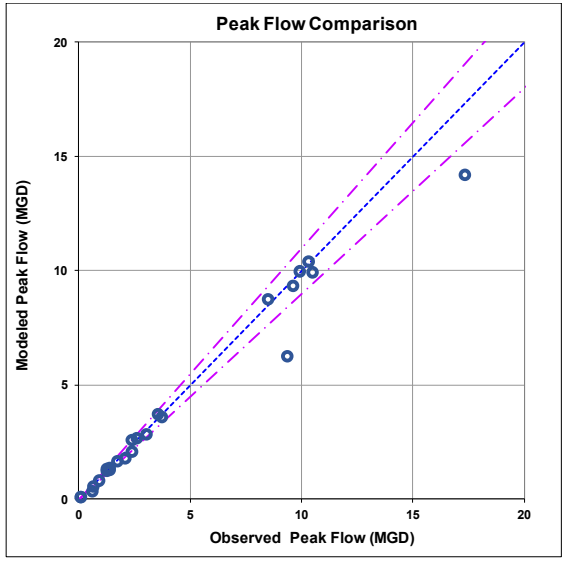
Hazen

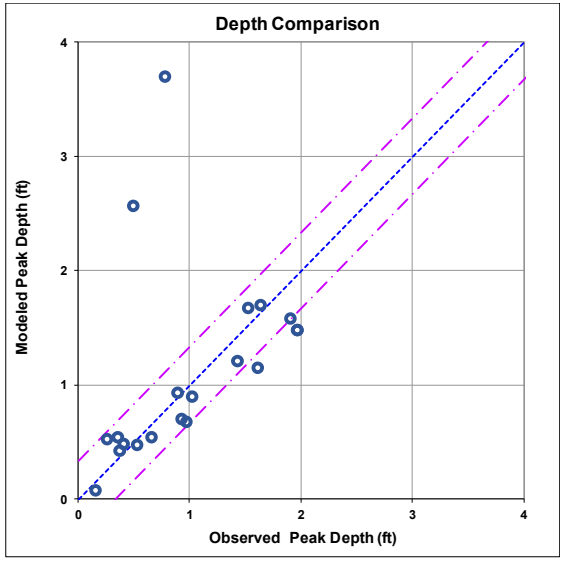
Lowell DWF Calibration Results

Hazen

Statistical Plots for All Meters

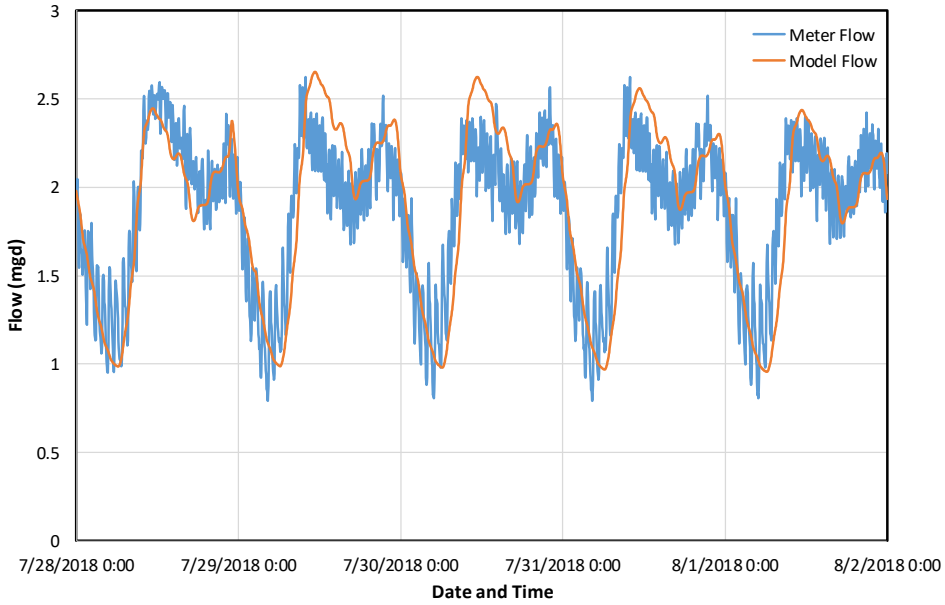


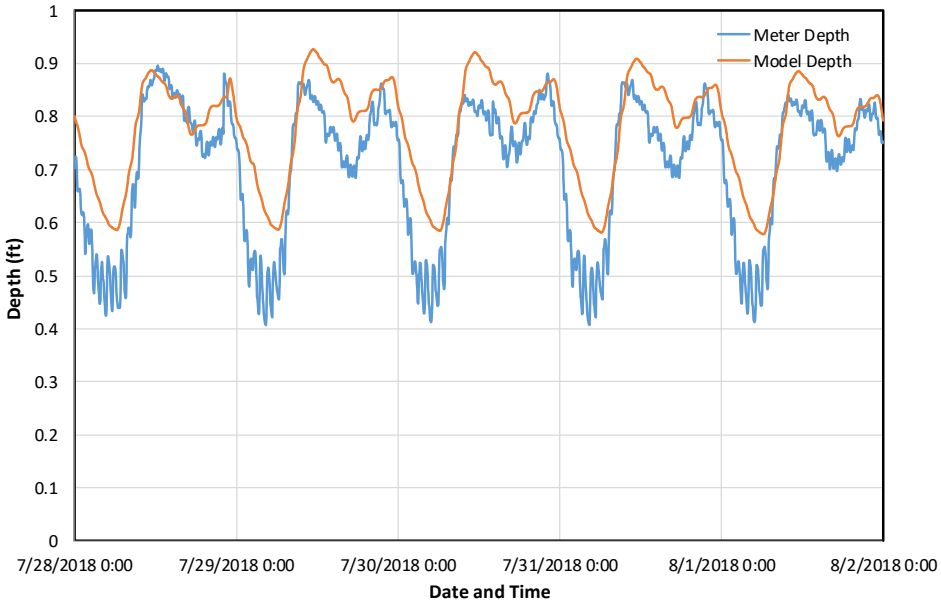




Hazen

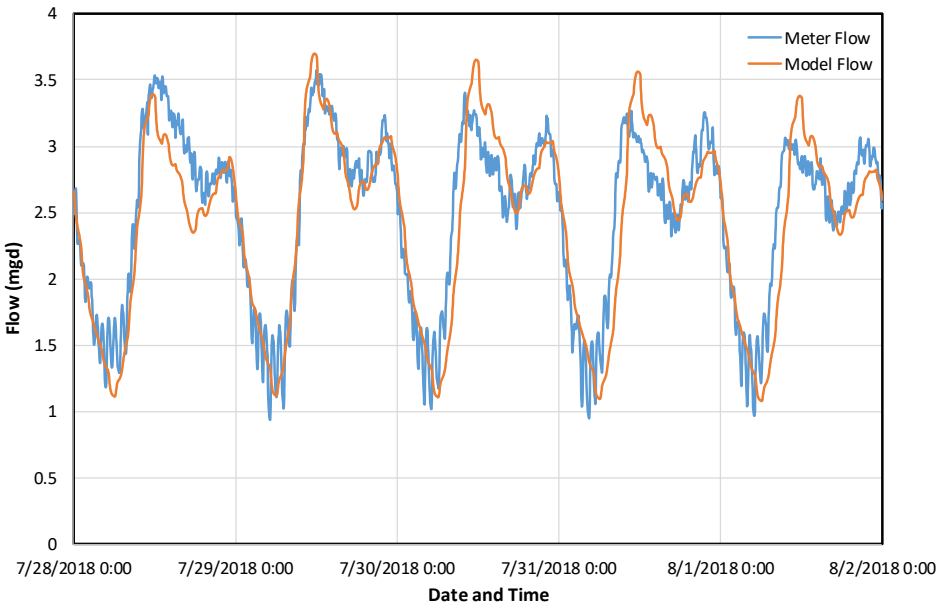
Meter NB1 Dry Weather Calibration

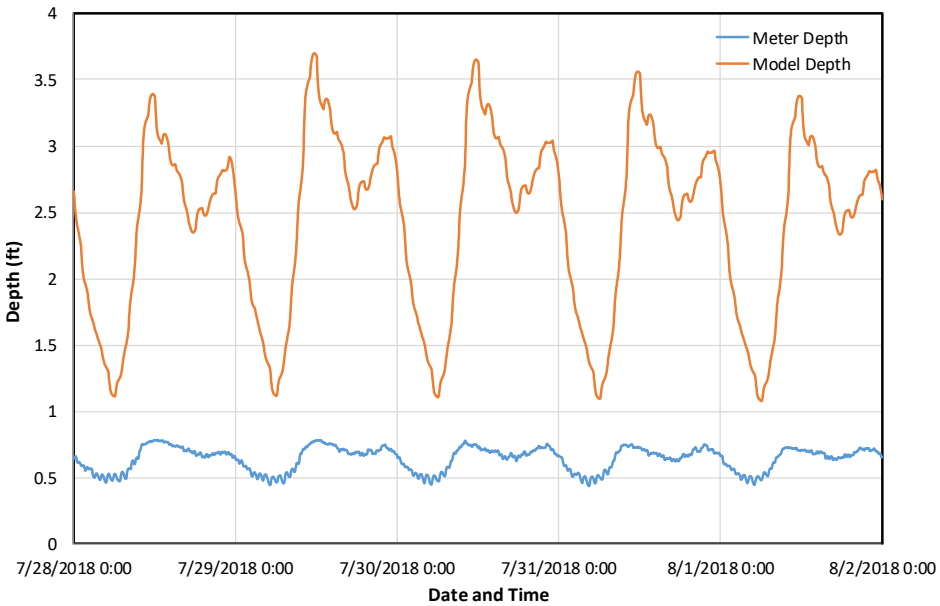




Hazen

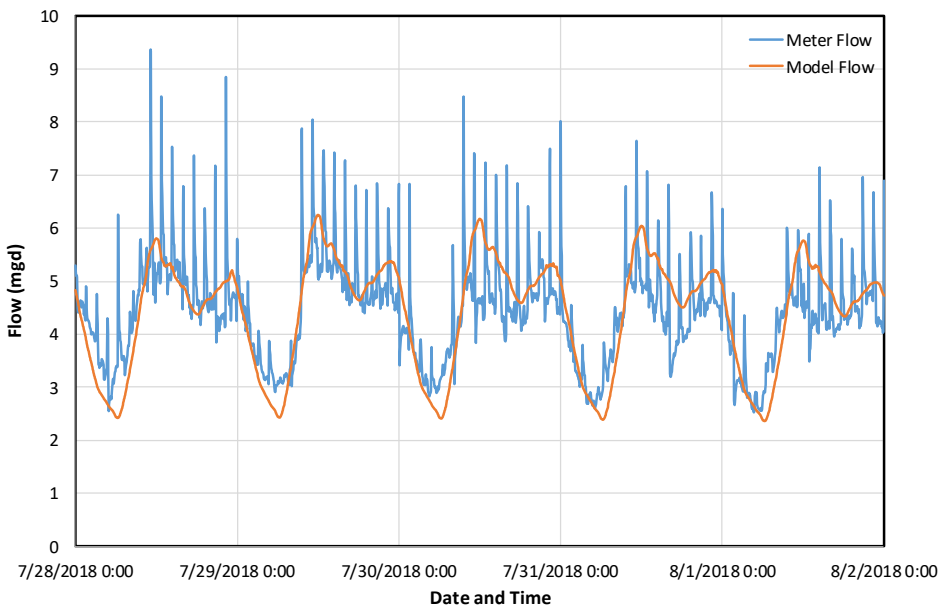
Meter NB2A Dry Weather Calibration

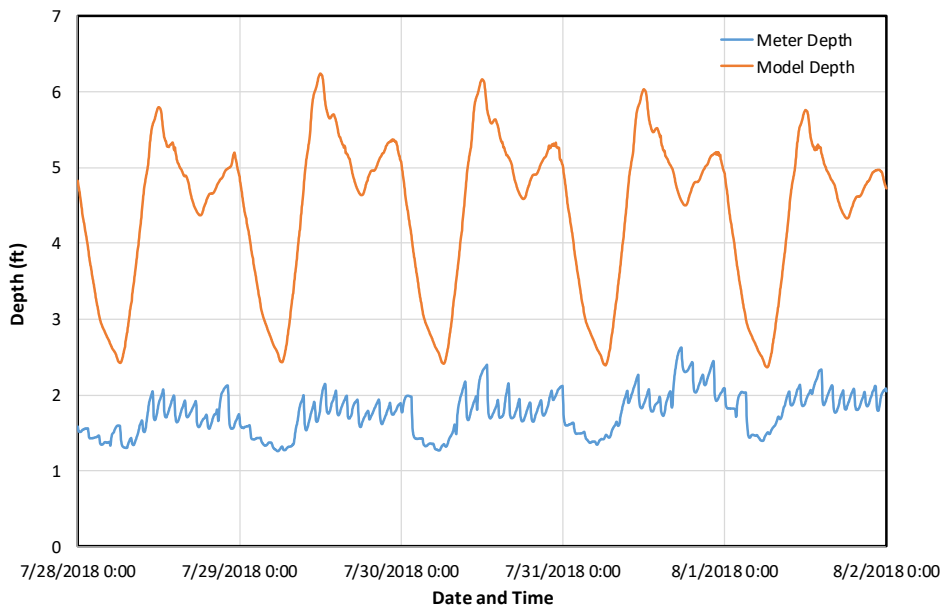




Hazen

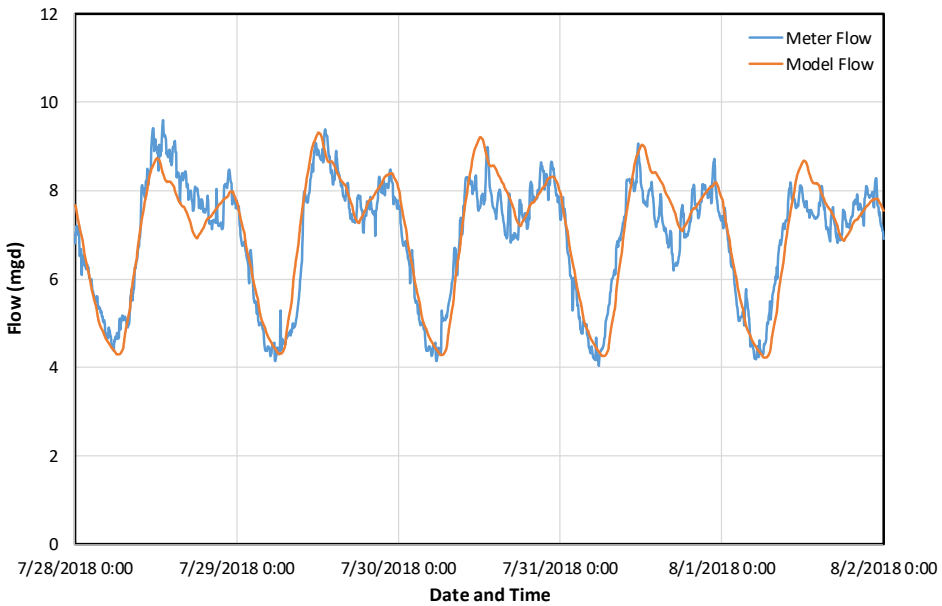
Meter NB3 Dry Weather Calibration

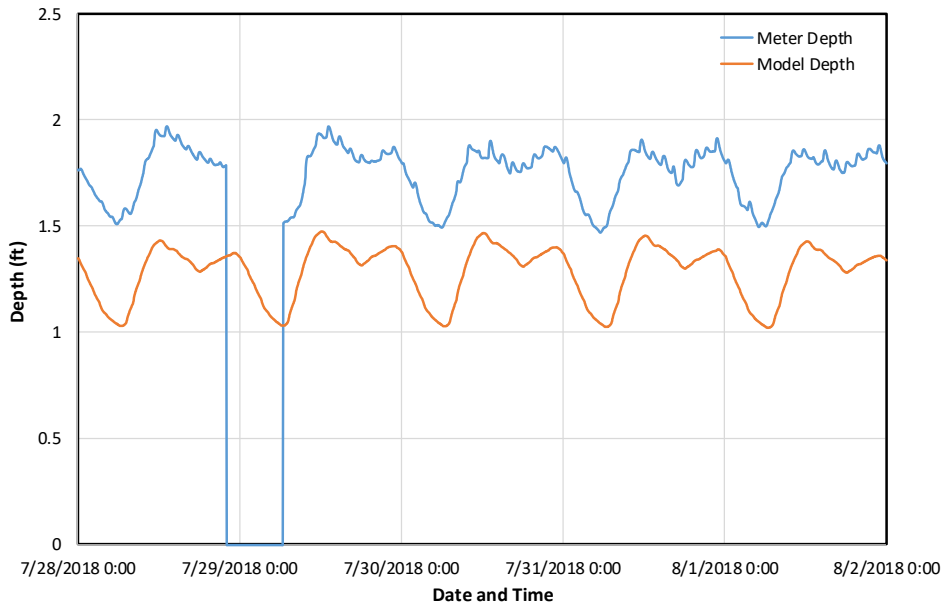




Hazen

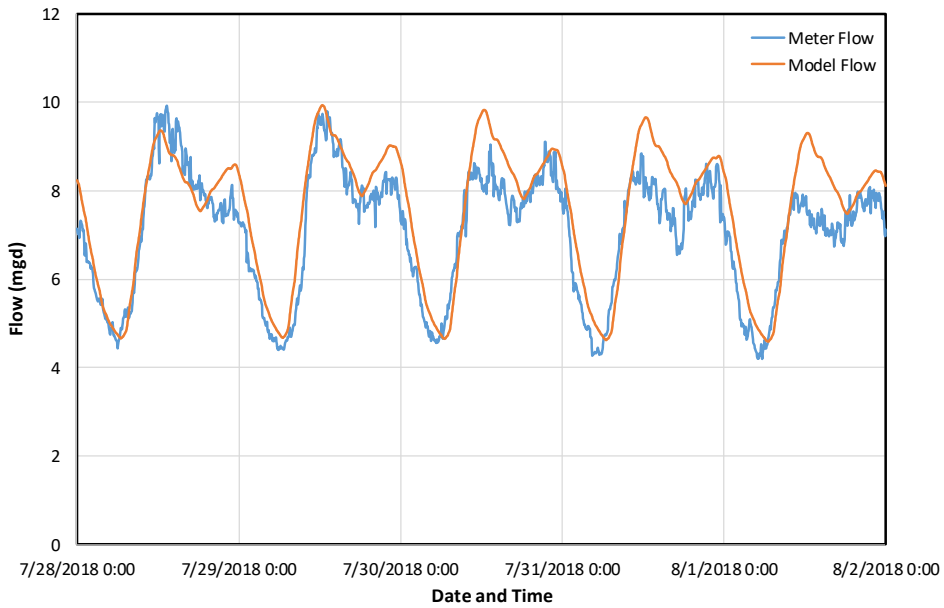
Meter NB4 Dry Weather Calibration

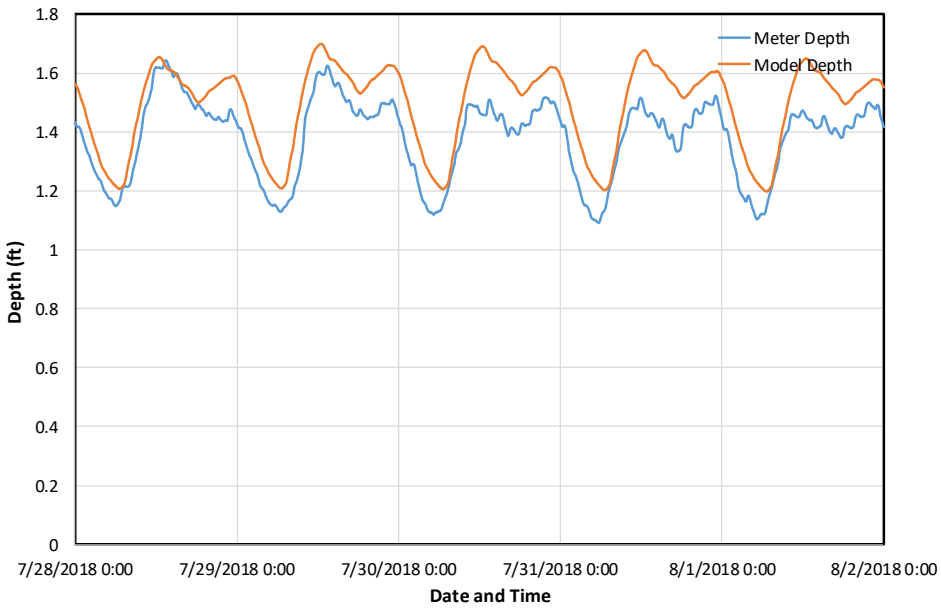




Hazen

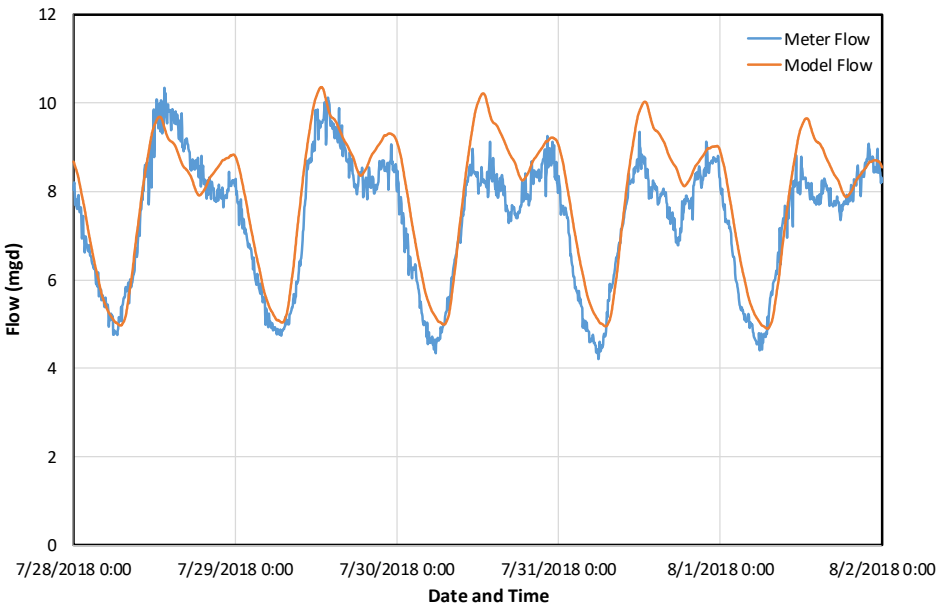
Meter NB5 Dry Weather Calibration

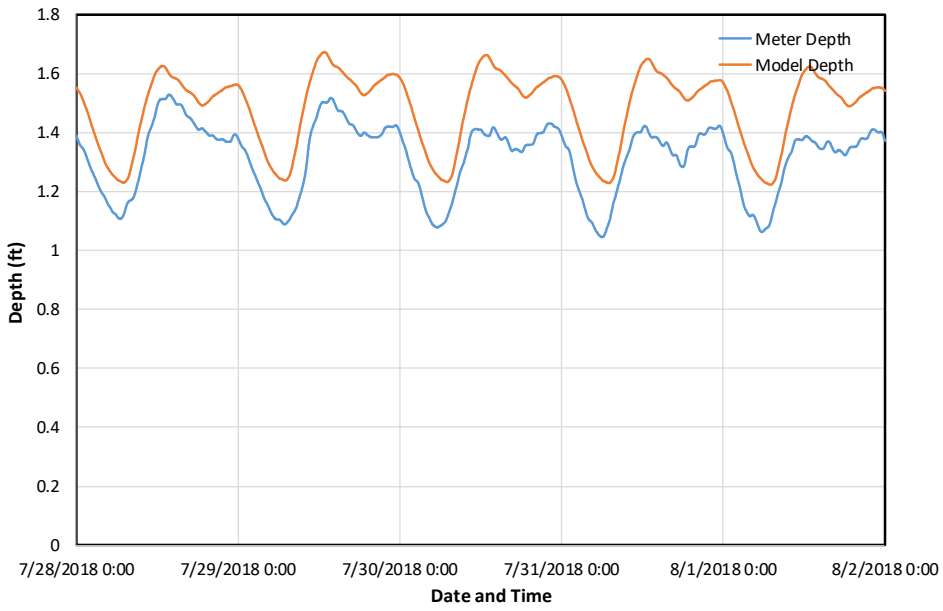




Hazen

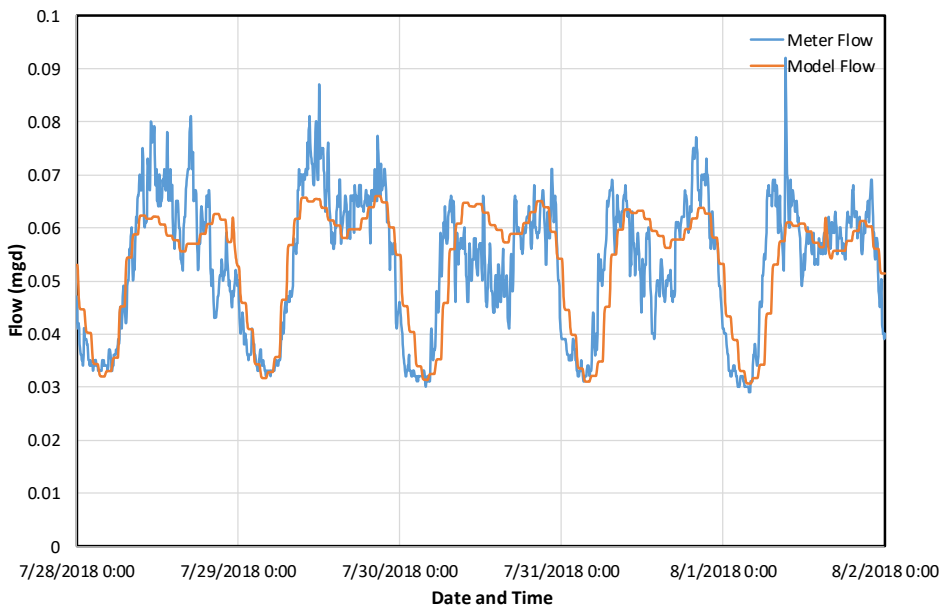
Meter NB7 Dry Weather Calibration

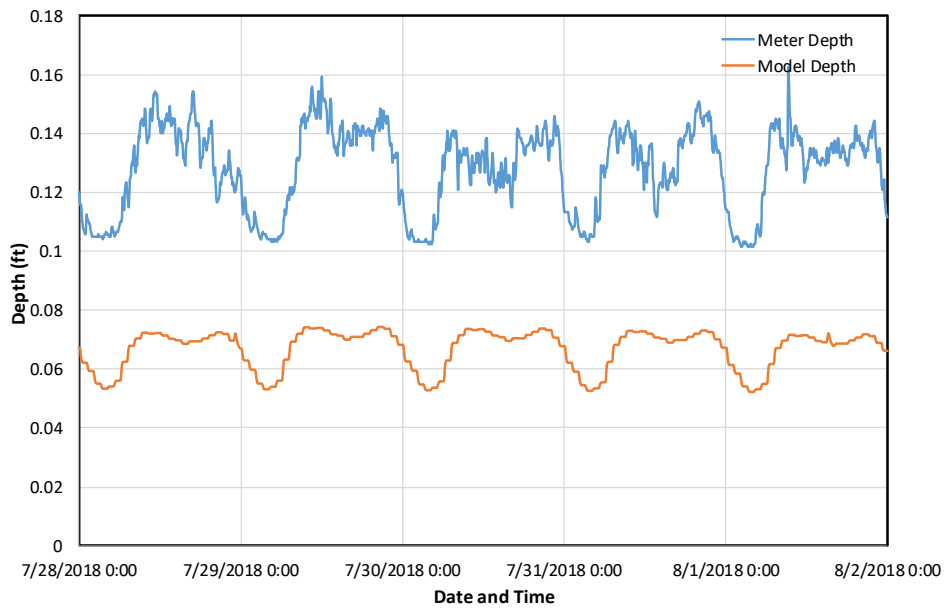




Hazen

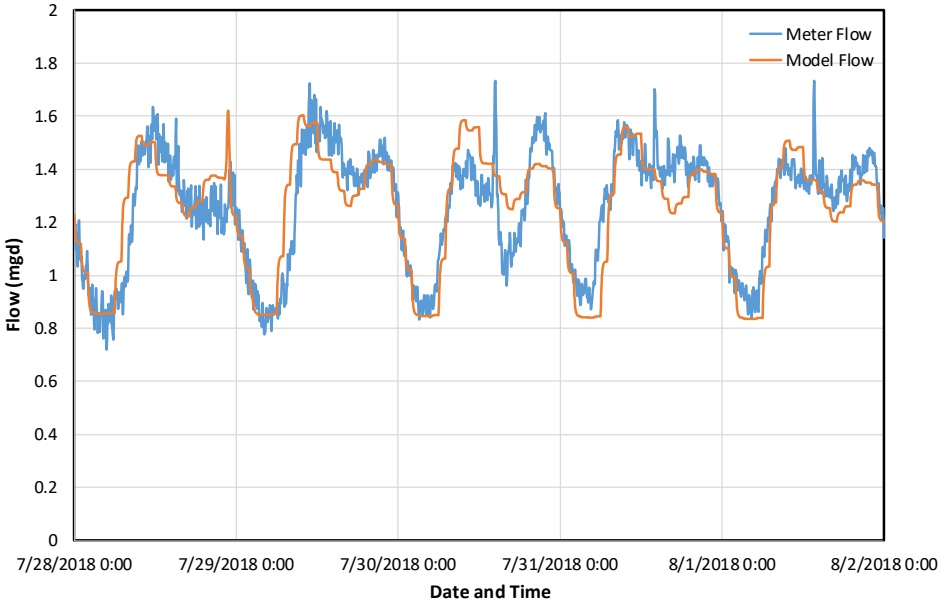
Meter NB9 Dry Weather Calibration

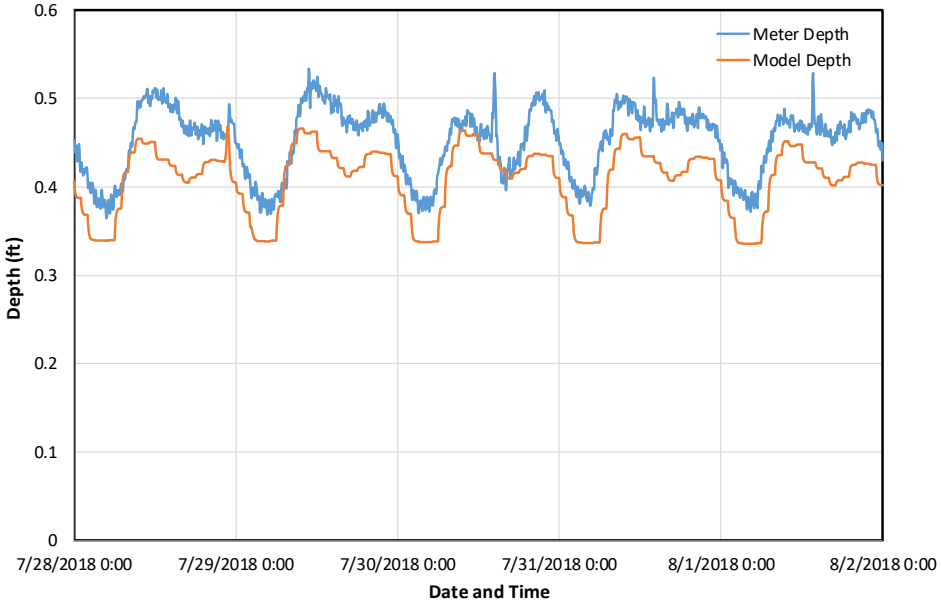




Hazen

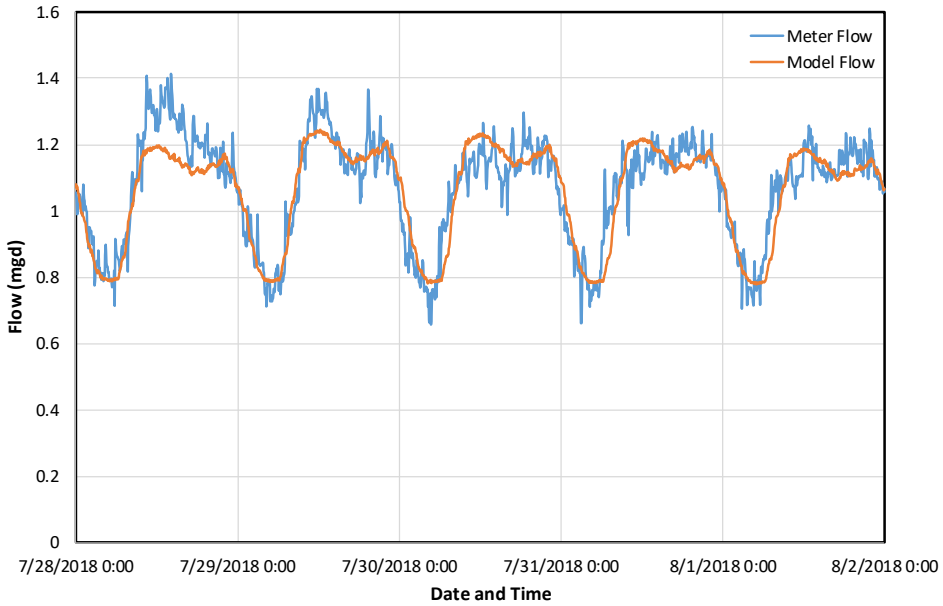
Meter NB10 Dry Weather Calibration

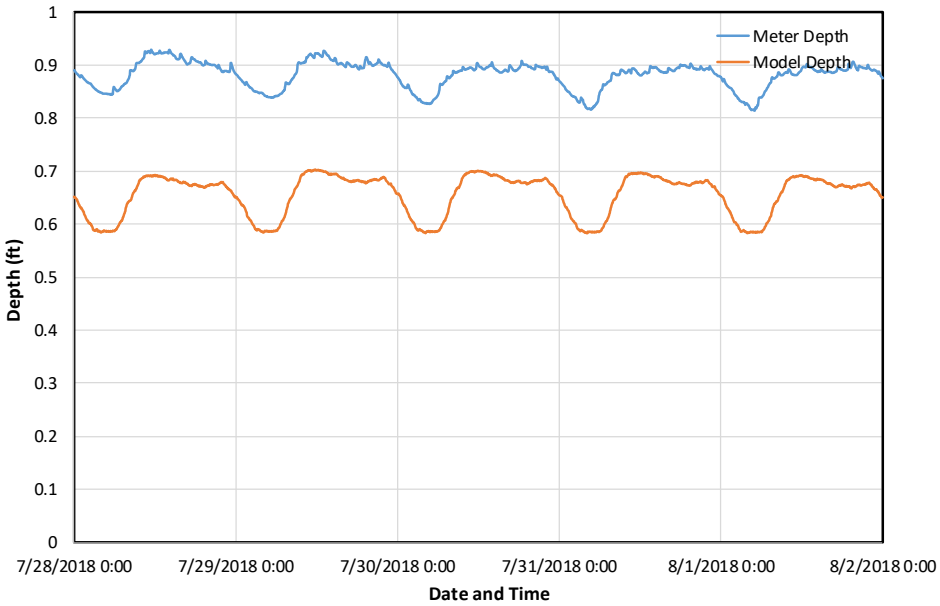




Hazen

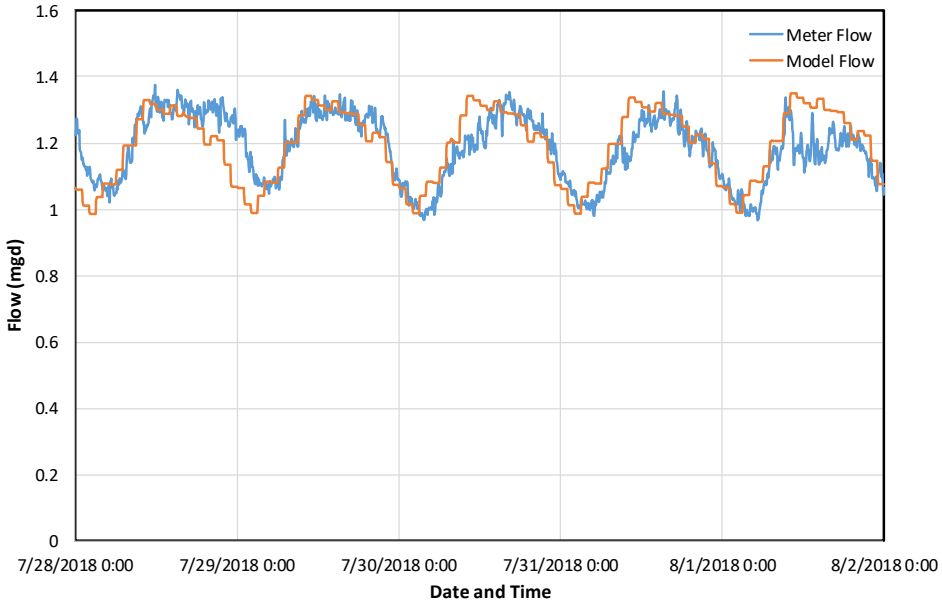
Meter SB1 Dry Weather Calibration

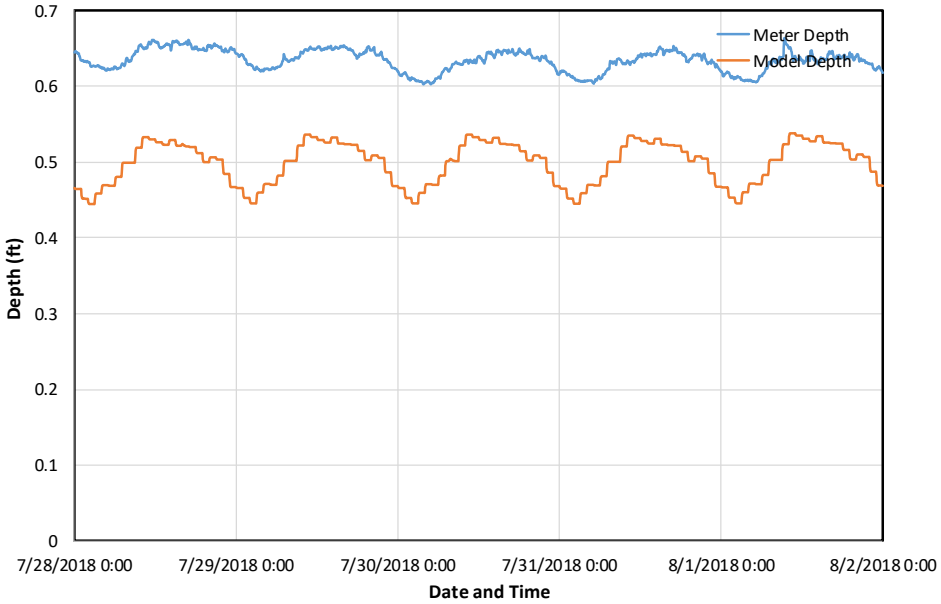




Hazen

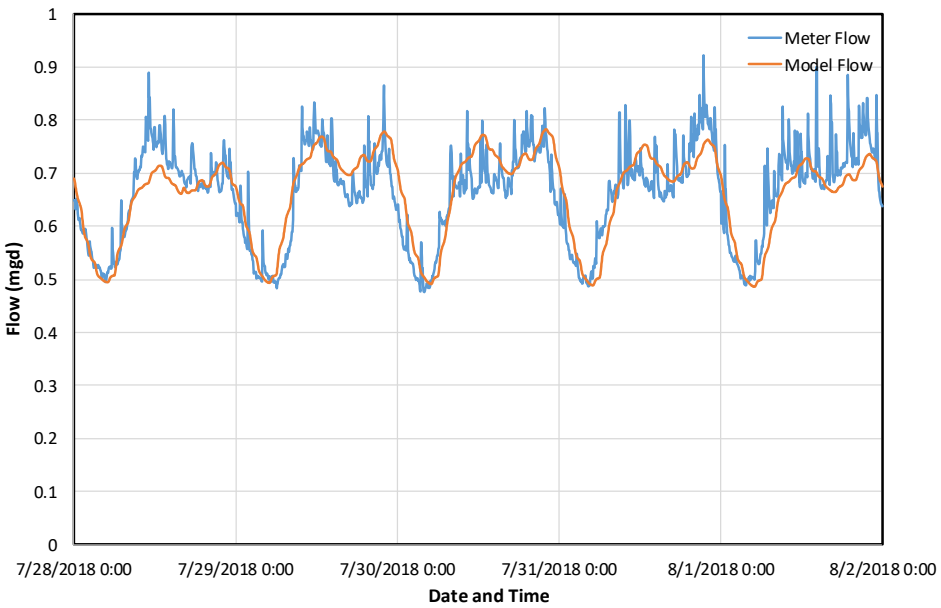
Meter SB2 Dry Weather Calibration

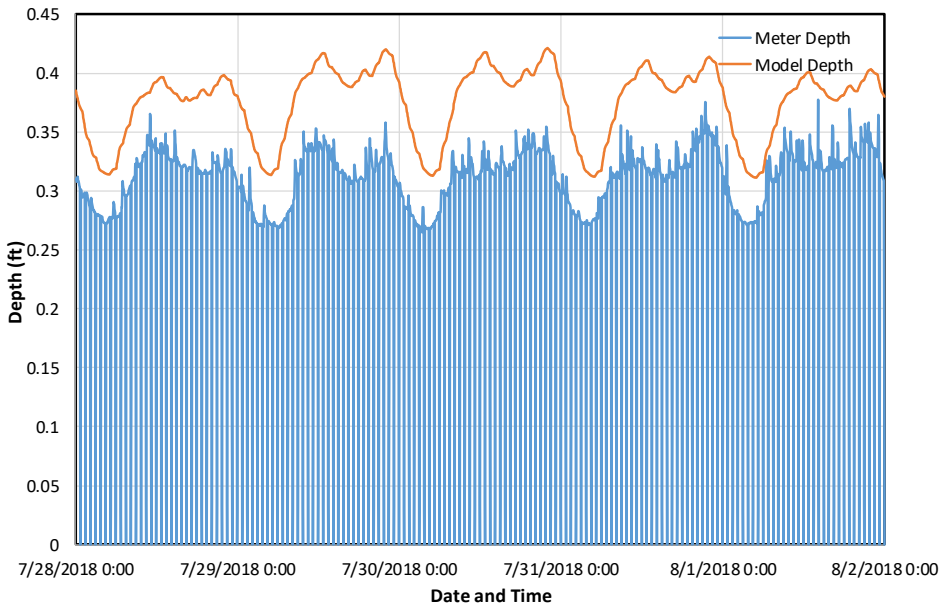




Hazen

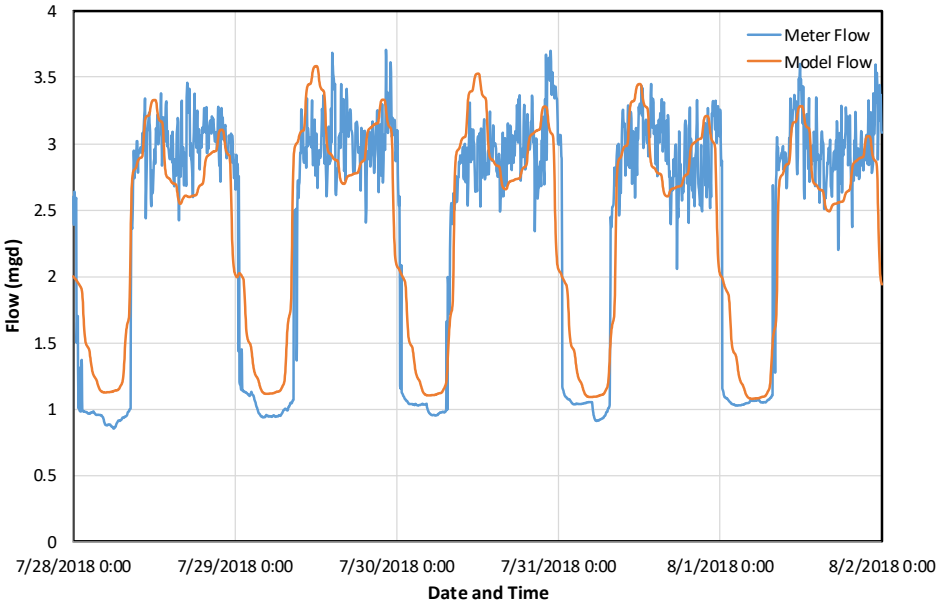
Meter SB3 Dry Weather Calibration

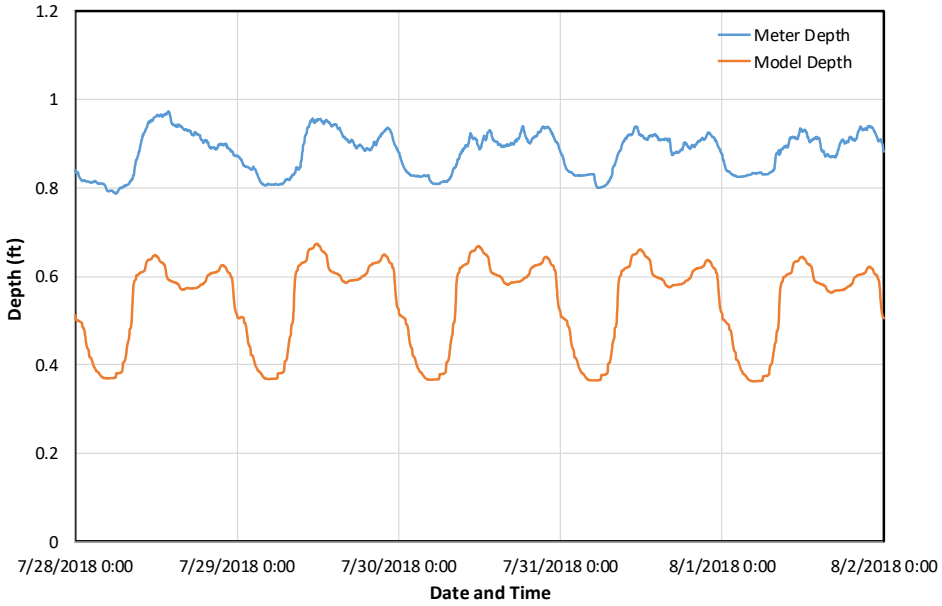




Hazen

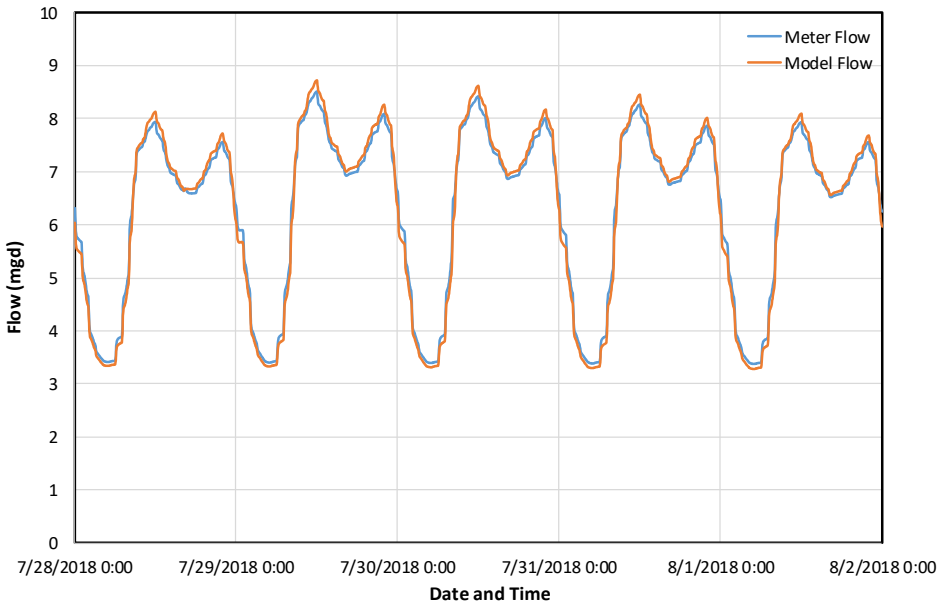
Meter SB4 Dry Weather Calibration

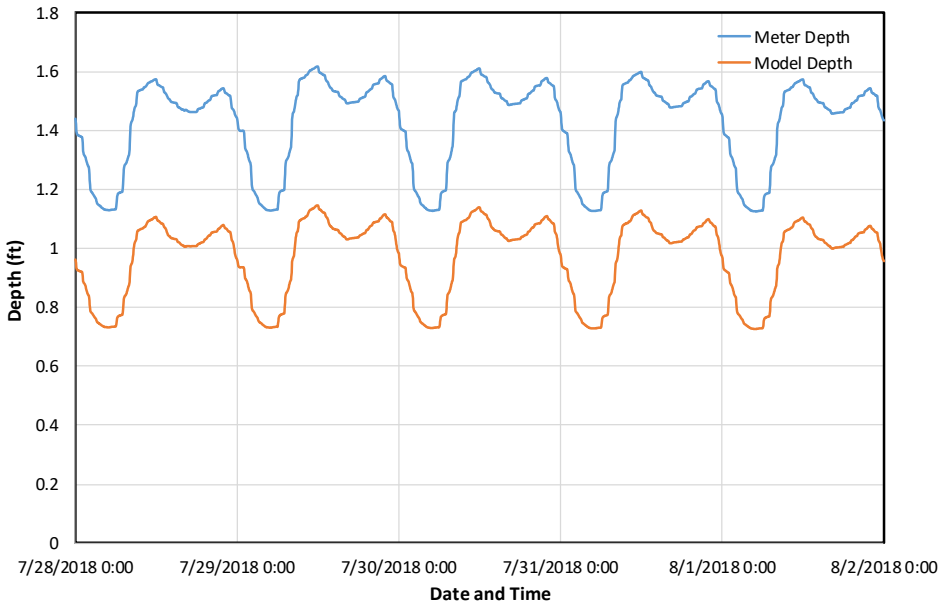




Hazen

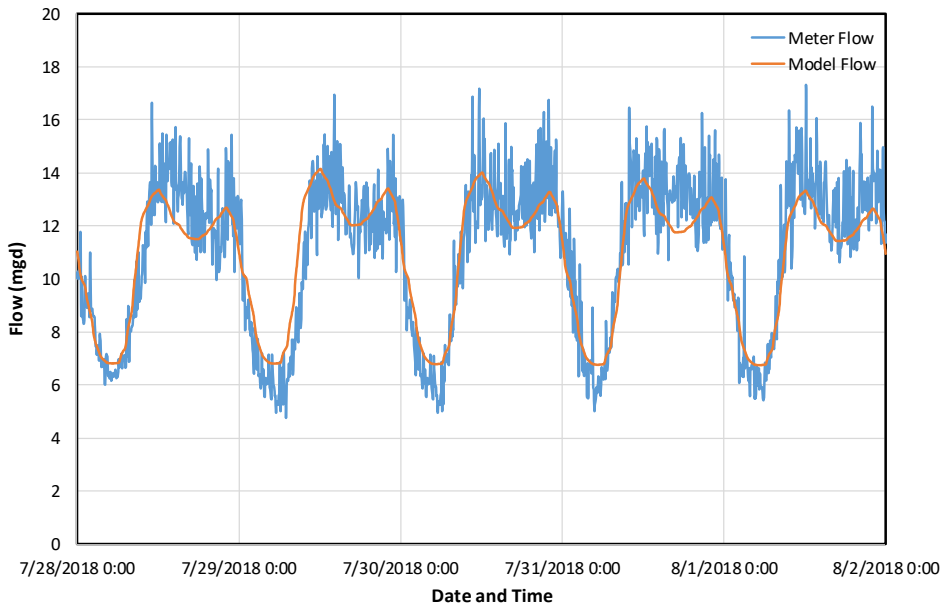
Meter SB5 Dry Weather Calibration

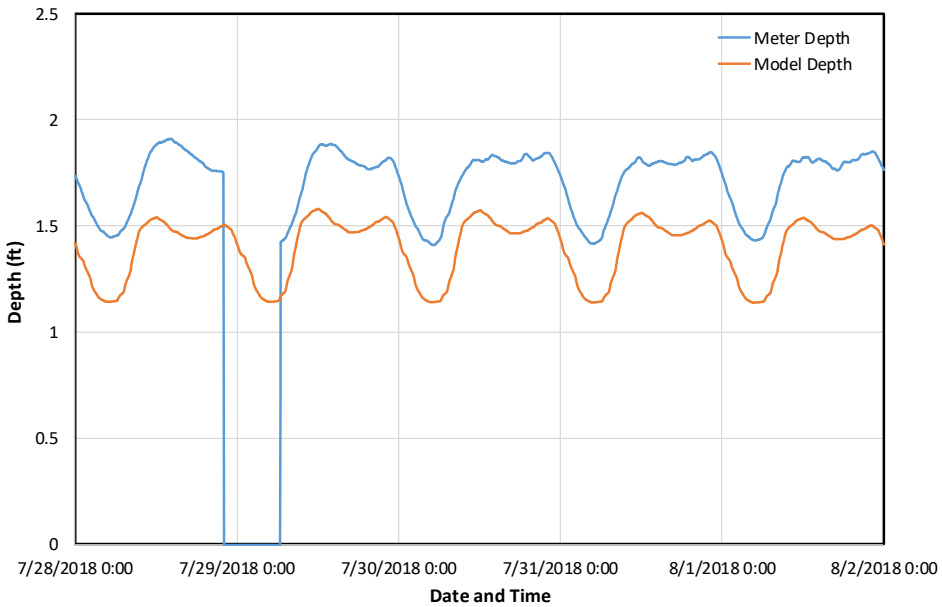




Hazen

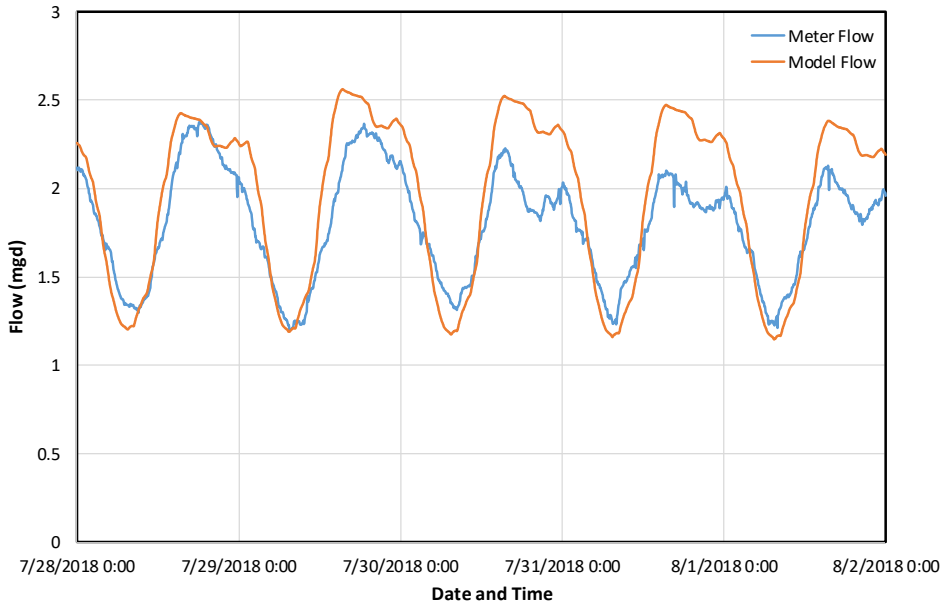
Meter SB6A Dry Weather Calibration

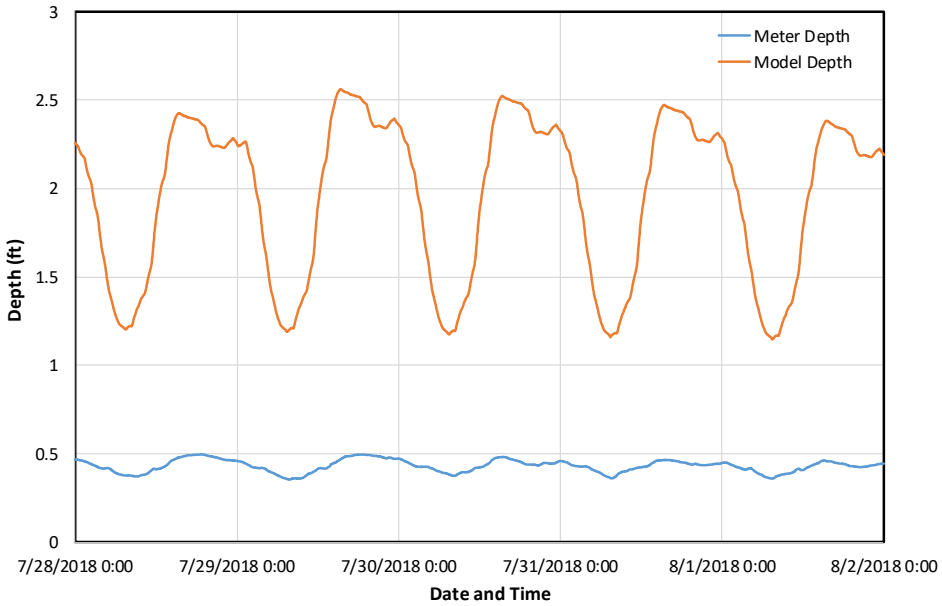




Hazen

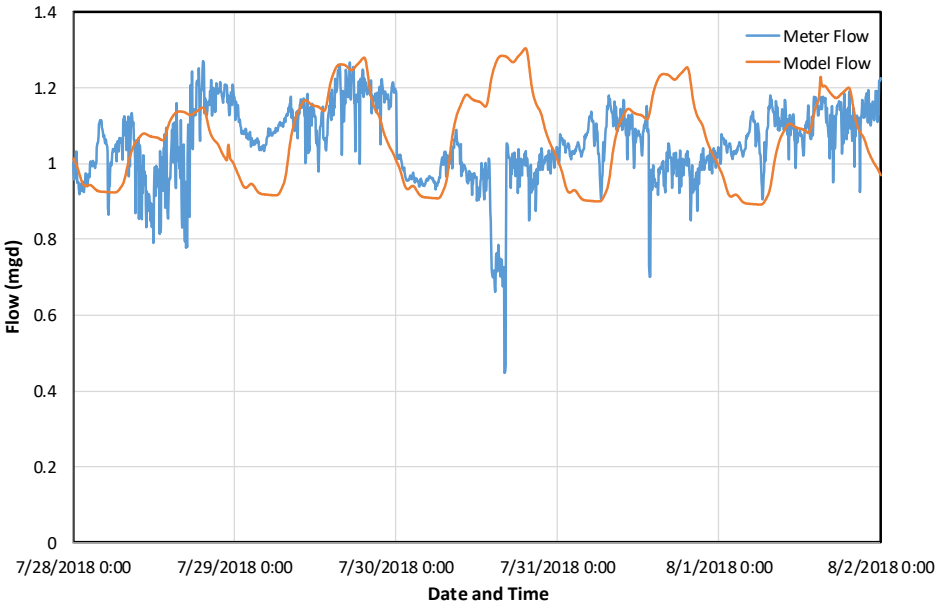
Meter SB7 Dry Weather Calibration

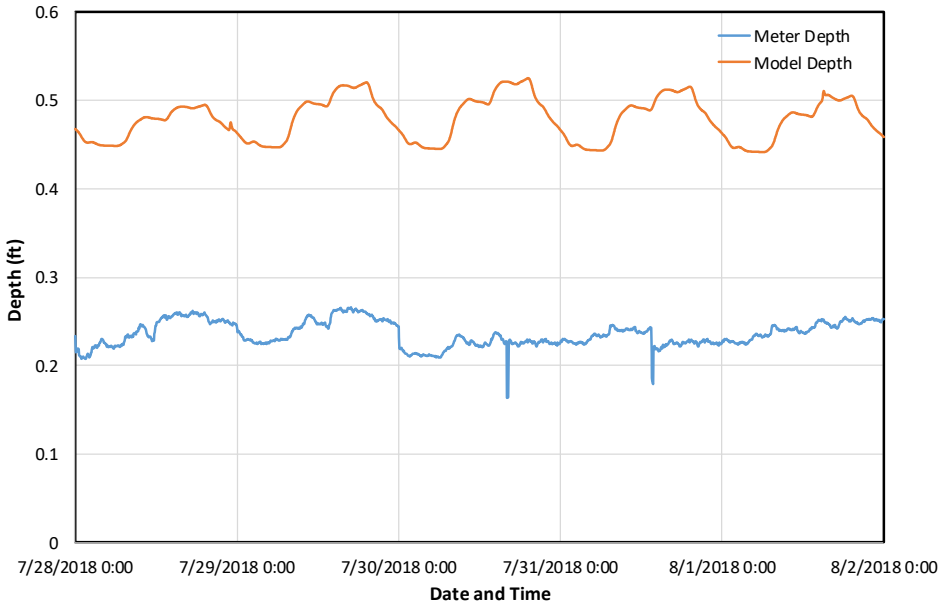




Hazen

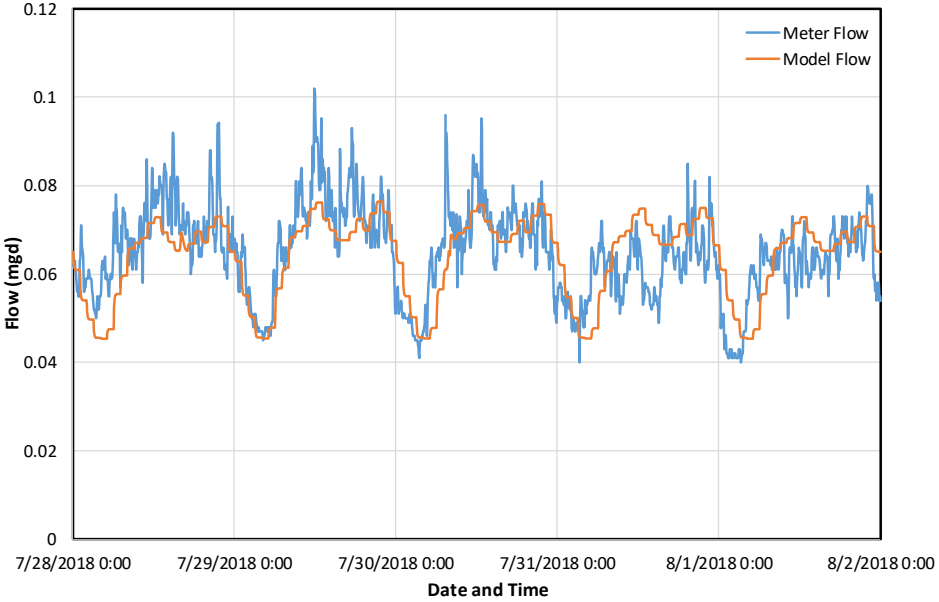
Meter SB8A Dry Weather Calibration

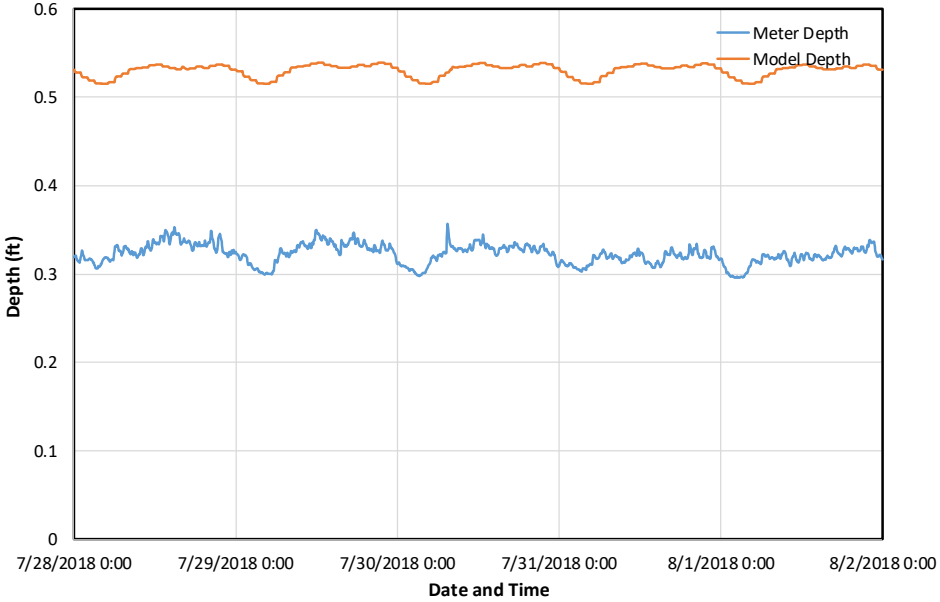




Hazen

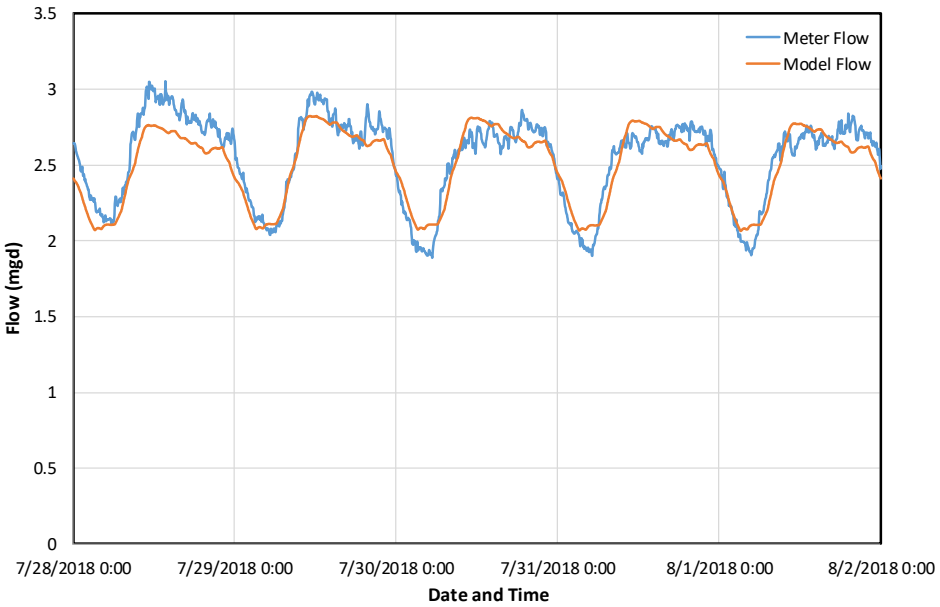
Meter SB9 Dry Weather Calibration

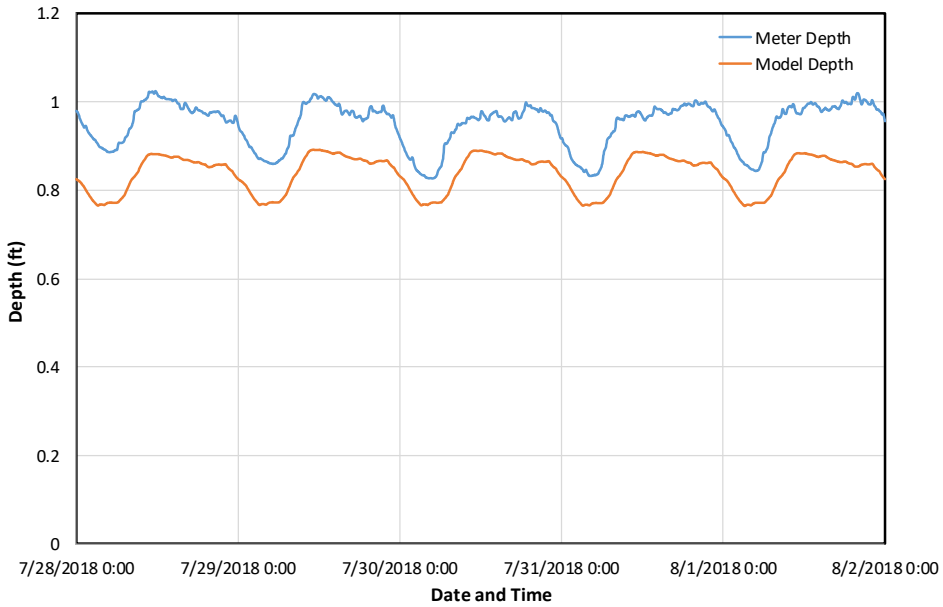




Hazen

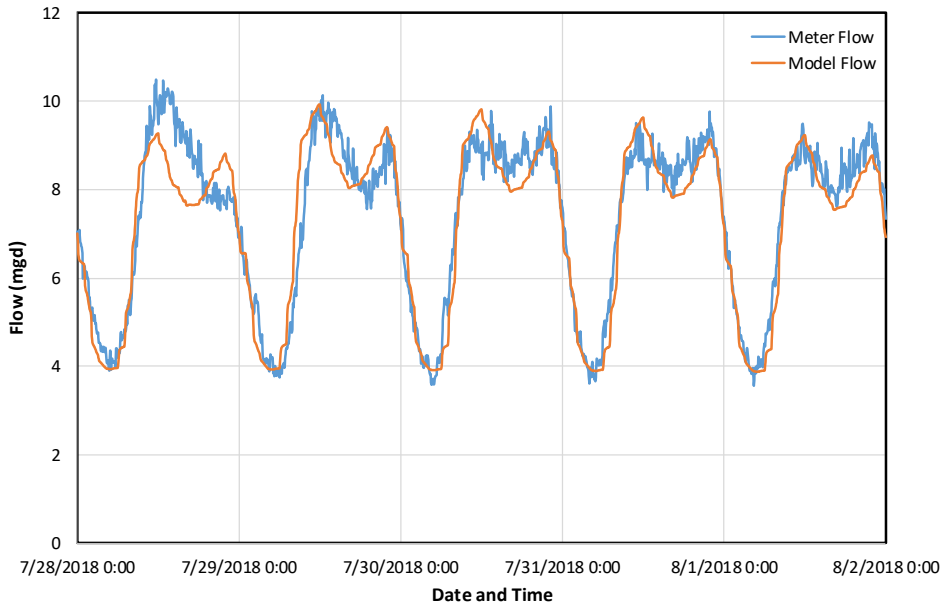
Meter SB11 Dry Weather Calibration

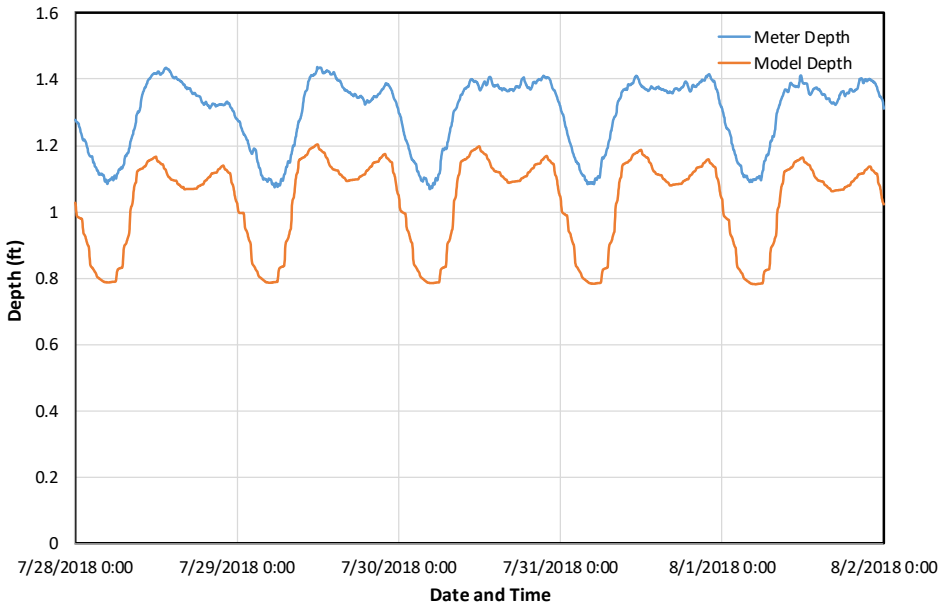




Hazen

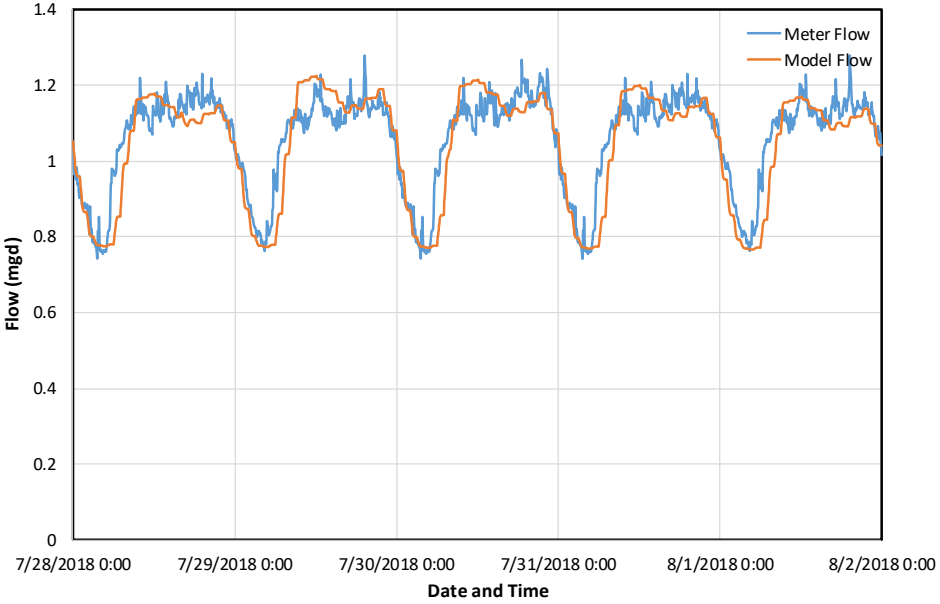
Meter SB12 Dry Weather Calibration

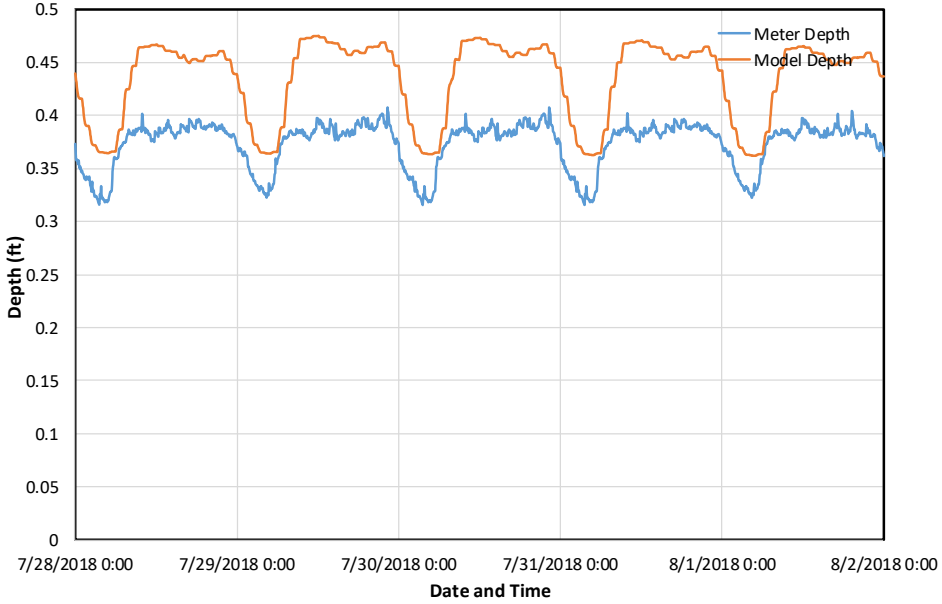




Hazen

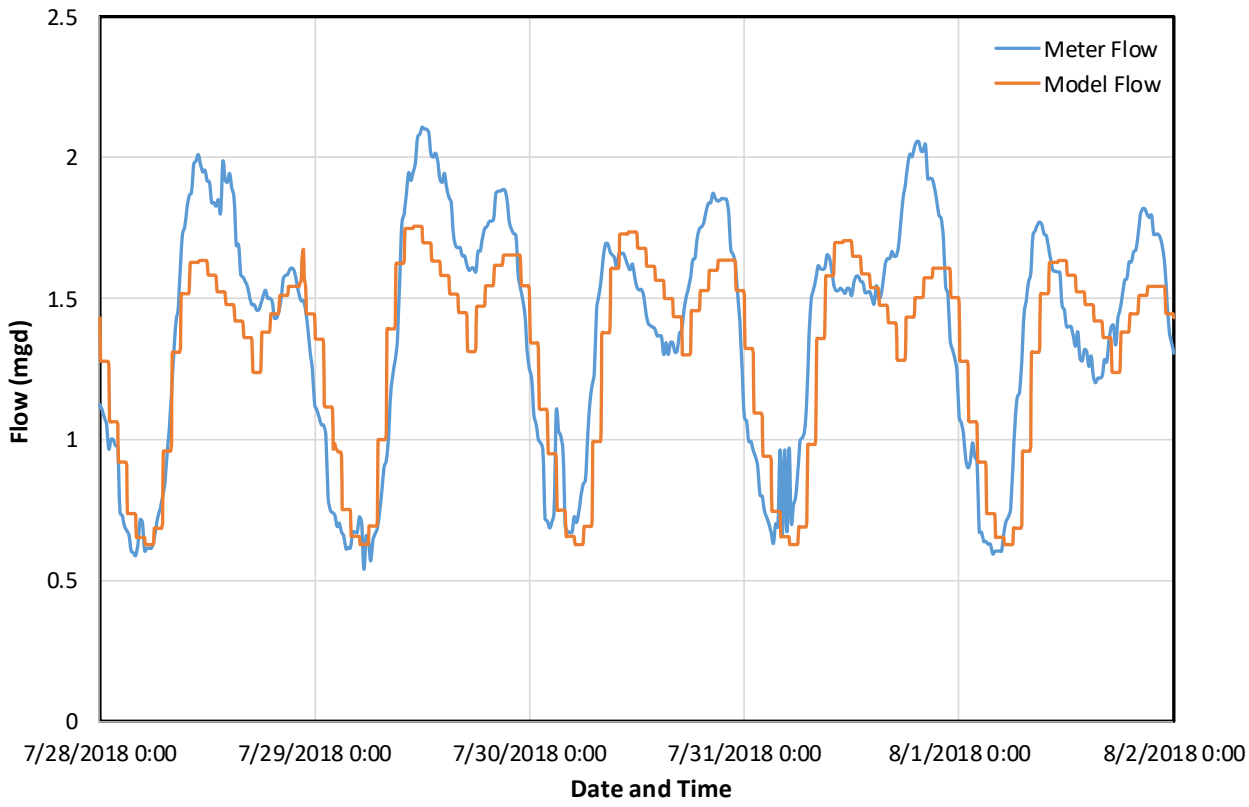
Meter SB13 Dry Weather Calibration





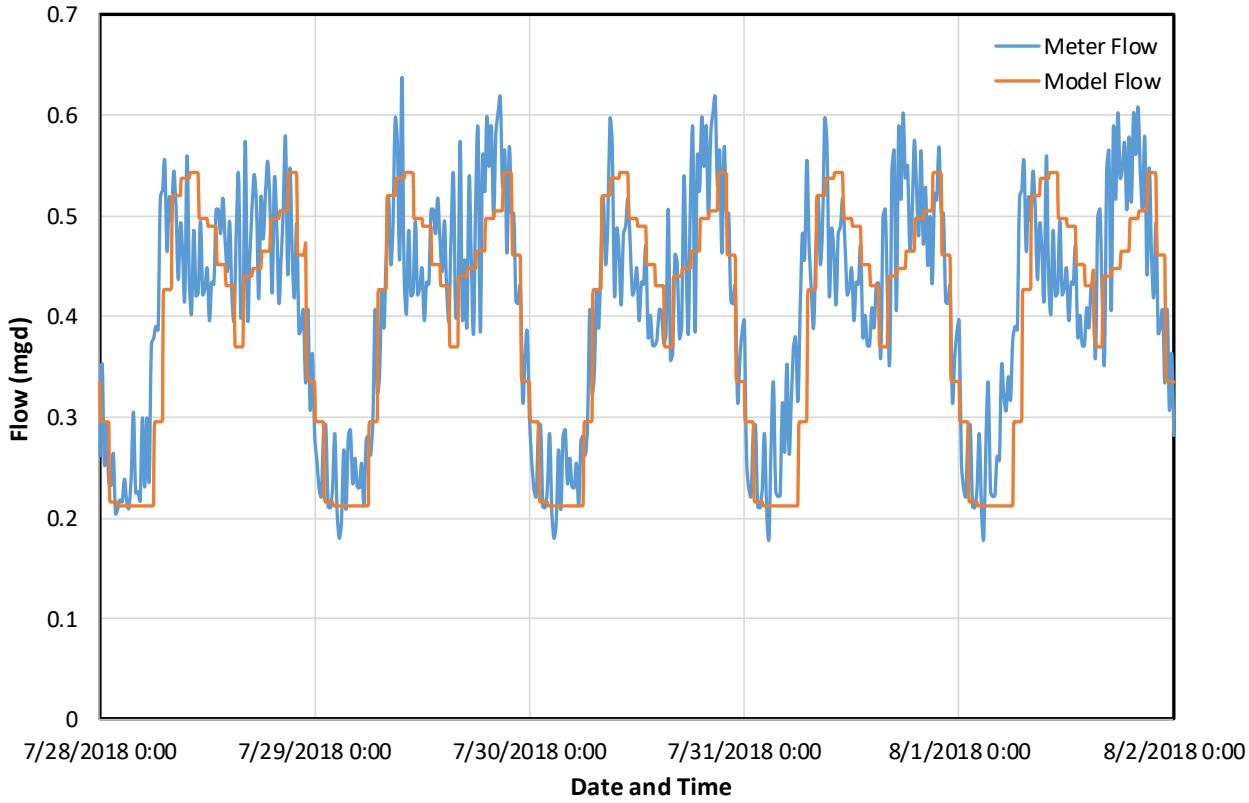
Hazen

Book Billing Meter Dry Weather Calibration



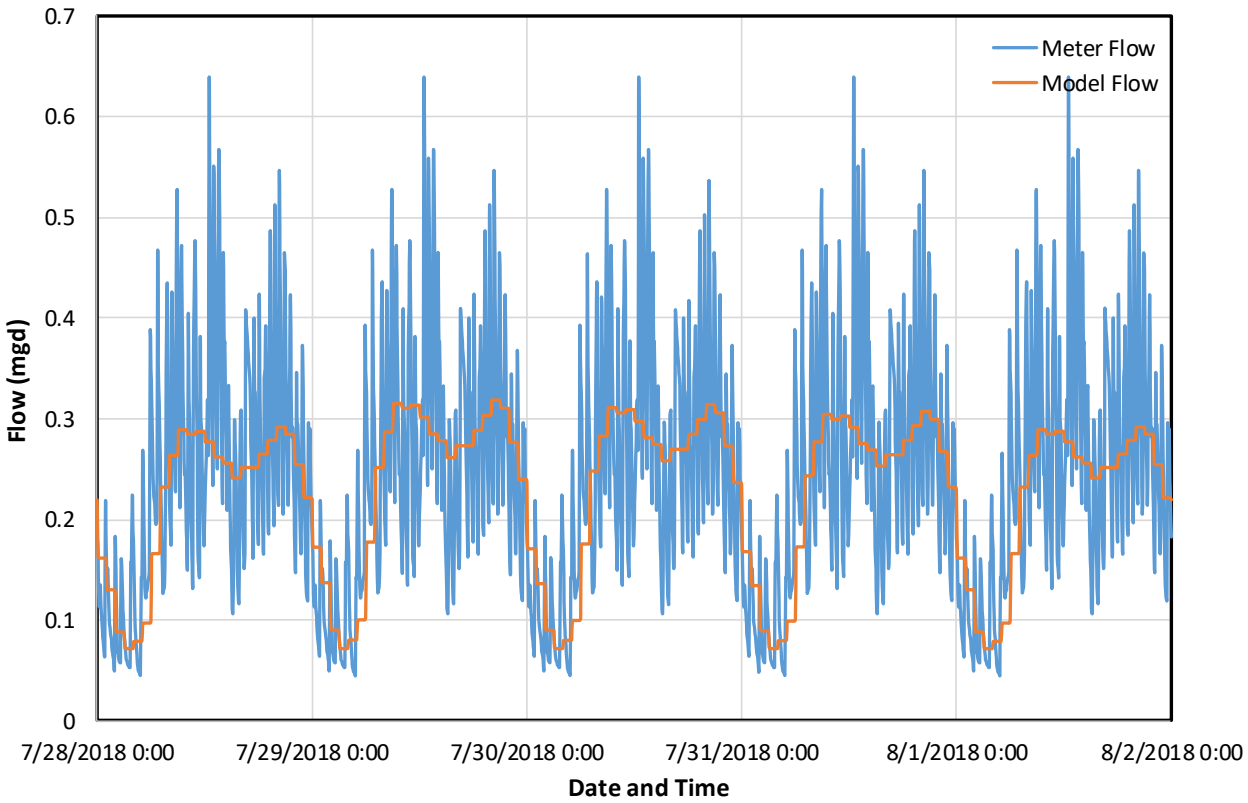
Hazen

Willard Billing Meter Dry Weather Calibration



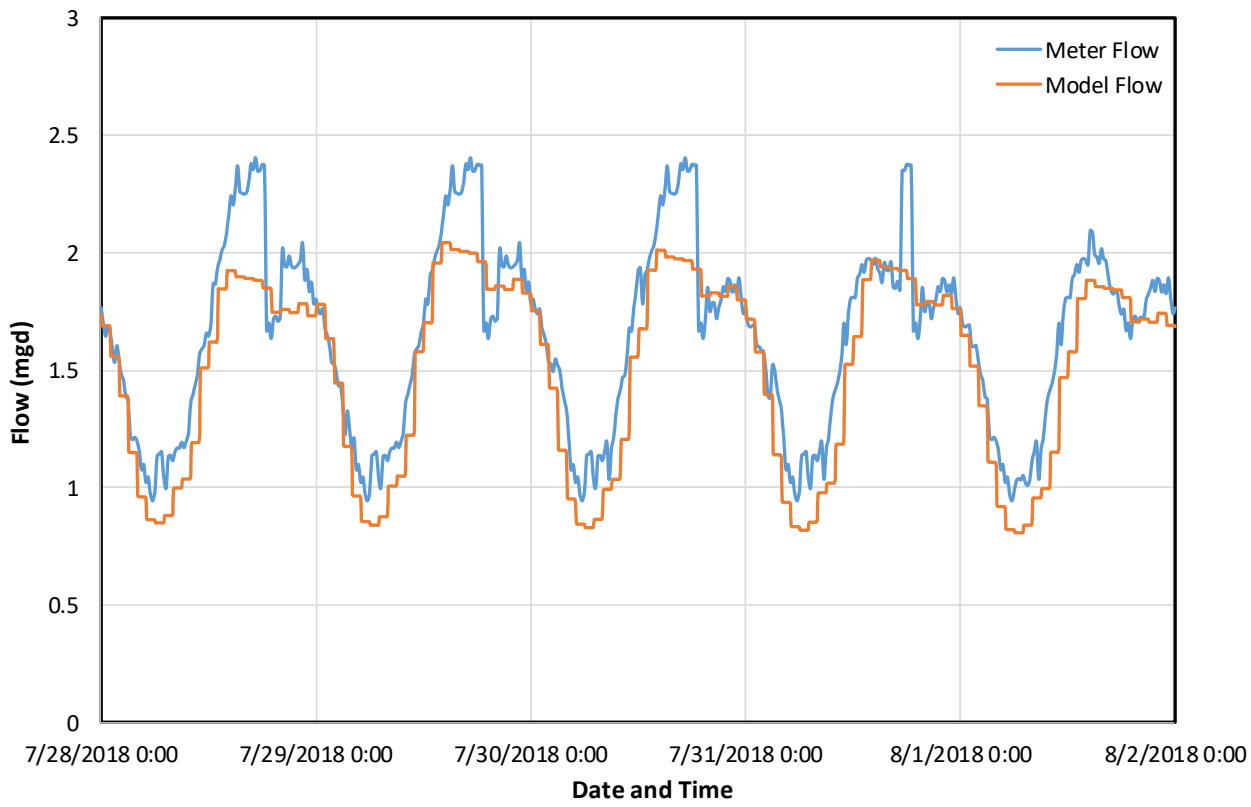
Hazen

First Billing Meter Dry Weather Calibration



Hazen

Merrimack Billing Meter Dry Weather Calibration

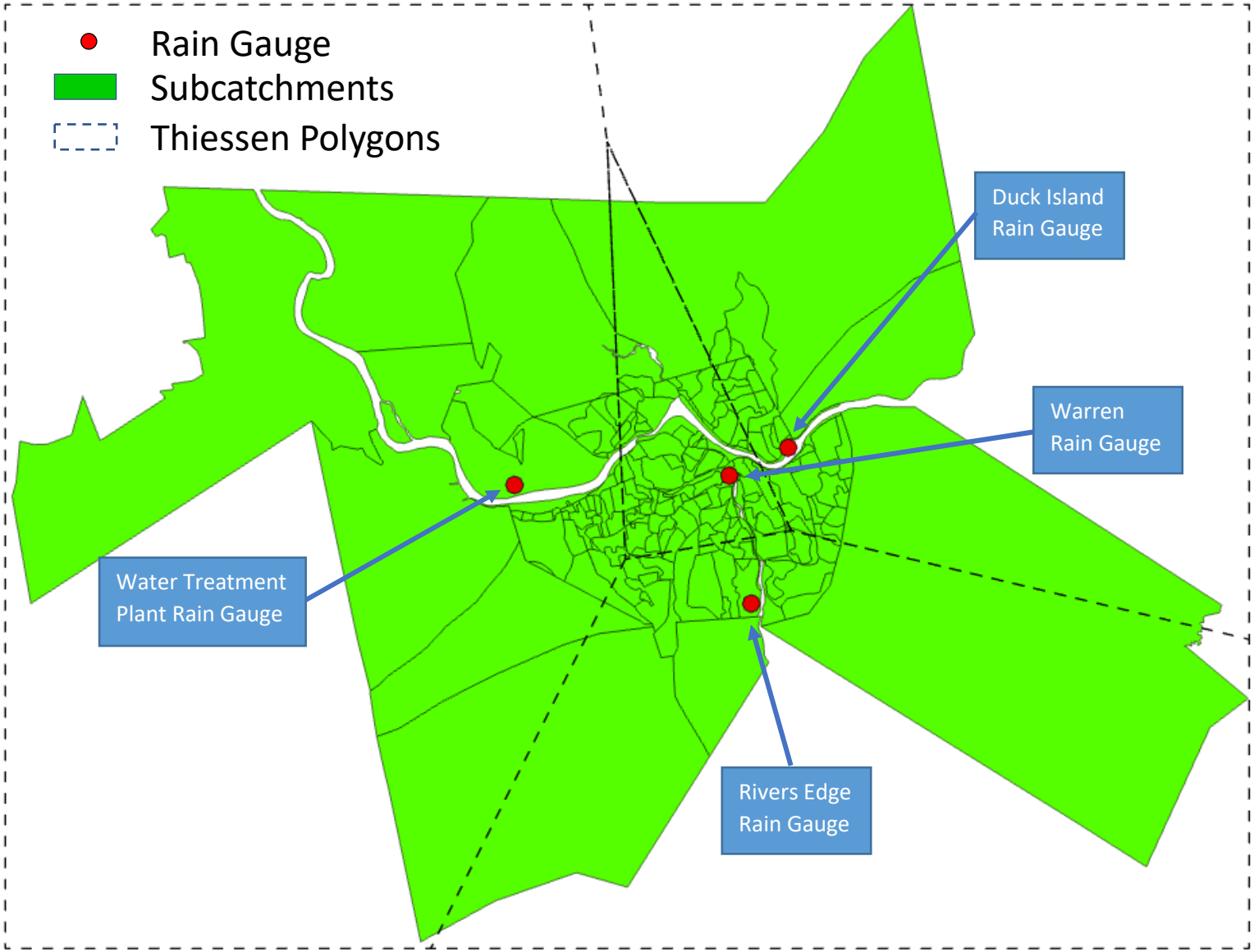


Hazen

Lowell WWF Calibration Results

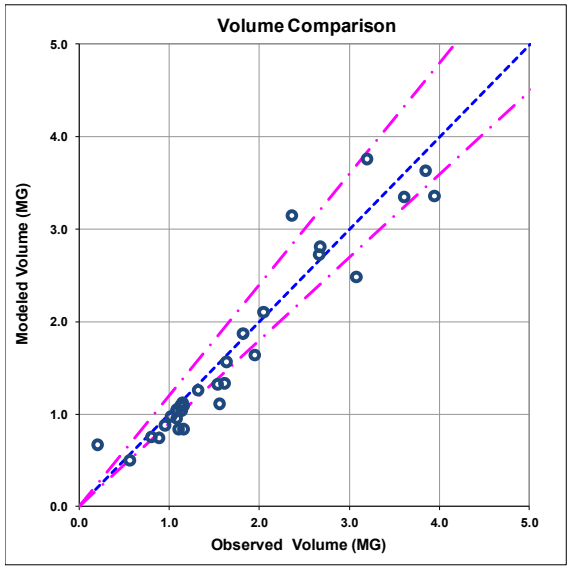
Hazen

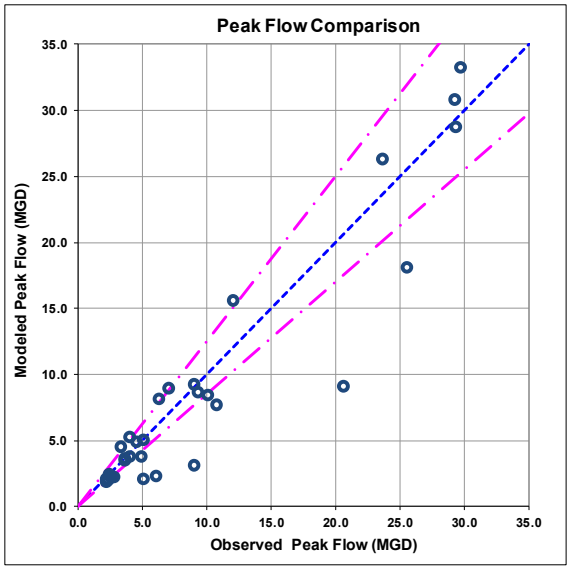
Thiessen Polygons Used to Distribute Rain Gauges

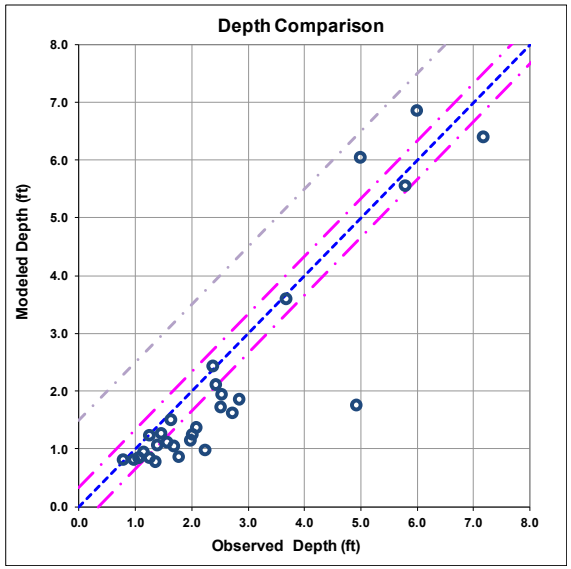


Hazen

Statistical Results for NB1

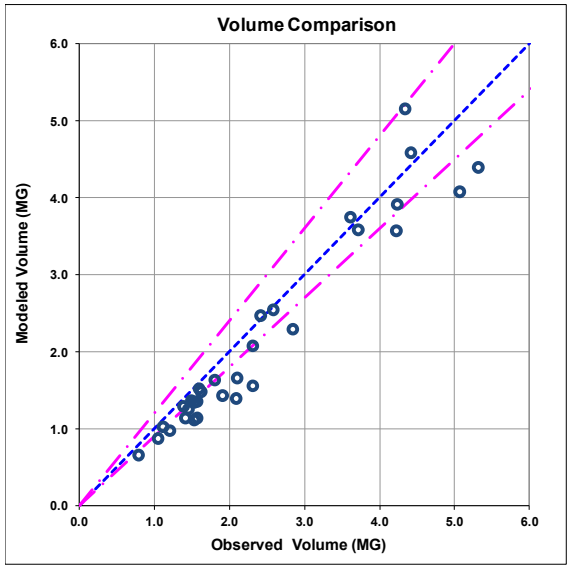


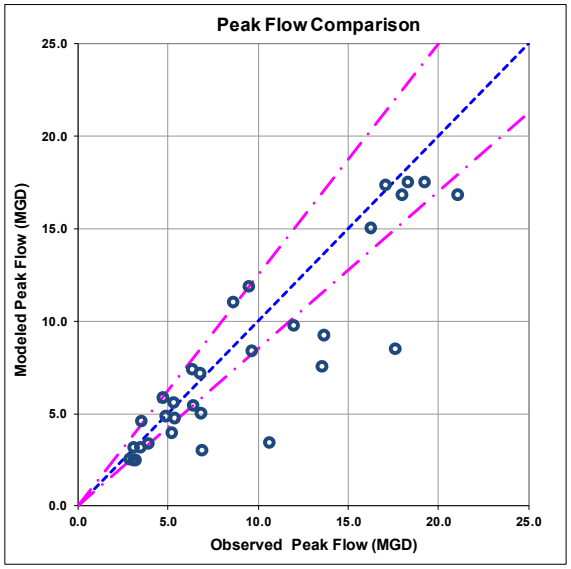


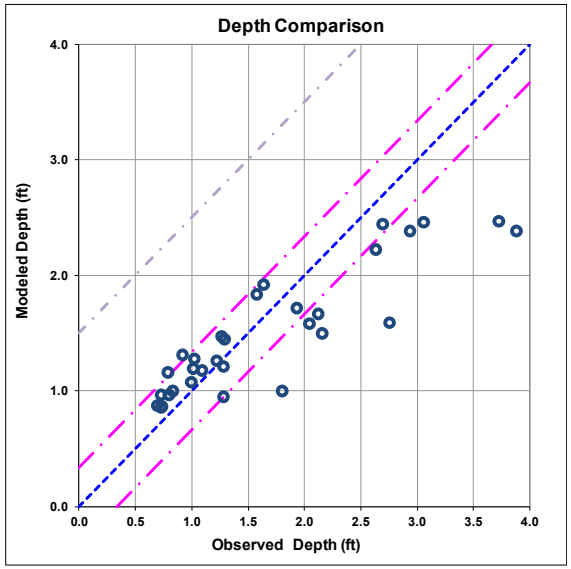


Hazen

Statistical Results for NB2A

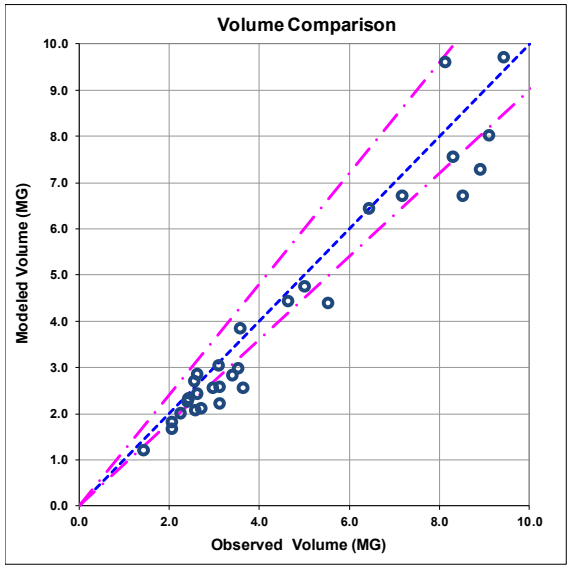


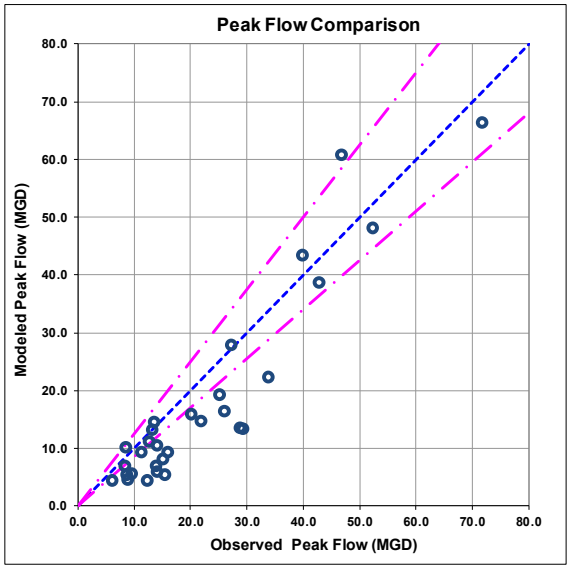


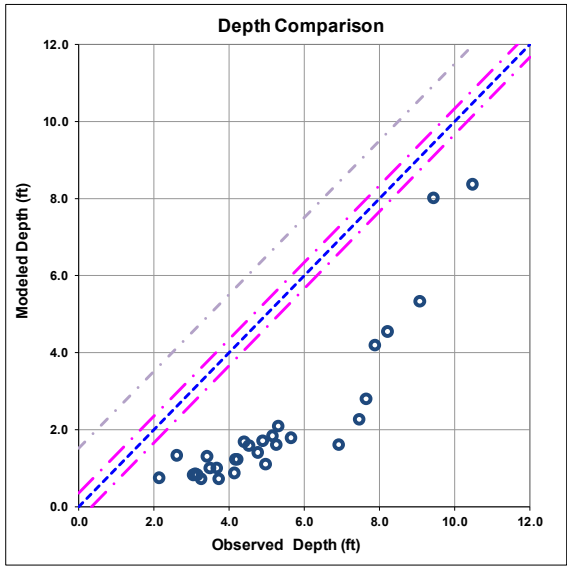


Hazen

Statistical Results for NB3

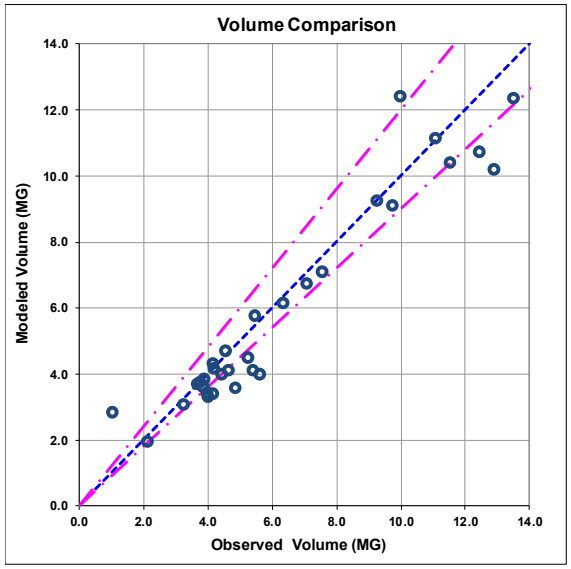


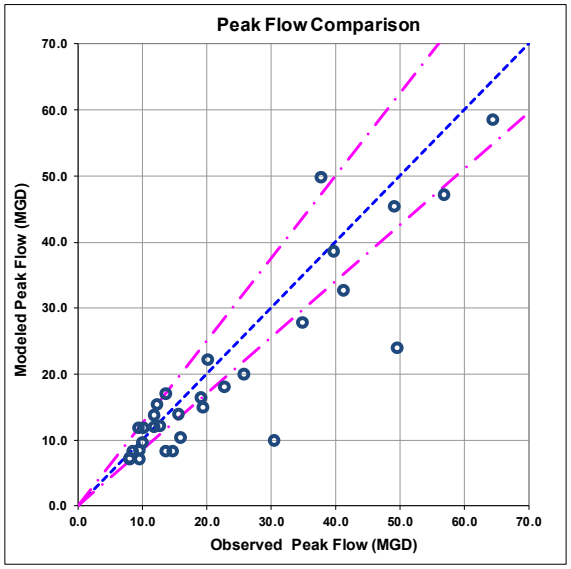


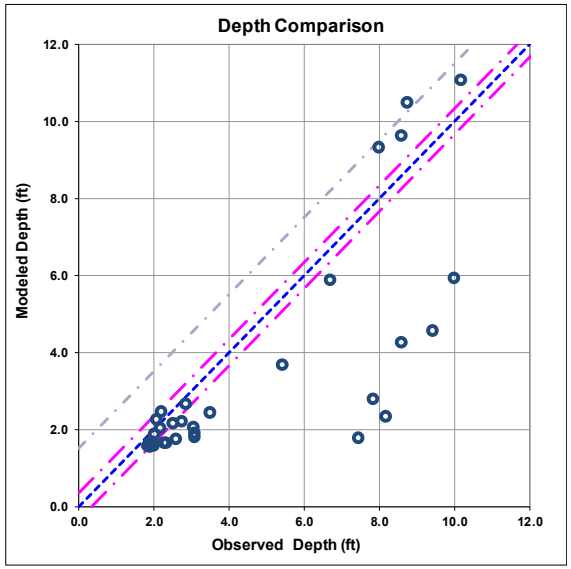


Hazen

Statistical Results for NB4

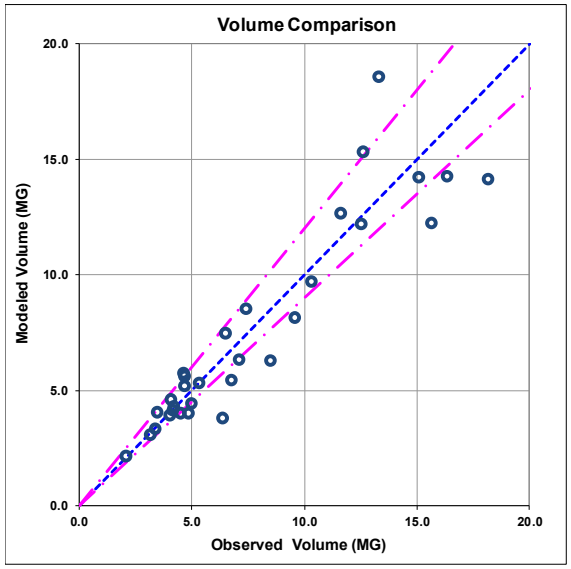


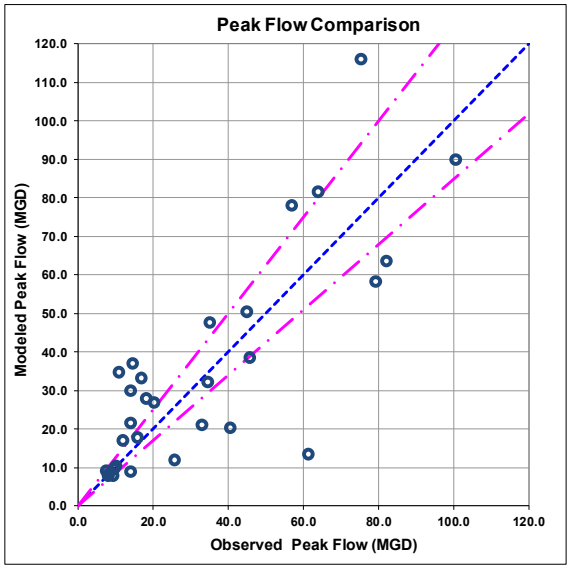


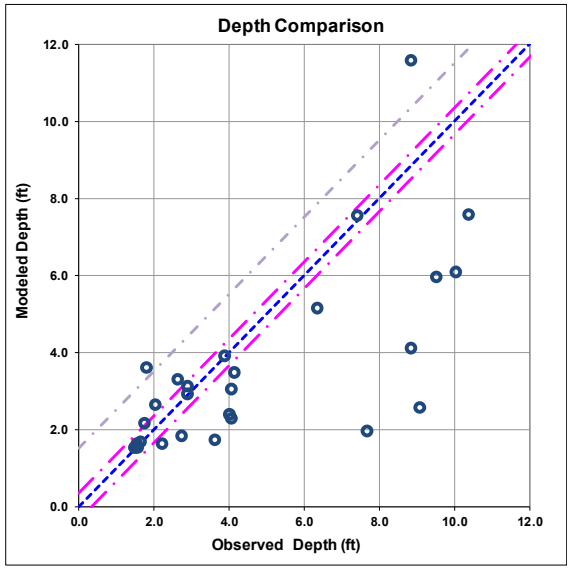


Hazen

Statistical Results for NB5

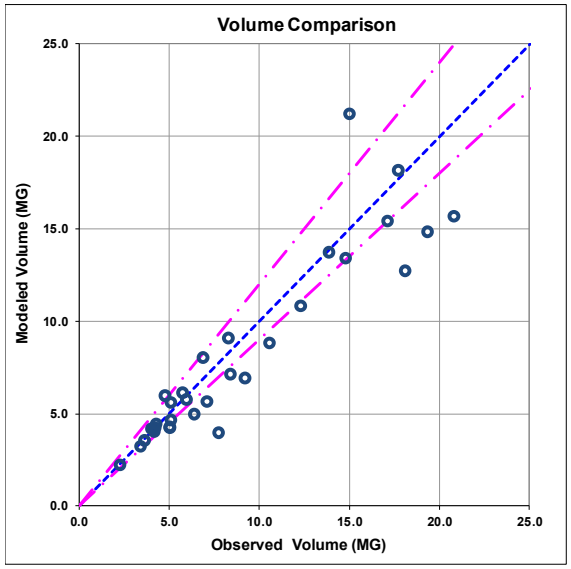


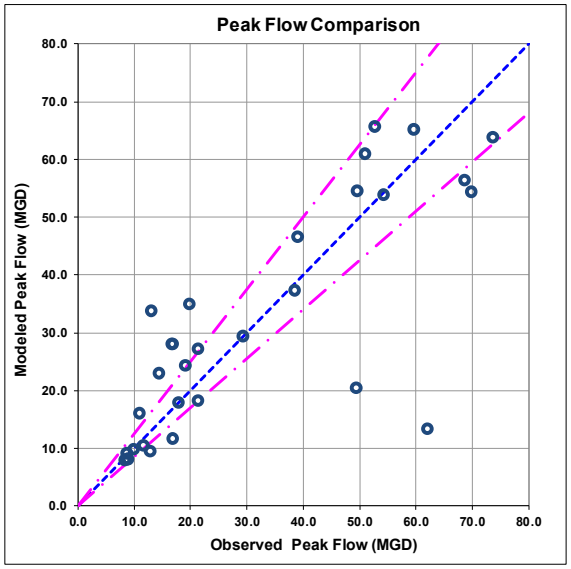


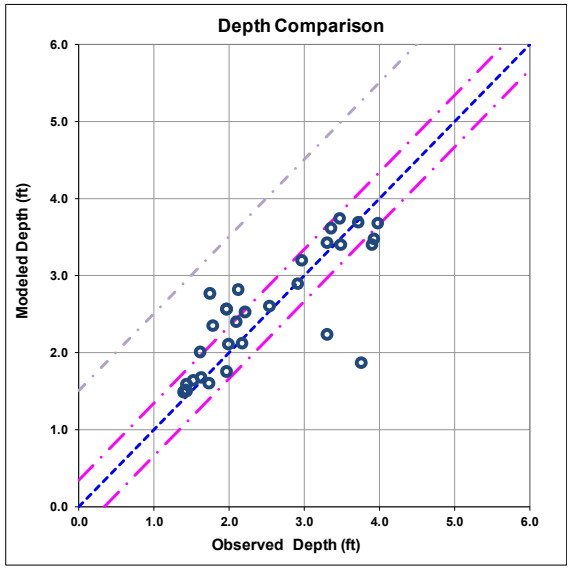


Hazen

Statistical Results for NB7

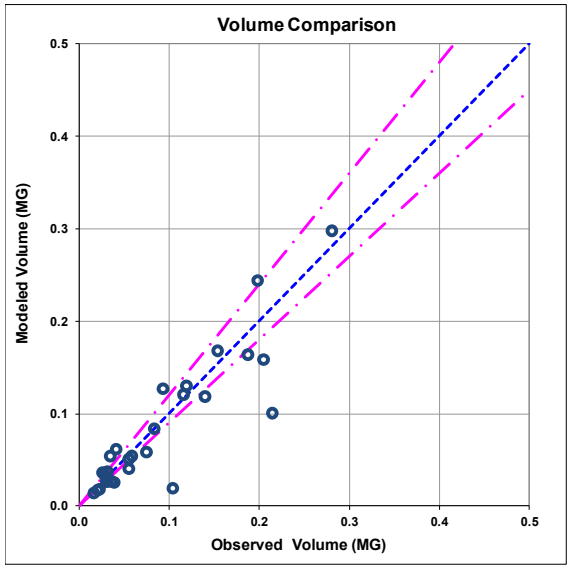


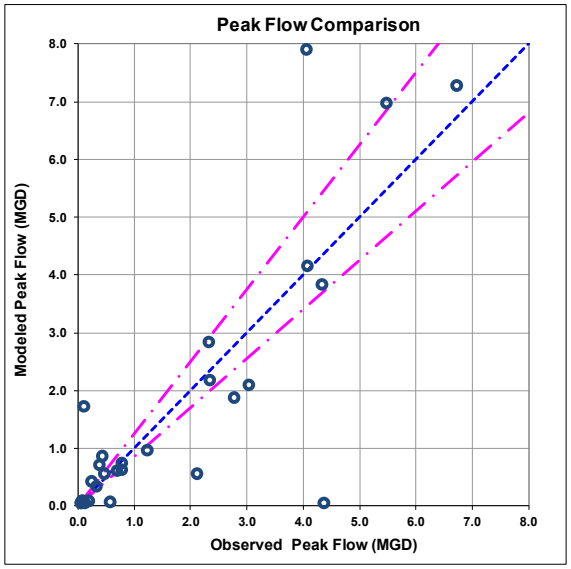


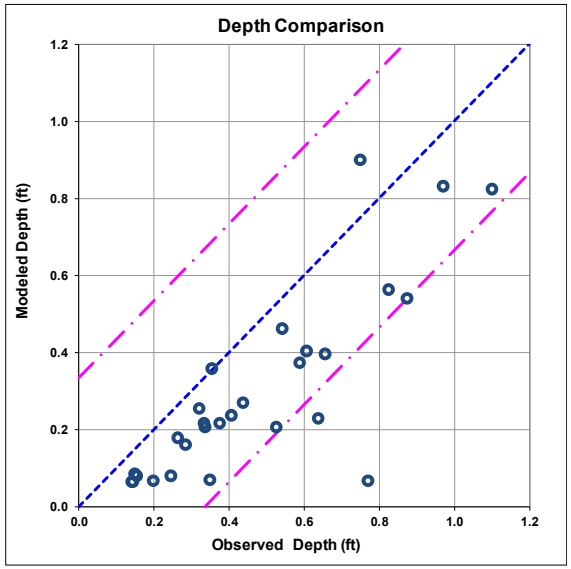


Hazen

Statistical Results for NB9

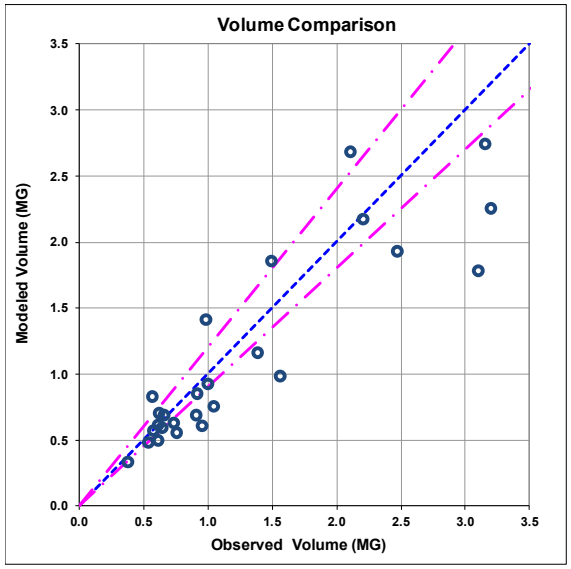


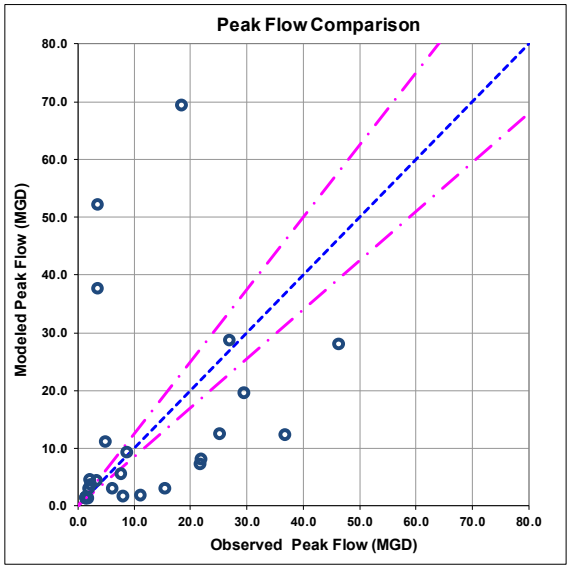


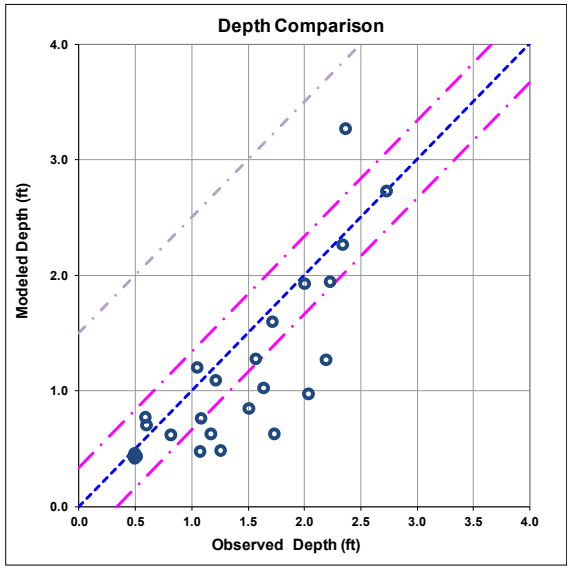


Hazen

Statistical Results for NB10

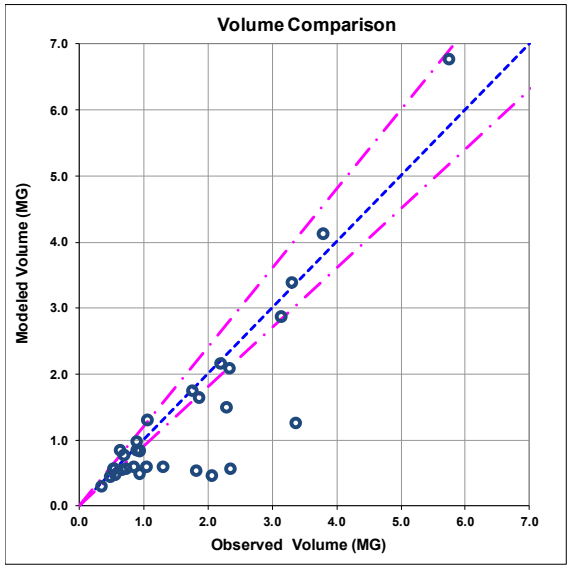


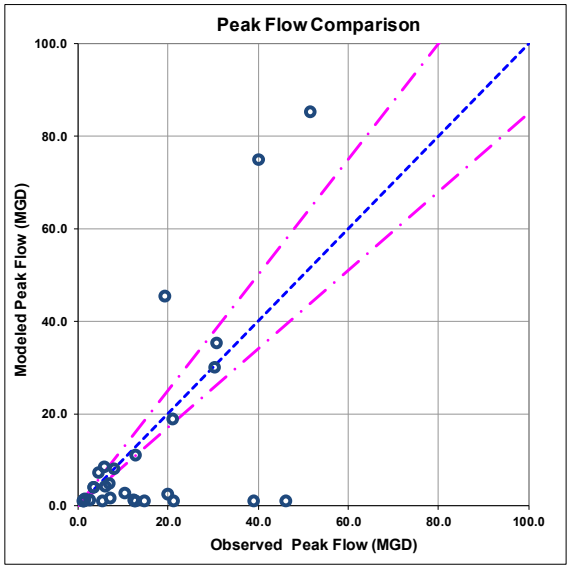


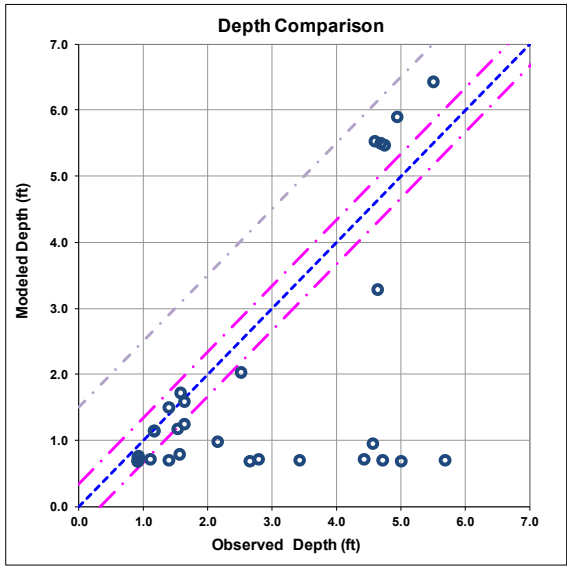


Hazen

Statistical Results for SB1

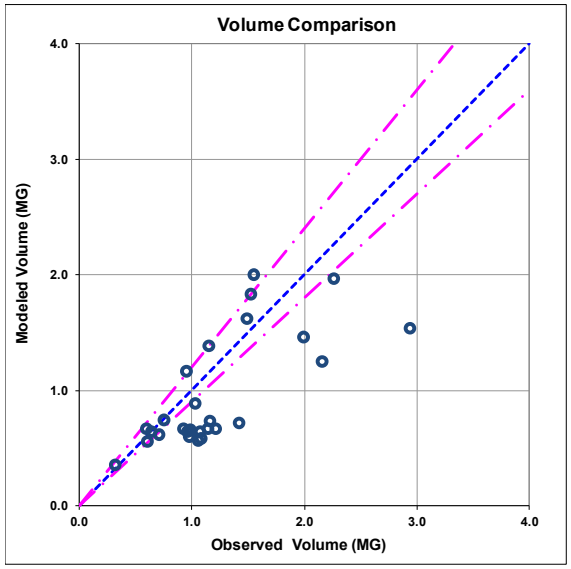


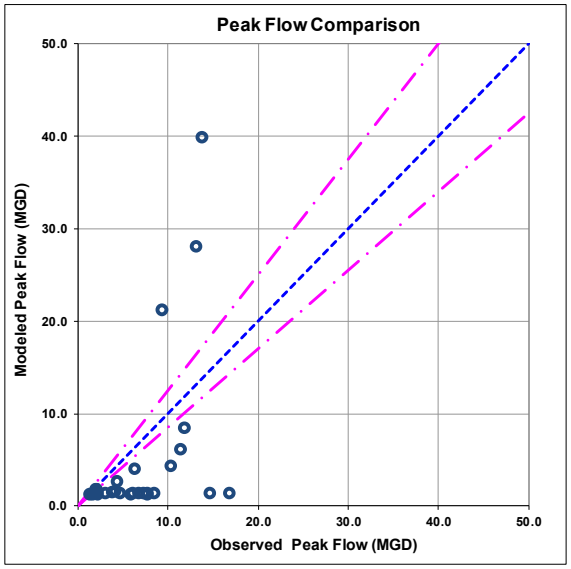


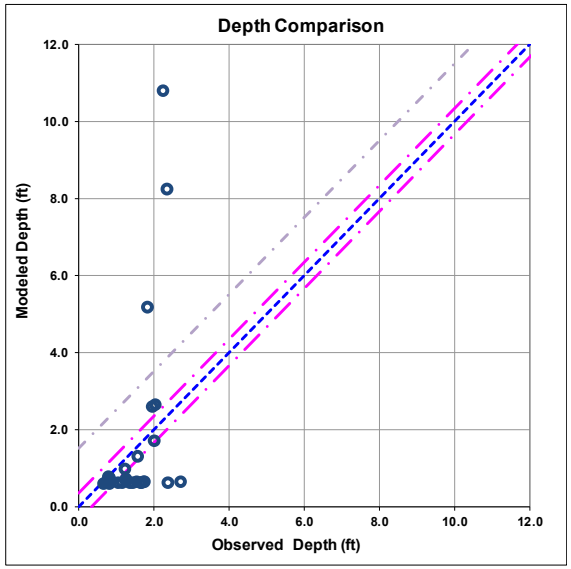


Hazen

Statistical Results for SB2

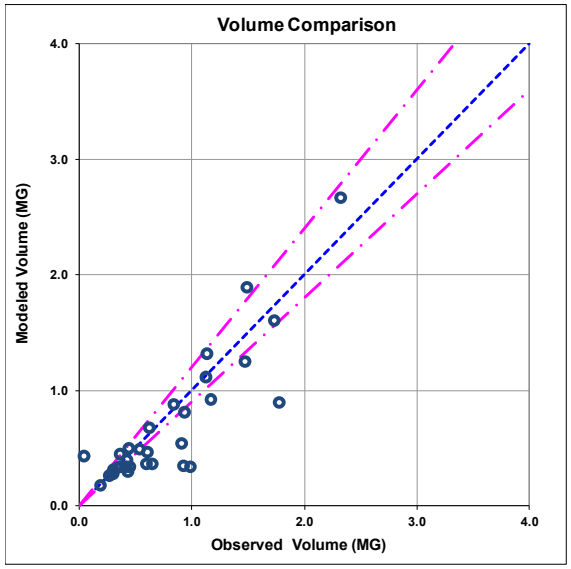


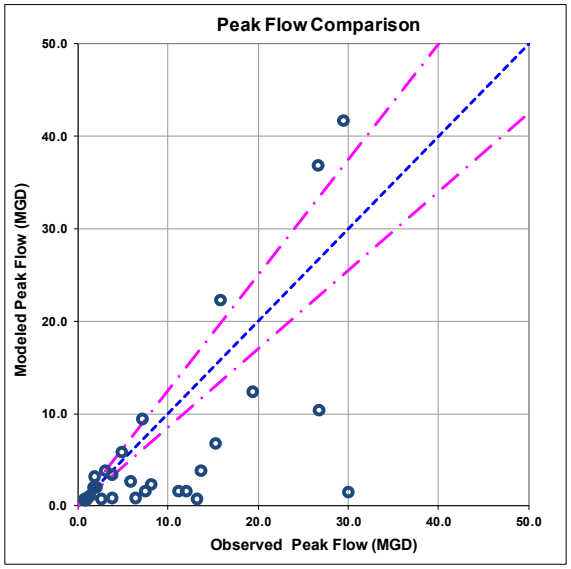


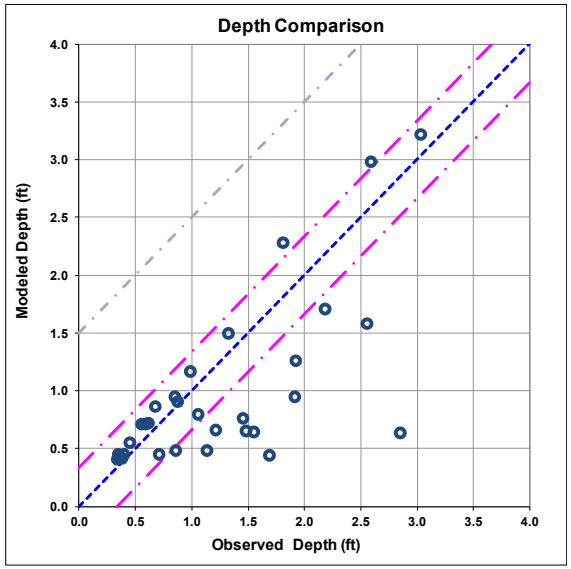


Hazen

Statistical Results for SB3

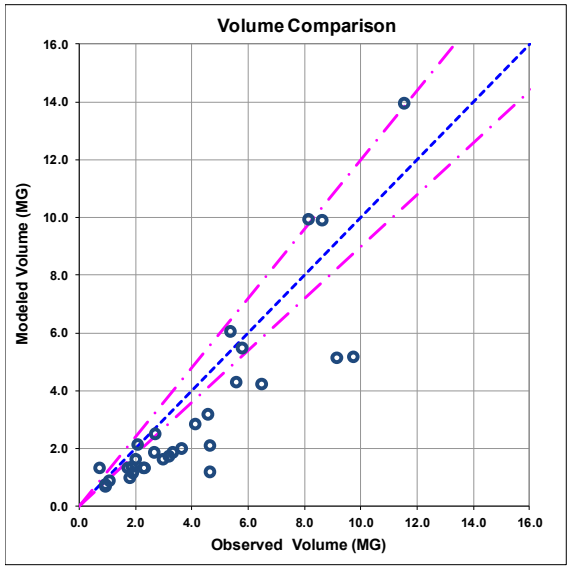


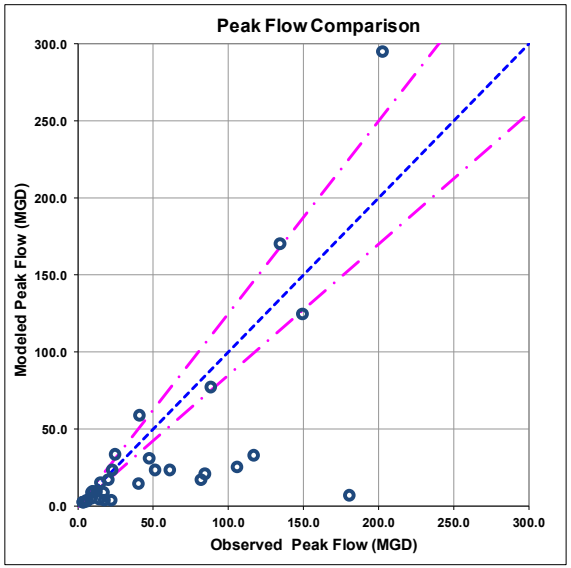


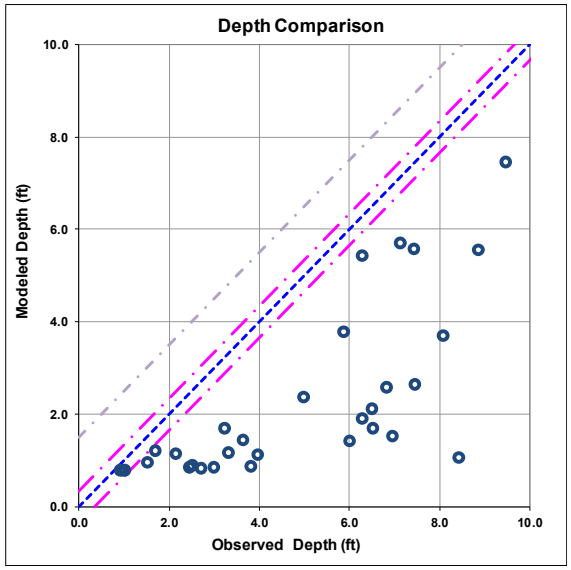


Hazen

Statistical Results for SB4

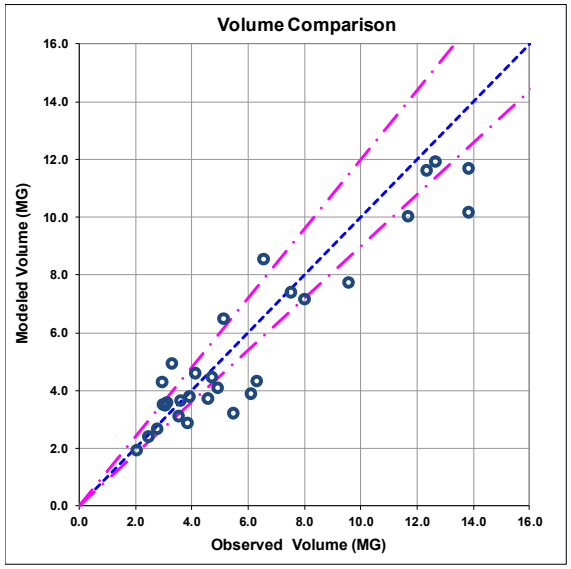


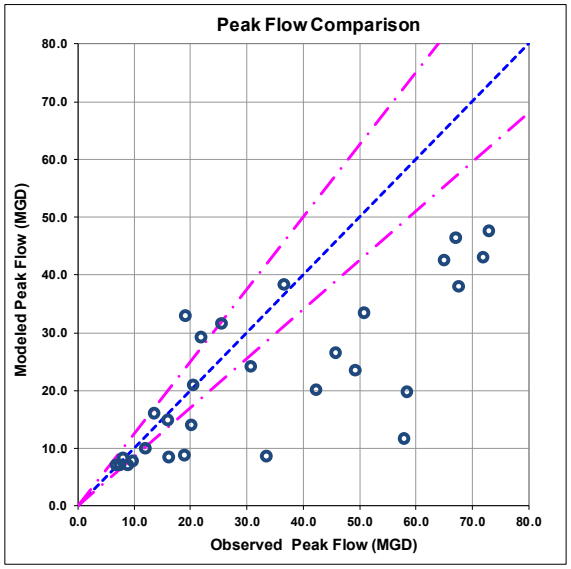


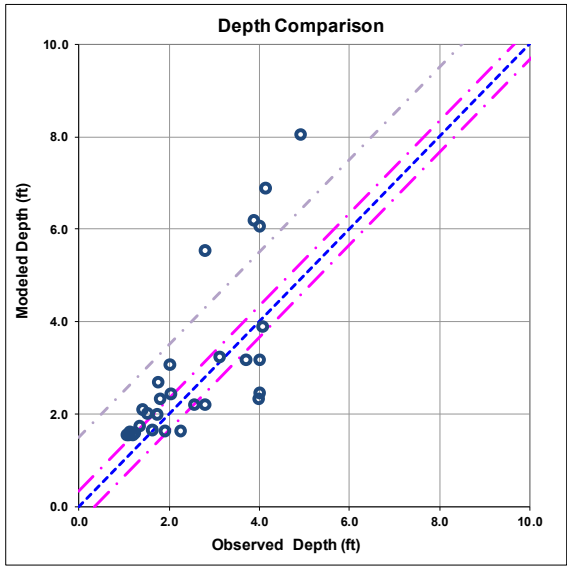


Hazen

Statistical Results for SB5

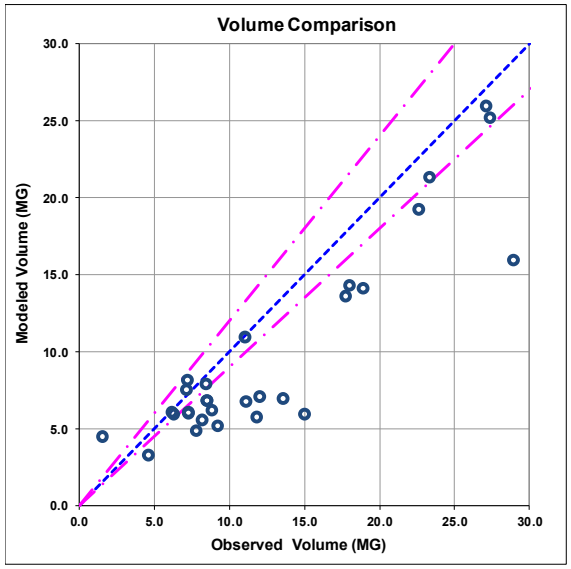


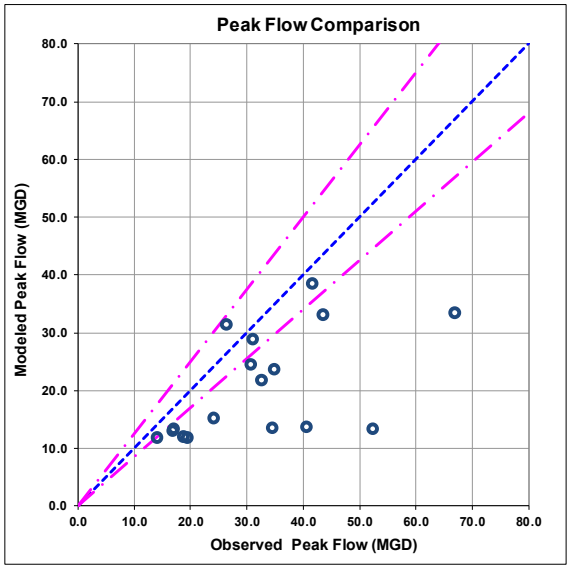


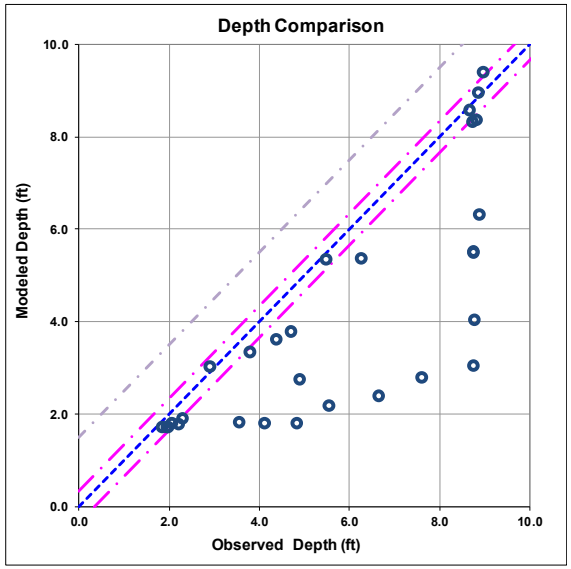


Hazen

Statistical Results for SB6A

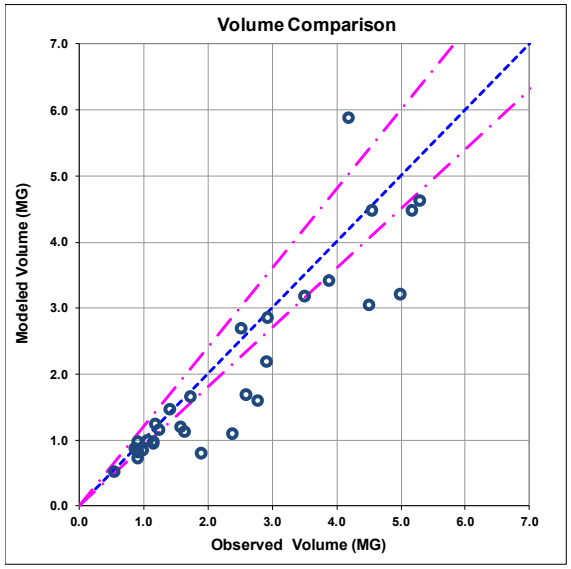


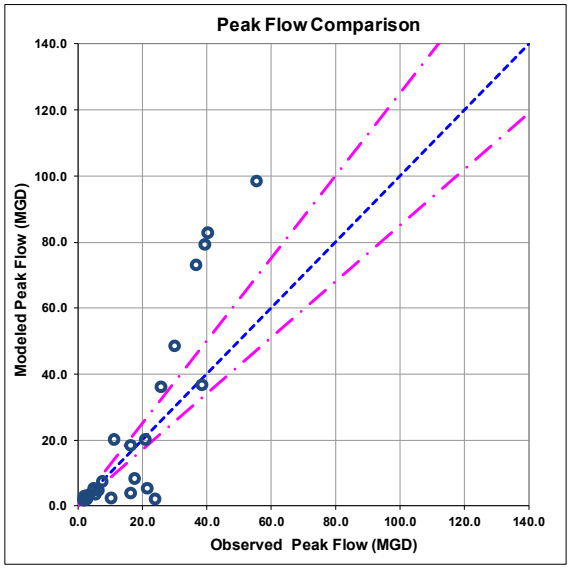


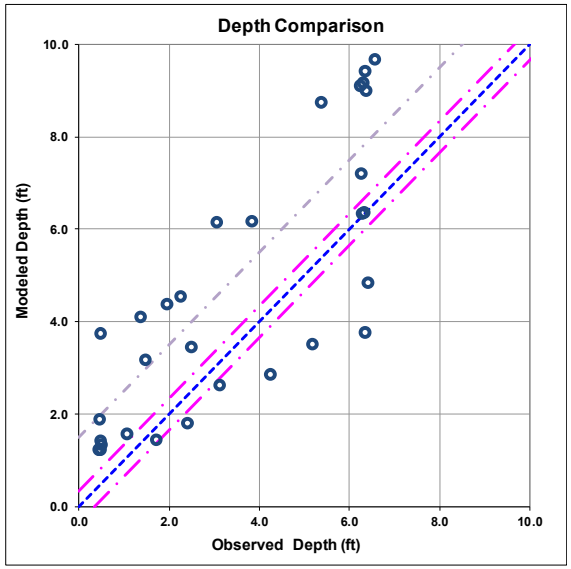


Hazen

Statistical Results for SB7

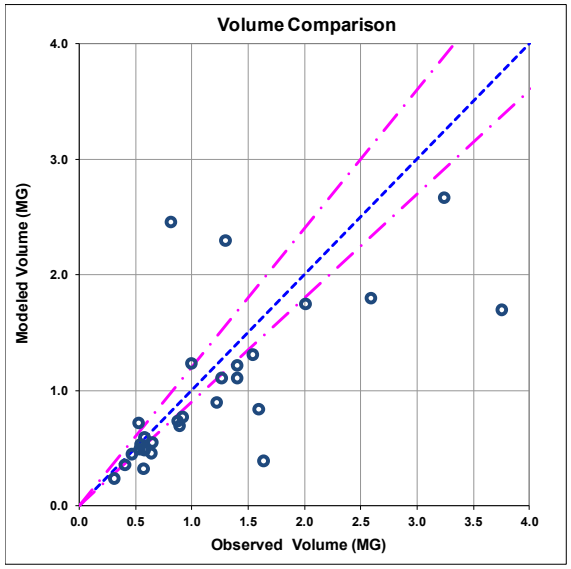


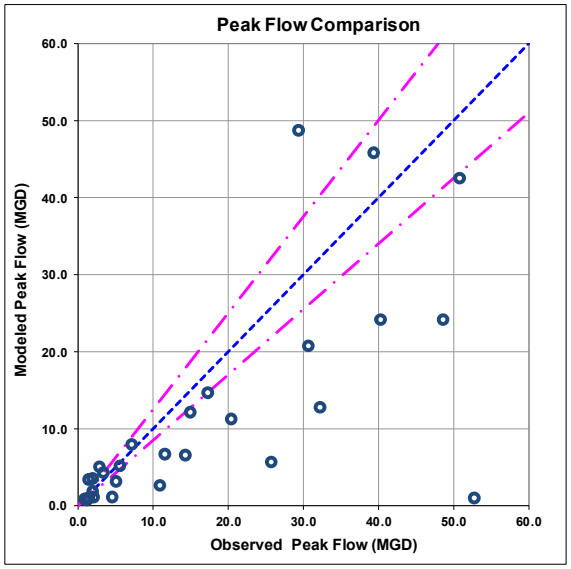


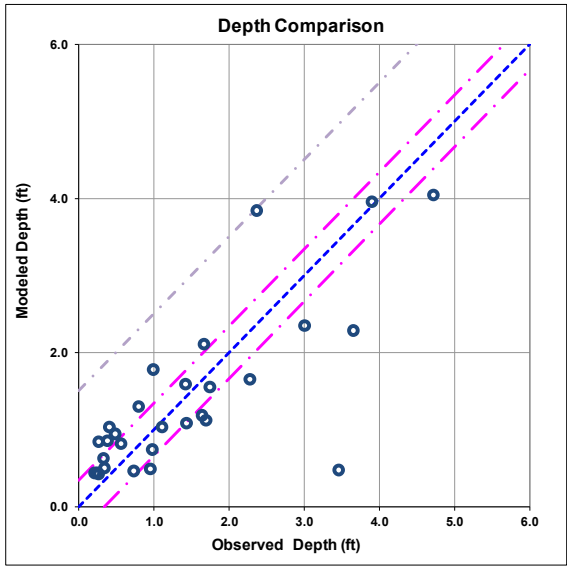


Hazen

Statistical Results for SB8A

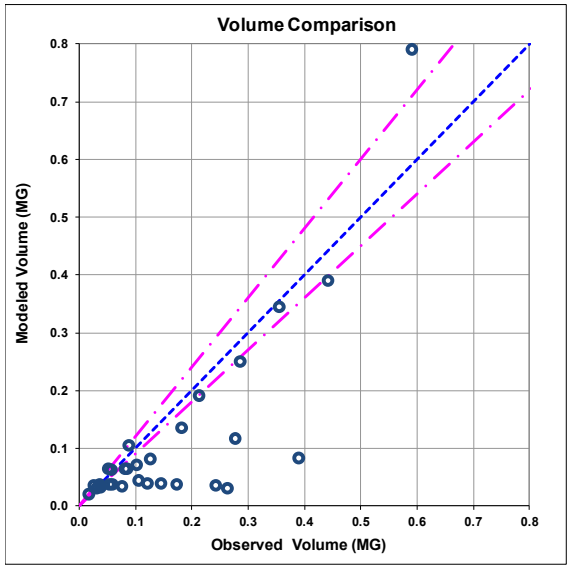


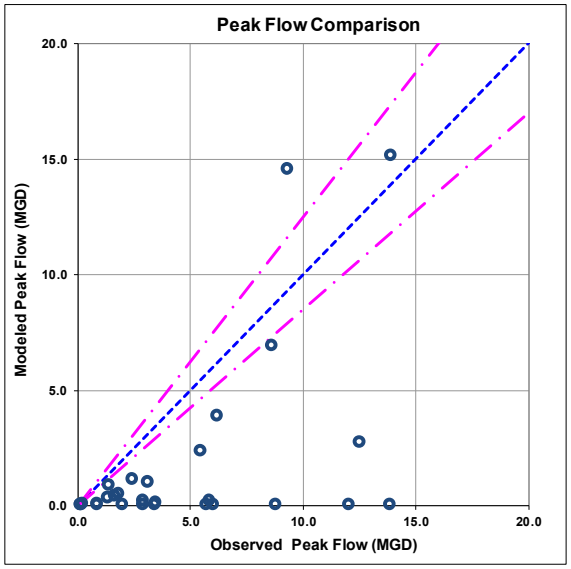


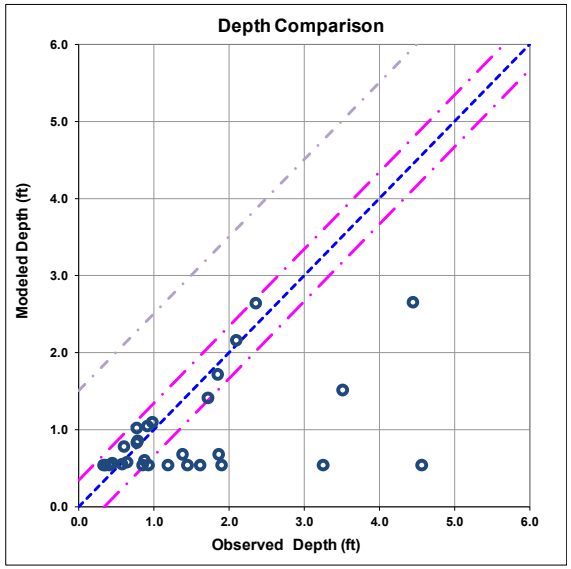


Hazen

Statistical Results for SB9

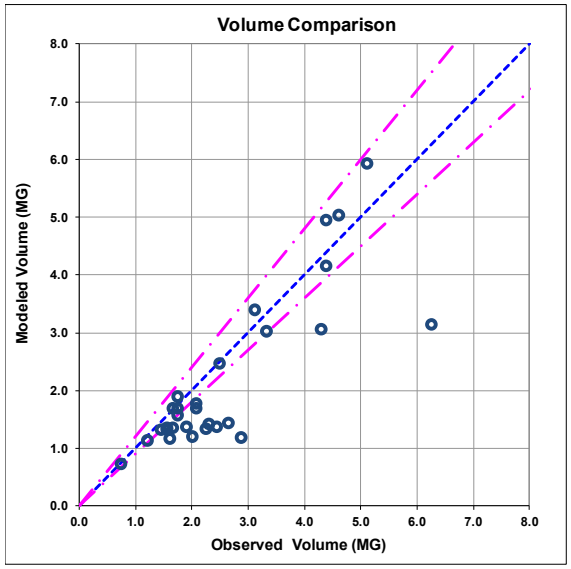


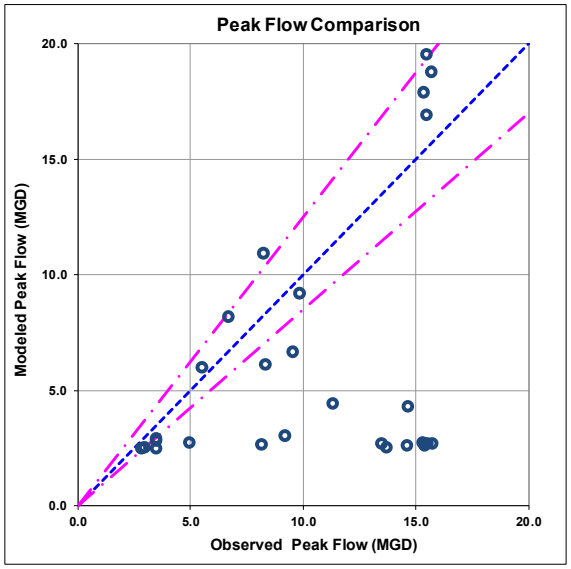


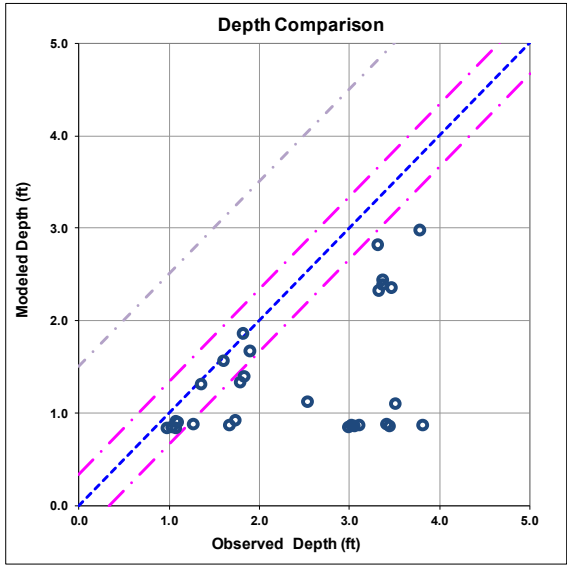


Hazen

Statistical Results for SB11

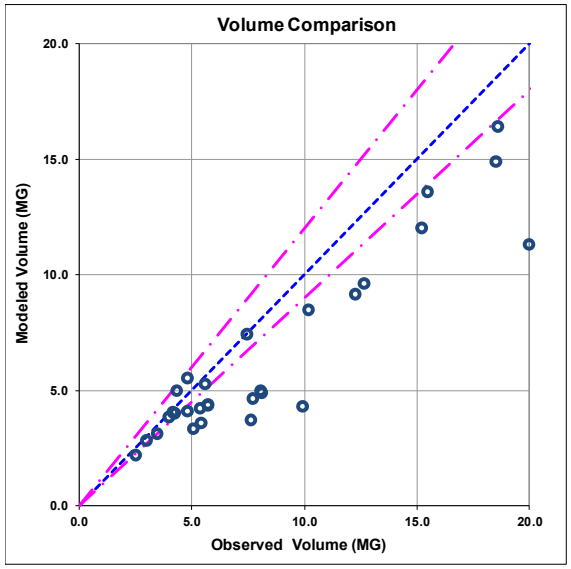


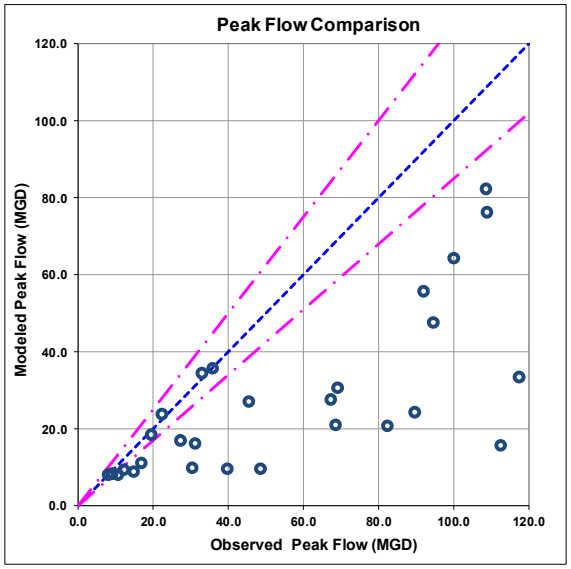


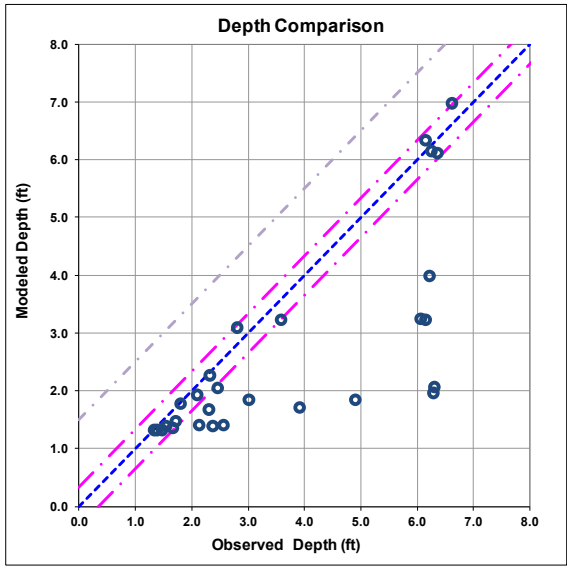


Hazen

Statistical Results for SB12

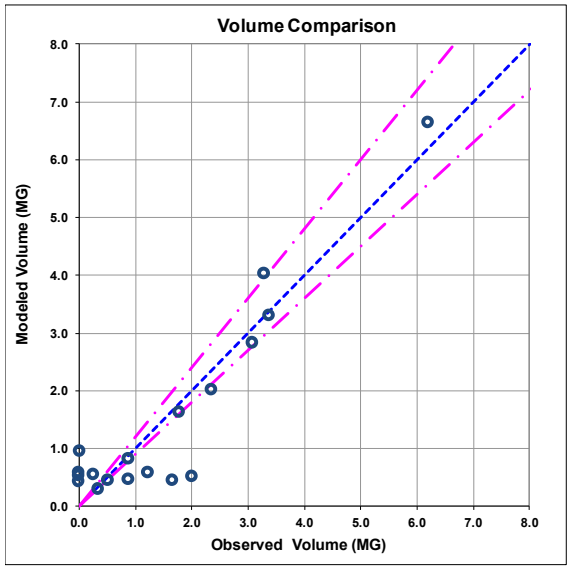


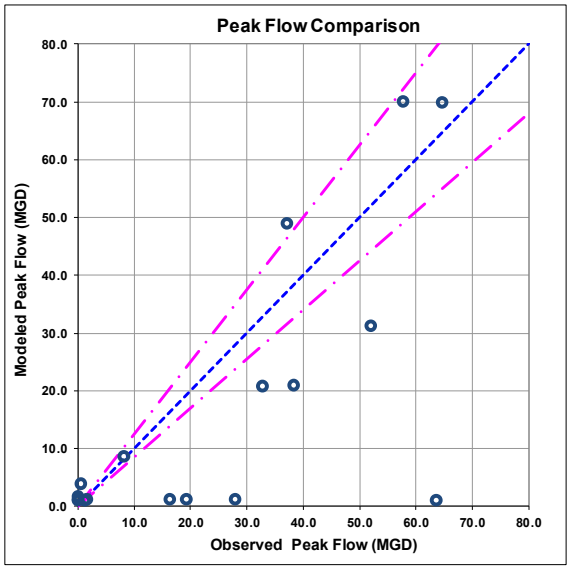


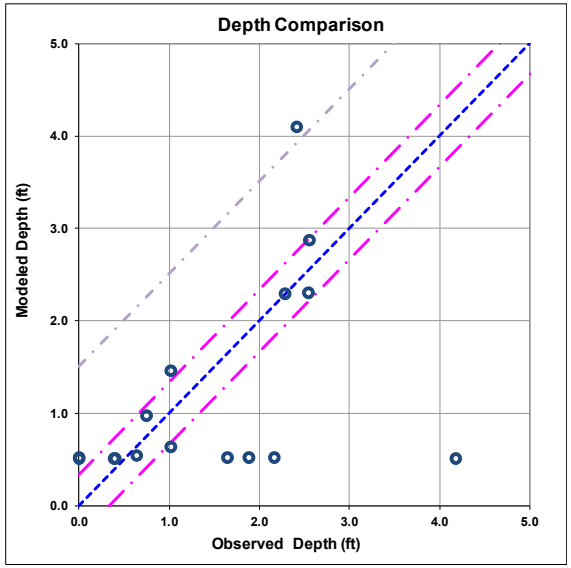


Hazen

Statistical Results for SB13







Hazen

APPENDIX E

Opinion of Probable Construction Costs
Lowell Regional Wastewater Utility
Diversion Stations: Wet Weather Conveyance
Warren

Date: 6/19/2019

CSI Division	Description		Amount
01	*General Conditions*	*20.0%*	*$ 8,717*
02	*Existing Conditions*		*$ 8,580*
03	*Concrete*		*$ 451*
33	*Utilities*		*$ 13,156*
35	*Waterway and Marine Construction*		*$ 21,399*
		Subtotal:	**$ 52,304**
	Value of Subcontracted Work		
	Subcontractor Overhead & Profit	*21.0%*	*$ -*
		Subtotal:	**$ 52,304**
	Labor Escalation at 3.5% annually	*3.25%*	*$ 1,082*
	Material/Equipment Escalation at 5% annually	*2.17%*	*$ 224*
		Subtotal:	**$ 53,610**
	Prime Contractor Overhead	*10.0%*	*$ 5,361*

Date: 6/19/2019

CSI Division	Description		Amount
	Subtotal:		**$ 58,971**
	Prime Contractor Profit	*30.0%*	*$ 17,691*
	Subtotal:		**$ 76,662**
	Prime Contractor Profit On Subcontracted Work	*5.0%*	*$ -*
	Subtotal:		**$ 76,662**
	Bond and Insurance	*3.0%*	*$ 2,300*
	Subtotal:		**$ 78,962**
	Design Contingency	*40.0%*	*$ 31,585*
	Subtotal:		**$ 110,547**
	Contract Allowances		*$ -*
	Total (rounded):		**$ 110,000**

CSI Division	Description	Quantity	Unit	Labor Amount	Equipment Amount	Material Amount	Total Amount
				$26,740	**$6,497**	**$10,350**	**$43,587**
02	**Existing Conditions**						
	Demolish existing gate	1	EA	$3,703	$1,038	$0	$4,741
	Sawcut concrete	1	LS	$1,412	$697	$0	$2,109
	Remove demolished concrete	1	LS	$1,555	$176	$0	$1,730
03	**Concrete**						
	Patch concrete	1	LS	$351	$50	$50	$451
33	**Utilities**						
	Temporary Bypass Pumping System	8	DAYS	$10,612	$2,544	$0	$13,156
35	**Waterway and Marine Construction**						
	72"x72" slide gate	1	EA	$9,107	$1,992	$10,300	$21,399

Hazen

Opinion of Probable Construction Costs
Lowell Regional Wastewater Utility
Diversion Stations: Wet Weather Conveyance
Merrimack

CSI Division	Description		Amount
01	General Conditions	20.0%	$ 13,956
02	Existing Conditions		$ 8,580
03	Concrete		$ 451
33	Utilities		$ 14,801
35	Waterway and Marine Construction		$ 45,948
		Subtotal:	**$ 83,736**
	Value of Subcontracted Work		
	Subcontractor Overhead & Profit	21.0%	$ -
		Subtotal:	**$ 83,736**
	Labor Escalation at 3.5% annually	3.25%	$ 1,737
	Material/Equipment Escalation at 5% annually	2.17%	$ 356
		Subtotal:	**$ 85,829**
	Prime Contractor Overhead	10.0%	$ 8,583
		Subtotal:	**$ 94,411**
	Prime Contractor Profit	30.0%	$ 28,323
		Subtotal:	**$ 122,735**

CSI Division	Description		Amount
	Prime Contractor Profit On Subcontracted Work	5.0%	$ -
	Subtotal:		**$ 122,735**
	Bond and Insurance	3.0%	$ 3,682
	Subtotal:		**$ 126,417**
	Design Contingency	40.0%	$ 50,567
	Subtotal:		**$ 176,984**
	Contract Allowances		$ -
	Total (rounded):		**$ 180,000**

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
					$69,780
02	**Existing Conditions**				
	Demolish existing gate	1	EA	$4,740.99	$4,741
	Sawcut concrete	1	LS	$2,108.56	$2,109
	Remove demolished concrete	1	LS	$1,730.44	$1,730
03	**Concrete**				
	Patch concrete	1	LS	$451.16	$451
33	**Utilities**				
	Temporary Bypass Pumping System	9	DAYS	$1,644.54	$14,801
35	**Waterway and Marine Construction**				
	60"x60" slide gates	2	EA	$22,973.99	$45,948

Hazen

Opinion of Probable Construction Costs
Lowell Regional Wastewater Utility
Drinking Water Backflow and Meter Improvements

CSI Division	Description		Amount
01	General Conditions		$ 487,758
22	Plumbing		$ 4,269,482
	Subtotal:		**$ 4,757,240**
	Value of Subcontracted Work		$ 951,448
	Subcontractor Overhead & Profit	21.0%	$ 199,804
	Subtotal:		**$ 4,957,044**
	Labor Escalation at 3.5% annually	10.55%	$ 207,470
	Material/Equipment Escalation at 5% annually	15.29%	$ 426,901
	Subtotal:		**$ 5,591,415**
	Prime Contractor Overhead	10.0%	$ 559,141
	Subtotal:		**$ 6,150,556**
	Prime Contractor Profit	10.0%	$ 615,056
	Subtotal:		**$ 6,765,612**

CSI Division	Description		Amount
	Prime Contractor Profit On Subcontracted Work	5.0%	$ 47,572
	Subtotal:		**$ 6,813,184**
	Bond and Insurance	3.0%	$ 204,396
	Subtotal:		**$ 7,017,580**
	Design Contingency	20.0%	$ 1,403,516
	Subtotal:		**$ 8,421,095**
	Contract Allowances		
	Total (rounded):		**$ 8,400,000**

SI Divisio	Description	Quantity	Unit	Total Unit Cost	Total Amount
					$4,757,240
01	**General Conditions**				
	Project Manager	3	MO	$15,400.00	$46,200
	Superintendent	27	MO	$14,520.00	$392,040
	Field Office Trailers	27	MO	$1,834.00	$49,518
	Subtotal General Conditions				**$487,758**
22	**Plumbing**				
	Remove existing water meters	1500	EA	$585.66	$878,491
	Water supply meter, bronze, compound, flanged, 4" diameter	1500	EA	$2,260.66	$3,390,991
					$4,269,482

	Description		Amount
	General Requirements		$ 454,448
	Demolition		$ 175,494
	Process Mechanical		$ 361,084
	Lagoons		$ 994,965
	Architectural		$ 154,067
	Electrical		$ 478,427
	Instrumentation and Control		$ 108,202
	Subtotal:		**$ 2,726,687**
	Value of Subcontracted Work		$ 545,337
	Subcontractor Overhead & Profit	21.0%	$ 114,521
	Subtotal:		**$ 2,841,208**
	Labor Escalation at 3.5% annually	4.69%	$ 43,527
	Material/Equipment Escalation at 5% annually	6.72%	$ 120,944
	Subtotal:		**$ 3,005,679**
	Prime Contractor Overhead	10.0%	$ 300,568
	Subtotal:		**$ 3,306,247**
	Prime Contractor Profit	10.0%	$ 330,625
	Subtotal:		**$ 3,636,872**

	Description		Amount
	Prime Contractor Profit On Subcontracted Work	5.0%	$ 32,993
	Subtotal:		**$ 3,669,865**
	Bond and Insurance	3.0%	$ 110,096
	Subtotal:		**$ 3,779,961**
	Design Contingency	40.0%	$ 1,511,984
	Subtotal:		**$ 5,291,945**
	Contract Allowances		
	Total (rounded):		**$ 5,300,000**

SI Divisio	Description	Quantity	Unit	Total Unit Cost	Total Amount
	General Requirements				
	Allowance at 20%	1	ls	$454,447.87	$454,448
	Subtotal				**$454,448**
	Demolition				
	Demolish existing gates at intake structure	1	ls	$81,256.54	$81,257
	Demolish existing lab cabinets, counters, benches	1	ls	$20,423.02	$20,423
	Remove existing refrigerator	1	ea	$95.93	$96
	Demolish existing sodium bicarbonate silo	1	ea	$37,769.66	$37,770
	Demolish existing analyzers	1	ls	$7,730.44	$7,730
	Demolish existing chloride dioxide system at intake building	1	ls	$4,137.82	$4,138
	Demolish existing video surveillance system	1	ls	$24,080.87	$24,081
	Subtotal				**$175,494**
	Process Mechanical				
	Influent gates	1	ls	$152,685.47	$152,685
	Sodium bicarbonate silo	1	ea	$101,342.74	$101,343
	Analyzers	1	ls	$46,183.93	$46,184
	Chlorine dioxide system	1	ls	$60,871.45	$60,871
	Subtotal				**$361,084**
	Lagoons				
	Excavation	17778	cy	$23.52	$418,203
	Subgrade crushed stone	2963	cy	$33.70	$99,847
	4" thick concrete lining	1086	cy	$158.00	$171,658
	Haul spoils	17778	cy	$17.17	$305,257
	Subtotal				**$994,965**
	Architectural				
	Lab cabinets, benches, counters	1	ls	$151,932.69	$151,933
	Lab refrigerator	1	ea	$2,134.51	$2,135
	Subtotal				**$154,067**
	Electrical				
	Video surveillance system	1	ls	$196,161.73	$196,162
	Allowance at 15%	1	ls	$282,265.76	$282,266
	Subtotal				**$478,427**
	Instrumentation and Control				
	Allowance at 5%	1	ls	$108,201.87	$108,202
	Subtotal				**$108,202**
	TOTALS				**$2,726,687**

Hazen

Opinion of Probable Construction Costs
Lowell Regional Wastewater Utility
Duck Island 200 MGD Treatment Facility

CSI Division	Description		Amount
01	General Conditions	20.0%	$ 2,928,874
02	Existing Conditions		$ 719,529
03	Concrete		$ 870,933
04	Masonry		$ 129,635
05	Metals		$ 318,692
07	Thermal and Moisture Protection		$ 1,483,200
08	Openings		$ 25,000
09	Finishes		$ 17,897
10	Specialties		$ 10,000
11	Equipment		$ 3,857,006
22	Plumbing		$ 155,000
23	HVAC		$ 609,000
26	Electrical		$ 1,910,136
31	Earthwork		$ 2,113,241
32	Exterior Improvements		$ 50,000
33	Utilities		$ 1,465,410
40	Process Interconnections		$ 425,000
		Subtotal:	**$ 17,088,553**
	Value of Subcontracted Work		$ 3,417,711
	Subcontractor Overhead & Profit	21.0%	$ 717,719
		Subtotal:	**$ 17,806,273**
	Escalation to Midpoint of Construction	9.27%	$ 1,651,122

CSI Division	Description		Amount
	Subtotal:		**$ 19,457,395**
	Prime Contractor Overhead	10.0%	$ 1,945,739
	Subtotal:		**$ 21,403,134**
	Prime Contractor Profit	10.0%	$ 2,140,313
	Subtotal:		**$ 23,543,448**
	Prime Contractor Profit On Subcontracted Work	5.0%	$ 206,771
	Subtotal:		**$ 23,750,219**
	Bond and Insurance	3.0%	$ 712,507
	Subtotal:		**$ 24,462,726**
	Design Contingency	40.0%	$ 9,785,090
	Subtotal:		**$ 34,247,816**
	Contract Allowances		$ -
	Total (rounded):		**$ 34,200,000**

SI Divisio	Description	Quantity	Unit	Total Unit Cost	Total Amount
	Assume new raw water pump station, Actiflo system, outfall, yard piping				
02	**Existing Conditions**				
	Relocate existing utilities	1	LS	$719,528.51	$719,529
03	**Concrete**				
	New Raw Water Pump Station				
	F/R/P base slab	533	CY	$710.00	$378,667
	F/R/P walls	427	CY	$710.00	$302,933
	F/R/P top slab	267	CY	$710.00	$189,333
	New Actiflo System Structure				
	F/R/P base slab	237	CY	$710.00	$168,296
	F/R/P walls	320	CY	$710.00	$227,200
	F/R/P top slab	119	CY	$710.00	$84,148
	New Outfall				
	F/R/P headwall	7	CY	$710.00	$5,049
04	**Masonry**				
	New Raw Water Pump Station				
	Exterior CMU walls	4320	SF	$10.75	$46,420
	Interior CMU walls	2880	SF	$9.45	$27,207
	Scaffold	288000	CF	$0.19	$56,008
05	**Metals**				
	New Raw Water Pump Station				
	Structural steel	1	LS	$173,986.00	$173,986
	Bar joists	1	LS	$15,894.00	$15,894
	Metal roof deck	7200	SF	$4.00	$28,812
	Railings, grating, platforms	1	LS	$65,000.00	$65,000
	New Actiflo System Structure				
	Railings, grating, platforms	1	LS	$35,000.00	$35,000
07	**Thermal and Moisture Protection**				
	EPDM roof system allowance	1	LS	$1,483,200.00	$1,483,200
08	**Openings**				
	Doors and windows allowance	1	LS	$25,000.00	$25,000
09	**Finishes**				
	Painting	10080	SF	$1.78	$17,897
10	**Specialties**				
	Allowance	1	LS	$10,000.00	$10,000
11	**Equipment**				
	Catenary bar screens + controls	2	EA	$347,636.58	$695,273
	Slide gates	4	EA	$11,261.55	$45,046
	Grit removal system	1	LS	$200,000.00	$200,000
	Microsand system	1	LS	$2,500,000.00	$2,500,000
	Chemical feed systems	1	LS	$275,000.00	$275,000

SI Divisio	Description	Quantity	Unit	Total Unit Cost	Total Amount
	Assume new raw water pump station, Actiflo system, outfall, yard piping				
	6,000 gpm pumps N+1	3	EA	$47,229.00	$141,687
22	**Plumbing**				
	Allowance	1	LS	$155,000.00	$155,000
23	**HVAC**				
	Allowance	1	LS	$609,000.00	$609,000
26	**Electrical**				
	Allowance	1	LS	$1,910,135.52	$1,910,136
31	**Earthwork**				
	Excavation	1	LS	$1,393,760.79	$1,393,761
	Backfill and compaction	1	LS	$348,440.20	$348,440
	Sheeting	15000	SF	$24.74	$371,040
32	**Exterior Improvements**				
	Allowance	1	LS	$50,000.00	$50,000
33	**Utilities**				
	Yard Pipe	1	LS	$1,234,357.02	$1,234,357
	Outfall pipe	400	LF	$577.63	$231,053
40	**Process Interconnections**				
	Process pipe allowance	1	LS	$225,000.00	$225,000
	SCADA allowance	1	LS	$200,000.00	$200,000

Hazen

Opinion of Probable Construction Costs
Lowell Regional Wastewater Utility
Duck Island Peak Flow Optimization

CSI Division	Description		Amount
01	General Conditions	20.0%	$ 1,597,186
02	Existing Conditions		$ 27,697
03	Concrete		$ 17,494
11	Equipment		$ 1,110,479
13	Special Construction		$ -
17	Instrumentation and Control		$ -
22	Plumbing		$ -
26	Electrical		$ 208,329
31	Earthwork		$ -
32	Exterior Improvements		$ -
40	Process Interconnections		$ 125,415
		Subtotal:	**$ 3,086,599**
	Value of Subcontracted Work		$ 617,320
	Subcontractor Overhead & Profit	21.0%	$ 129,637
		Subtotal:	**$ 3,216,237**
	Labor Escalation at 3.5% annually	3.50%	$ 7,149
	Material/Equipment Escalation at 5% annually	5.00%	$ 59,231
		Subtotal:	**$ 3,282,616**
	Prime Contractor Overhead	10.0%	$ 328,262
		Subtotal:	**$ 3,610,877**
	Prime Contractor Profit	10.0%	$ 361,088
		Subtotal:	**$ 3,971,965**

CSI Division	Description		Amount
	Prime Contractor Profit On Subcontracted Work	5.0%	$ 37,348
		Subtotal:	**$ 4,009,313**
	Bond and Insurance	3.0%	$ 120,279
		Subtotal:	**$ 4,129,592**
	Design Contingency	40.0%	$ 1,651,837
		Subtotal:	**$ 5,781,429**
	Contract Allowances		$ -
		Total (rounded):	**$ 5,800,000**

SI Divisio	Description	Quantity	Unit	Total Unit Cost	Total Amount
02	**Existing Conditions**				
	Demolish existing pipe and fittings	6	EA	$5,539.31	$33,236
	Demolish existing bar screens	2	EA	$11,078.62	$22,157
	Demolish existing slide gates	4	EA	$11,078.62	$44,314
	Demolish existing concrete for new channel	1	LS	$27,696.56	$27,697
	Sawcut concrete	1	LS	$8,064.23	$8,064
03	**Concrete**				
	Add third channel				
	F/R/P concrete walls and slabs	25	CY	$710.00	$17,494
11	**Equipment**				
	Catenary bar screens + controls	3	EA	$347,636.58	$1,042,910
	Slide gates	6	EA	$11,261.55	$67,569
26	**Electrical**				
	Allowance	1	LS	$208,328.56	$208,329
40	**Process Interconnections**				
	30" spool piece FLxFL	6	EA	$6,396.77	$38,381

CSI Div.	Description				Total
	General Conditions	20.0%	on	$1,942,745	$ 388,549
	Scope of Work				$ 1,942,745
		Subtotal:			**$ 2,331,294**
	Value of Subcontracted Work			$ 466,259	
	Subcontractor Overhead, Profit & Fee	21.0%	on	$ 466,259	$ 97,914
		Subtotal:			**$ 2,429,208**
	Prime Contractor Overhead	10.0%	on	$1,865,035	$ 186,503
		Subtotal:			**$ 2,615,712**
	Prime Contractor Profit	10.0%	on	$2,051,538	$ 205,154
		Subtotal:			**$ 2,820,865**
	GC Profit on Subcontracted Work	5.0%	on	$ 564,173	$ 28,209
		Subtotal:			**$ 2,849,074**
	Labor Escalation at 3.5% annually	6.2%	on	$ 339,880	$ 21,090
	Equipment/Material Escalation at 5% annually	8.9%	on	$1,602,865	$ 142,870
		Subtotal:			**$ 3,013,034**
	Bond and Insurance	3.0%			$ 90,391
		Subtotal:			**$ 3,103,425**
	Design Contingency	40.0%			$ 1,241,370
		Subtotal:			**$ 4,344,795**
	Contract Allowances	2.0%			$ 86,896
	Unit Price Items				$ -

	Total (rounded):	**$4,432,000**

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
					$1,942,745
	Per Woodard & Curran Construction Plan				
	Modify horizontal conveyor	1	ea	$26,400.53	$26,401
	Demo equipment and facilities in dewatering room	1	ea	$109,577.96	$109,578
	Install centrifuges	2	ea	$720,594.86	$1,441,190
	Remove transfer conveyor	1	ea	$11,898.80	$11,899
	Remove Sharples centrifuge	1	ea	$19,831.34	$19,831
	Electrical				
	Allowance at 15%	1	ls		$241,335
	Instrumentation and Control				
	Allowance at 5%	1	ls		$92,512

Hazen

Opinion of Probable Construction Costs
Lowell Regional Wastewater Utility
Duck Island WWTF Upgrades

Item	Description					Total
1	General Requirements					$ 478,868
2	Demolition					$ 385,227
3	Concrete					$ 389,545
4	Thermal & Moisture Protection					$ 3,776
5	Finishes					$ 12,381
6	Process Mechanical					$ 1,641,418
7	Electrical					$ 608,086
8	Instrumentation & Controls					$ 152,022
		Subtotal:				**$ 3,671,322**
	Value of Subcontracted Work			$	734,264	
	Subcontractor Overhead, Profit & Fee	21.0%	on	$	734,264	$ 154,196
		Subtotal:				**$ 3,825,518**
	Prime Contractor Overhead	10.0%	on	$	2,937,058	$ 293,706
		Subtotal:				**$ 4,119,224**
	Prime Contractor Profit	15.0%	on	$	3,230,764	$ 484,615
		Subtotal:				**$ 4,603,838**
	GC Profit on Subcontracted Work	5.0%	on	$	888,460	$ 44,423
		Subtotal:				**$ 4,648,261**
	Labor Escalation at 3.5% annually	8.7%	on	$	1,365,922	$ 118,412
	Equipment/Material Escalation at 5% annually	12.5%	on	$	2,305,400	$ 288,503
		Subtotal:				**$ 5,055,177**
	Bond and Insurance	3.0%				$ 151,655

Item	Description		Total
	Subtotal:		**$ 5,206,832**
	Design Contingency	40.0%	$ 2,082,733
	Subtotal:		**$ 7,289,565**
	Contract Allowances	2.0%	$ 145,791
	Unit Price Items		$ -
	Total (rounded):		**$ 7,400,000**

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
					$3,671,322
	General Requirements				
	Allowance at 15%				$478,868
	Subtotal				**$478,868**
	Demolition				
	Demolish MCCs	1	ls	$122,655.75	$122,656
	Demolish VFDs	1	ls	$25,131.18	$25,131
	Demolish existing aeration tank equipment	9540	sf	$3.41	$32,574
	Demolish classifiers	2	ea	$34,144.36	$68,289
	Demolish cyclones	2	ea	$34,144.36	$68,289
	Demolish bar racks	2	ea	$34,144.36	$68,289
	Subtotal				**$385,227**
	Concrete				
	Form, Rebar, and Place Concrete	500	cy	$779.09	$389,545
	Subtotal				**$389,545**
	Thermal and Moisture Protection				
	Joint sealants	1	ls	$3,775.99	$3,776
	Subtotal				**$3,776**
	Finishes				
	Painting	1	ls	$12,380.57	$12,381
	Subtotal				**$12,381**
	Process Mechanical				
	Aeration diffusers	9540	sf	$32.61	$311,126
	Classifiers	2	ea	$183,428.98	$366,858
	Cyclones	2	ea	$183,428.98	$366,858
	Bar racks	2	ea	$233,428.98	$466,858
	Odor control duct repairs	1	ls	$104,793.04	$104,793
	Chlorination injection spray bars	1	ls	$24,925.48	$24,925
	Subtotal				**$1,641,418**
	Electrical				
	Allowance at 25%				$608,086
	Subtotal				**$608,086**
	Instrumentatio and Control				
	Allowance at 5%				$152,022
	Subtotal				**$152,022**

Hazen

Opinion of Probable Construction Costs
Lowell Regional Wastewater Utility
Finished Water Storage Tank

Item	Description					Total
1	General Conditions					$ 1,592,744
2	Site Work					$ 544,097
3	Concrete					$ 2,692,024
4	Composite Tank					$ 5,000,000
5	Yard Pipe					$ 557,499
6	Electrical					$ 1,319,043
7	Instrumentation and Control					$ 505,633
		Subtotal:				**$ 12,211,040**
	Value of Subcontracted Work			$	6,824,676	
	Subcontractor Overhead, Profit & Fee	21.0%	on	$	6,824,676	$ 1,433,182
		Subtotal:				**$ 13,644,222**
	Prime Contractor Overhead	10.0%	on	$	5,386,364	$ 538,636
		Subtotal:				**$ 14,182,859**
	Prime Contractor Profit	10.0%	on	$	5,925,001	$ 592,500
		Subtotal:				**$ 14,775,359**
	GC Profit on Subcontracted Work	5.0%	on	$	8,257,858	$ 412,893
		Subtotal:				**$ 15,188,252**
	Labor Escalation at 3.5% annually	6.8%	on	$	4,763,226	$ 324,654
	Material/Equip Escalation at 5% annually	9.8%	on	$	7,447,815	$ 730,083
		Subtotal:				**$ 16,242,989**
	Bond and Insurance	3.0%				$ 487,290
		Subtotal:				**$ 16,730,279**

Item	Description		Total
	Design Contingency	10.0%	$ 1,673,028
	Subtotal:		**$ 18,403,306**
	Contract Allowances		$ -
	Unit Price Items		$ -
	Total (rounded):		**$ 18,403,000**

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
					$12,211,040
	General Requirements				
	Allowance at 15%	1	ls		$1,592,744
	Subtotal				**$1,592,744**
	Site Work				
	Clear and grub	1	acre	$6,898.07	$6,898
	Stockpile topsoil	807	cy	$1.80	$1,454
	Excavation for tanks	8889	cy	$11.08	$98,478
	Haul spoils	8889	cy	$17.01	$151,244
	Structural fill	2222	cy	$26.93	$59,844
				$0.00	$0
	Pipe trench			$0.00	$0
	Excavation	4537	cy	$11.08	$50,265
	Pipe bedding	648	cy	$26.93	$17,454
	Backfill	3889	cy	$25.73	$100,054
	Trench width pavement 6" thick	1944	sy	$23.51	$45,723
	Haul spoils	745	cy	$17.01	$12,682
	Subtotal				**$544,097**
	Concrete				
	Formwork	32000	sf	$14.50	$463,958
	Rebar	332	tons	$3,371.78	$1,119,432
	Concrete	6800	cy	$152.35	$1,035,964
	Finish and cure	60000	sf	$1.21	$72,670
	Subtotal				**$2,692,024**
	Composite Tank and Pump Station				
	Per manufactuer	1	ls		$5,000,000
	Subtotal				**$5,000,000**
	Yard Pipe				
	16" DI pipe water main	3500	lf	$159.29	$557,499
	Subtotal				**$557,499**
	Electrical				
	Allowance at 15%	1	ls		$1,319,043
	Subtotal				**$1,319,043**
	Instrumentation and Control				
	Allowance at 5%	1	ls		$505,633
	Subtotal				**$505,633**
	TOTALS				**$12,211,040**

Hazen

Opinion of Probable Construction Costs
Lowell Regional Wastewater Utility
Lead Service Replacements

CSI Division	Description		Amount
01	General Conditions		$ 696,230
02	Existing Conditions		$ 189,231
31	Earthwork		$ 583,480
32	Exterior Improvements		$ 580,909
33	Utilities		$ 544,078
	Subtotal:		**$ 2,593,929**
	Value of Subcontracted Work		$ 518,786
	Subcontractor Overhead & Profit	21.0%	$ 108,945
	Subtotal:		**$ 2,702,874**
	Labor Escalation at 3.5% annually	10.24%	$ 134,078
	Material/Equipment Escalation at 5% annually	14.82%	$ 87,182
	Subtotal:		**$ 2,924,134**
	Prime Contractor Overhead	10.0%	$ 292,413
	Subtotal:		**$ 3,216,547**
	Prime Contractor Profit	10.0%	$ 321,655
	Subtotal:		**$ 3,538,202**
	Prime Contractor Profit On Subcontracted Work	5.0%	$ 31,387

CSI Division	Description		Amount
	Subtotal:		**$ 3,569,588**
	Bond and Insurance	3.0%	$ 107,088
	Subtotal:		**$ 3,676,676**
	Design Contingency	10.0%	$ 367,668
	Subtotal:		**$ 4,044,343**
	Contract Allowances		
	Total (rounded):		**$ 4,000,000**

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
					$1,897,699
	Existing Conditions				
	Test pits	10	CY	$418.02	$4,180
	Demolish, remove pavement & curb, remove bituminous pave	4583	SY	$9.89	$45,313
	Hauling and disposal	764	CY	$17.17	$13,117
	Remove existing services	27500	LF	$4.60	$126,622
	Subtotal Division 02				**$189,231**
	Earthwork				
	Excavate trench	15278	CY	$6.34	$96,865
	Backfill, plus 15% compaction, assume reuse excavated mate	8158	CY	$12.98	$105,880
	12" pipe bedding	82500	SF	$2.17	$179,201
	8" pavement subbase	1019	CY	$22.01	$22,415
	Erosion & Sedimentation Control	5500	LF	$7.98	$43,896
	Dewatering	550	EA	$81.63	$44,897
	Haul surplus material	4074	CY	$22.17	$90,325
	Subtotal Division 31				**$583,480**
	Exterior Improvements				
	Plant-mix asphalt paving, pavement over trench, 4" thick	4583	SY	$73.85	$338,476
	Remove and reset granite curb	5500	LF	$38.51	$211,831
	Concrete for reset curb	204	CY	$117.39	$23,913
	Hydroseed	6111	SY	$1.09	$6,690
	Subtotal Division 32				**$580,909**
	Utilities				
	1" curb stops	550	EA	$194.51	$106,980
	Curb boxes	275	EA	$162.51	$44,691
	1" copper tubing	27500	LF	$14.27	$392,407
	Subtotal Division 33				**$544,078**

Division	Description	General Contract	Unit Masonry Subcontract	Metal Subcontract	Roofing & Flashing Subcontract	Acoustical Tile Subcontract	Painting & Coating Subcontract	Fire Protection Subcontract	HVAC Subcontract	Plumbing Subcontract	Electrical Subcontract	Total
	General Conditions	$ 929,434	$ 14,572		$ 8,802	$ -	$ 1,086	$ -	$ 6,905	$ 15,529	$ 22,036	$ 998,364
	Sitework	$ 25,062										$ 25,062
	Concrete	$ 3,534,847										$ 3,534,847
	Masonry		$ 72,862									$ 72,862
	Wood, Plastics, & Composites				$ 23,563							$ 23,563
	Thermal & Moisture Protection				$ 20,449							$ 20,449
	Openings	$ 20,965										$ 20,965
	Finishes	$ 1,157					$ 5,428					$ 6,585
	Specialties	$ 14,577										$ 14,577
	Equipment	$ 742,149										$ 742,149
	Special Construction	$ 58,766										$ 58,766
	Mechanical	$ 173,364										$ 173,364
	Instrumentation & Control	$ 109,644										$ 109,644
	Plumbing									$ 77,643		$ 77,643
	HVAC								$ 34,526			$ 34,526
	Electrical										$ 110,179	$ 110,179
	Earthwork	$ 4,652,696										$ 4,652,696
	Exterior Improvements	$ 50,959										$ 50,959
	Utilities	$ 318,097										$ 318,097
	Subtotal:	**$ 10,631,718**	**$ 87,435**	**$ -**	**$ 52,815**	**$ -**	**$ 6,514**	**$ -**	**$ 41,431**	**$ 93,171**	**$ 132,215**	**$ 11,045,299**
	Subcontractor Overhead & Profit 25.0%	$ 531,586		$ -		$ -		$ -				$ 531,586
	Subtotal:	**$ 11,163,304**	**$ 87,435**	**$ -**	**$ 52,815**	**$ -**	**$ 6,514**	**$ -**	**$ 41,431**	**$ 93,171**	**$ 132,215**	**$ 11,576,885**

Division	Description		General Contract	Unit Masonry Subcontract	Metal Subcontract	Roofing & Flashing Subcontract	Acoustical Tile Subcontract	Painting & Coating Subcontract	Fire Protection Subcontract	HVAC Subcontract	Plumbing Subcontract	Electrical Subcontract	Total
	Escalation at 4.5% annually	8.01%	$ 893,890	$ 7,001	$ -	$ 4,229	$ -	$ 522	$ -	$ 3,318	$ 7,461	$ 10,587	$ 927,007
		Subtotal:	**$ 12,057,194**	**$ 94,436**	**$ -**	**$ 57,044**	**$ -**	**$ 7,035**	**$ -**	**$ 44,749**	**$ 100,632**	**$ 142,802**	**$ 12,503,892**
	Contractor Overhead (Not on subcontract)	10.0%	$ 1,052,207	$ 9,444	$ -	$ 5,704	$ -	$ 704	$ -	$ 4,475	$ 10,063	$ 14,280	$ 1,096,877
		Subtotal:	**$ 13,109,401**	**$ 103,880**	**$ -**	**$ 62,748**	**$ -**	**$ 7,739**	**$ -**	**$ 49,224**	**$ 110,695**	**$ 157,082**	**$ 13,600,769**
	Contractor Profit (Not on subcontract)	10.0%	$ 1,157,428	$ 10,388	$ -	$ 6,275	$ -	$ 774	$ -	$ 4,922	$ 11,070	$ 15,708	$ 1,206,565
		Subtotal:	**$ 14,266,830**	**$ 114,268**	**$ -**	**$ 69,023**	**$ -**	**$ 8,512**	**$ -**	**$ 54,146**	**$ 121,765**	**$ 172,790**	**$ 14,807,334**
	GC Profit on Subcontracted Work	5.0%	$ 60,029										$ 60,029
		Subtotal:	**$ 14,326,859**	**$ 114,268**	**$ -**	**$ 69,023**	**$ -**	**$ 8,512**	**$ -**	**$ 54,146**	**$ 121,765**	**$ 172,790**	**$ 14,867,363**
	Bonds and Insurance	3.0%	$ 429,806	$ 3,428	$ -	$ 2,071	$ -	$ 255	$ -	$ 1,624	$ 3,653	$ 5,184	$ 446,021
		Subtotal:	**$ 14,756,665**	**$ 117,696**	**$ -**	**$ 71,094**	**$ -**	**$ 8,768**	**$ -**	**$ 55,770**	**$ 125,418**	**$ 177,974**	**$ 15,313,384**
	Design Contingency	20.0%	$ 2,951,333	$ 23,539	$ -	$ 14,219	$ -	$ 1,754	$ -	$ 11,154	$ 25,084	$ 35,595	$ 3,062,677
		Subtotal:	**$ 17,707,998**	**$ 141,235**	**$ -**	**$ 85,313**	**$ -**	**$ 10,521**	**$ -**	**$ 66,925**	**$ 150,501**	**$ 213,569**	**$ 18,376,061**
	Police Details												$ 316,800
	Allowances/Unit Price Items	5.0%											$ 918,803
		Total (rounded):	**$ 17,708,000**	**$ 141,000**	**$ -**	**$ 85,000**	**$ -**	**$ 11,000**	**$ -**	**$ 67,000**	**$ 151,000**	**$ 214,000**	**$ 19,700,000**

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
02	**General Conditions**				
	Project Manager	18	MO	$17,105.83	$307,905
	Assistant Project Manager	18	MO	$13,422.50	$241,605
	Superintendent	18	MO	$16,022.50	$288,405
	Field Offices	36	MO	$1,834.00	$66,024
	Temporary fence	850	LF	$7.50	$6,378
	Survey	10	DAYS	$1,911.70	$19,117
	Subtotal Division 02				**$929,434**
02	**Existing Conditions**				
	Test pit	25	CY	$279.08	$6,977
	Pavement demolition	1008	SY	$11.38	$11,472
	Haul pavement demolition	168	CY	$39.36	$6,613
	Subtotal Division 02				**$25,062**
03	**Concrete**				
	Form mat foundation elevation 39.00	595	SF	$15.72	$9,355
	Form mat foundation elevation 44.10 A1	570	SF	$15.72	$8,962
	Form mat foundation elevation 44.10 A2	101	SF	$15.72	$1,588
	Rebar mat foundations	161752	LBS	$2.13	$343,910
	Place concrete	869	CY	$143.35	$124,573
	Water stop	735	LF	$18.66	$13,712
	Form north walls 2'-6" thick	8228	SF	$15.72	$129,366
	Form east walls 2'-6" thick	3159	SF	$15.72	$49,668
	Form south walls 2'-6" thick	10234	SF	$15.72	$160,905
	Form west walls 2'-6" thick	2754	SF	$15.72	$43,300
	Rebar exterior walls	246007	LBS	$2.13	$523,049
	Place concrete	1129	CY	$143.35	$161,845
	Form interior walls 2'-0" thick	20502	SF	$15.72	$322,345
	Rebar interior walls	165535	LBS	$2.13	$351,953
	Place concrete	760	CY	$143.35	$108,948
	Form roof slab 1'-0" thick A1	18225	SF	$12.89	$234,983
	Form roof slab 1'-0" thick A2	128	SF	$12.89	$1,650
	Form roof slab 1'-0" thick A3	865	SF	$12.89	$11,153
	Rebar roof slab	155163	LBS	$2.13	$329,901
	Place concrete	712	CY	$143.35	$102,067
	Form exterior walls inlet structure 2'-6" thick	4816	SF	$15.72	$75,720
	Rebar exterior walls inlet structure 2'-6" thick	48606	LBS	$2.13	$103,344
	Place concrete	223	CY	$143.35	$31,968
	Form overflow slab 1'-0" thick	464	SF	$15.94	$7,397
	Rebar overflow slab 1'-0" thick	3062	LBS	$2.13	$6,510
	Place concrete	17	CY	$143.35	$2,437
	Form manhole riser walls 2'-6" thick	423	SF	$15.72	$6,651
	Rebar manhole riser walls 2'-6" thick	2792	LBS	$2.13	$5,936
	Place concrete	40	CY	$143.35	$5,734
	Fill concrete A1	50	CY	$137.51	$6,876
	Fill concrete A2	29	CY	$137.51	$3,988
	Fill concrete A3	45	CY	$137.51	$6,188
	Fill concrete A4	9	CY	$137.51	$1,238

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
	Junction Chamber				
	Form mat foundation	168	SF	$15.72	$2,641
	Rebar mat foundations	8514	LBS	$2.13	$18,102
	Place concrete	39	CY	$143.35	$5,591
	Water stop	108	LF	$18.66	$2,015
	Form walls 1'-4" thick	3112	SF	$15.72	$48,929
	Rebar walls	10268	LBS	$2.13	$21,831
	Place concrete	77	CY	$143.35	$11,038
	Form roof slab 1'-0"	595	SF	$12.89	$7,672
	Rebar roof slab	4804	LBS	$2.13	$10,214
	Place concrete	22	CY	$143.35	$3,154
	Form 2'-6" beams	90	SF	$12.89	$1,160
	Rebar 2'-6" beams	480	LBS	$2.13	$1,021
	Place concrete	3	CY	$143.35	$430
	Form 1'-8" beams	2273	SF	$12.89	$29,307
	Rebar 1'-8" beams	9360	LBS	$2.13	$19,901
	Place concrete	39	CY	$143.35	$5,591
	Form 1'-0" beams	255	SF	$12.89	$3,288
	Rebar 1'-0" beams	720	LBS	$2.13	$1,531
	Place concrete	3	CY	$143.35	$430
	Subtotal Division 03				**$3,491,065**
11	**Equipment**				
	ACU-SCREEN 60 MGD	1	EA	$221,436.52	$221,437
	Flushing gates	4	EA	$61,474.74	$245,899
	Bending weir	1	EA	$126,050.18	$126,050
	Tipping bucket	2	EA	$35,481.67	$70,963
	Subtotal Division 11				**$664,349**
31	**Earthwork**				
	Erosion & Sedimentation Control	837	LF	$8.25	$6,909
	Clear and grub site	0.7	AC	$7,295.95	$5,107
	Strip and stockpile soil	566	CY	$3.53	$1,999
	Dewatering	17	MO	$42,500.00	$722,500
	Steel sheet storage facility A1	24800	SF	$48.43	$1,201,145
	W14x159 Whalers: lower level	620	LF	$108.16	$67,057
	W14x99 Whalers: upper level	620	LF	$94.81	$58,780
	W14x99 Braces: both levels, based on 5' width 8' oc	775	LF	$94.81	$73,475
	Vibration and Movement Monitoring	52	DAYS	$490.00	$25,480
	Steel sheet storage facility A2	5760	SF	$46.69	$268,953
	W14x159 Whalers: lower level	144	LF	$108.16	$15,574
	W14x99 Whalers: upper level	144	LF	$94.81	$13,652
	W14x99 Braces: both levels, based on 5' width 8' oc	180	LF	$94.81	$17,065
	Vibration and Movement Monitoring	12	DAYS	$490.00	$5,880
	Steel sheet junction chamber	5120	SF	$46.69	$239,069
	W14x159 Whalers: lower level	128	LF	$108.16	$13,844
	W14x99 Whalers: upper level	128	LF	$94.81	$12,135
	W14x99 Braces: both levels, based on 5' width 8' oc	160	LF	$94.81	$15,169
	Vibration and Movement Monitoring	11	DAYS	$490.00	$5,390

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
	Excavate storage facility A1	22671	CY	$9.83	$222,791
	Haul surplus fill storage facility A1	24938.1	CY	$40.45	$1,008,770
	Geotextile storage facility A1	2061	SY	$3.03	$6,249
	12" thick structural fill storage facility A1	18549	SF	$2.17	$40,320
	Backfill storage facility A1	8792	CY	$37.99	$334,021
	Excavate storage facility A2	1565	CY	$9.83	$15,379
	Haul surplus fill storage facility A2	1721.5	CY	$40.45	$69,636
	Geotextile storage facility A2	142	SY	$3.03	$431
	12" thick structural fill storage facility A2	1280	SF	$2.17	$2,782
	Backfill storage facility A2	790	CY	$37.99	$30,013
	Excavate junction chamber	1153	CY	$9.83	$11,331
	Haul surplus fill junction chamber	1268.3	CY	$40.45	$51,304
	Geotextile junction chamber	105	SY	$3.03	$318
	12" thick structural fill junction chamber	943	SF	$2.17	$2,050
	Backfill junction chamber	610	CY	$37.99	$23,175
	Yard Pipe				
	Excavate trench	1307	CY	$6.35	$8,296
	12" pipe bedding	1260	SF	$2.17	$2,739
	Backfill, plus 15% compaction, assume reuse excavated mate	1126	CY	$12.99	$14,628
	Haul surplus fill material	181	CY	$40.45	$7,322
	Spread stockpiled loam	530	CY	$12.14	$6,432
	Subtotal Division 31				**$4,627,170**
32	**Exterior Improvements**				
	12" thick pavement subbase	1210	SY	$12.18	$14,742
	2" thick binder course pavement	1210	SY	$10.66	$12,901
	1-1/2" thick wearing course pavement	1210	SY	$9.51	$11,509
	Hydroseed site	28.611	MSF	$48.13	$1,377
	Subtotal Division 32				**$40,529**
33	**Utilities**				
	Connect to Existing System (2 locations)	1	LS	$100,000.00	$100,000
	Temporary Bypass Pumping System	1	LS	$125,000.00	$125,000
	Frame and cover, brick work	6	EA	$1,628.68	$9,772
	96" PCCP pipe	72	LF	$1,157.29	$83,325
	Subtotal Division 33				**$318,097**
	Total CSO Storage Facility				**$9,166,272**
	CHEMICAL BUILDING				
03	**Concrete**				
	Form footings	176	SF	$15.72	$2,767
	Rebar footings	2131	LBS	$2.13	$4,531
	Place concrete	10	CY	$134.01	$1,340
	Water stop	88	LF	$18.66	$1,642
	Form walls 3'-6" high	616	SF	$15.72	$9,685
	Rebar walls	2487	LBS	$2.13	$5,288
	Place concrete	12	CY	$134.01	$1,608

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
	Form 12" thick slab	80	SF	$15.72	$1,258
	Rebar slab	3100	LBS	$2.13	$6,591
	Place concrete	14	CY	$134.01	$1,876
	Form curb 15"x8"	61	SF	$12.89	$787
	Rebar curb	24	LBS	$2.13	$51
	Place concrete	27	CF	$67.02	$1,810
	Form tank pads	32	SF	$15.72	$503
	Rebar tank pads	94	LBS	$2.13	$200
	Place concrete	32	CF	$67.02	$2,145
	Form equipment pads	24	SF	$15.94	$383
	Rebar equipment pads	53	LBS	$2.13	$113
	Place concrete	18	CF	$67.02	$1,206
	Subtotal Division 03				**$43,783**
04	**Masonry**				
	8" CMU walls	640	SF	$26.31	$16,835
	Lull and operator	44	DAYS	$970.97	$42,723
	Scaffold	640	SF	$20.79	$13,304
	Subtotal Division 04				**$72,862**
06	**Wood, Plastics, and Composites**				
	1/2" Sheathing	640	SF	$5.58	$3,573
	Air barrier	640	SF	$0.57	$364
	Fiber Cement Sill, 8"	78	SF	$6.91	$539
	Fiber Cement Siding	640	SF	$6.91	$4,424
	Fiber Cement Trim	92	SF	$6.91	$636
	Fiber Cement eave, trim, and blocking at the soffit	1	LS	$754.95	$755
	Roof truss system	640	SF	$3.32	$2,123
	Framing, sheathing and trim for dormers	1	LS	$6,480.21	$6,480
	Plywood roof sheathing	405	SF	$5.58	$2,261
	Plywood at ceiling	405	SF	$5.58	$2,261
	Building number	1	EA	$146.60	$147
	Subtotal Division 06				**$23,563**
07	**Thermal and Moisture Protection**				
	Asphalt Shingles	405	SF	$7.46	$3,021
	Felt underlayment	405	SF	$1.56	$632
	Vented nailable insulation & blocking	405	SF	$4.65	$1,882
	Spray on insulation at underside of roof deck	405	SF	$4.94	$2,001
	Misc. caulking & sealant	1	LS	$2,853.20	$2,853
	Fascia's, eaves, flashings, etc.	1	LS	$3,853.20	$3,853
	Dormer, insulated false louver	2	EA	$1,676.60	$3,353
	Fall protection	1	LS	$2,853.20	$2,853
	Subtotal Division 07				**$20,449**
08	**Openings**				
	Aluminum Roll-up Door, 8' x 10'	1	EA	$16,310.08	$16,310
	Aluminum Door, 3' x 7'-10"	1	EA	$4,655.04	$4,655
	Subtotal Division 08				**$20,965**
09	**Finishes**				
	Allow water repellant on masonry surfaces	640	SF	$1.81	$1,157
	Paint interior walls and ceiling	1024	SF	$4.28	$4,382

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
	Paint floor	384	SF	$2.72	$1,046
	Subtotal Division 09				**$6,585**
10	**Specialties**				
	Fire extinguisher, carbon dioxide	1	EA	$460.18	$460
	Fire extinguisher, dry chemical	1	EA	$475.18	$475
	Toilet accessories	1	LS	$13,641.36	$13,641
	Subtotal Division 10				**$14,577**
11	**Equipment**				
	NaOCl Pumps	2	EA	$15,633.41	$31,267
	NaHSO3 Pumps	2	EA	$9,633.41	$19,267
	Sample Pumps	2	EA	$13,633.41	$27,267
	Subtotal Division 11				**$77,800**
13	**Special Construction**				
	FRP Tank, 625-gal	2	EA	$18,303.42	$36,607
	Day tanks	2	EA	$6,837.59	$13,675
	Drum Scale	1	EA	$7,368.80	$7,369
	Drum Storage	1	EA	$1,115.40	$1,115
	Subtotal Division 13				**$58,766**
15	**Mechanical**				
	NaOCl Piping	1	LS	$93,182.21	$93,182
	NaHSO3 Piping	1	LS	$80,182.21	$80,182
	Subtotal Division 15				**$173,364**
17	**Instrumentation & Controls**				
	Cl Analyzer	2	EA	$5,522.87	$11,046
	Isolation Valve LCS	6	EA	$5,145.75	$30,874
	Weight Sensor (WE)	6	EA	$1,411.44	$8,469
	Weight Transmitter (WIT)	6	EA	$1,411.44	$8,469
	Flow Control Valve LCS	4	EA	$5,145.75	$20,583
	Pressure Indicator (PI)	12	EA	$711.44	$8,537
	Misc. controls	1	LS	$6,991.49	$6,991
	Testing	4	CD	$2,445.75	$9,783
	Programming/Integration	1	LS	$4,891.49	$4,891
	Subtotal Division 17				**$109,644**
22	**Plumbing**				
	Eyewash/Shower Station	1	EA	$20,436.44	$20,436
	Flush Valve Water Closet	1	EA	$5,679.44	$5,679
	Wall Hang Lav	1	EA	$1,475.11	$1,475
	Wall Hydrant	1	EA	$610.04	$610
	Floor Drain	1	EA	$2,930.22	$2,930
	Wall Clean Out	1	EA	$498.78	$499
	Floor Clean Out	1	EA	$741.56	$742
	Water Hammer Arrestor	1	EA	$714.56	$715
	Water Heater	2	EA	$2,259.11	$4,518
	Sanitary Piping	1	LS	$17,311.11	$17,311
	Water Distribution Piping	1	LS	$8,136.44	$8,136
	Toilet & accessories	1	EA	$4,843.22	$4,843
	Sink, including faucet & drain	1	EA	$3,780.22	$3,780

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
	Misc. piping	1	LS	$3,249.22	$3,249
	Testing	1	CD	$2,718.22	$2,718
	Subtotal Division 22				**$77,643**
23	**HVAC**				
	Centrifugal Fans	2	EA	$3,860.40	$7,721
	Restroom Exhaust Fan	1	EA	$3,648.40	$3,648
	Precision Control Air Conditioning, wall mounted	1	EA	$2,638.40	$2,638
	Louvers	2	EA	$1,292.70	$2,585
	AL Register	1	EA	$1,926.70	$1,927
	AL Duct & Accessories	1	LS	$1,372.70	$1,373
	Electric Duct Heater	1	EA	$3,151.70	$3,152
	Electric Unit Heater	1	EA	$3,619.70	$3,620
	Thermostat	2	EA	$1,451.70	$2,903
	Testing & Balancing	2	CD	$2,479.40	$4,959
	Subtotal Division 23				**$34,526**
26	**Electrical**				
	Electrical: allow 15% of total	1	LS		$110,179
	Subtotal Division 26				**$110,179**
31	**Earthwork**				
	Erosion & Sedimentation Control	1	LS	$6,000.00	$6,000
	Site Preparation	1296	SF	$3.51	$4,547
	Excavation	240	CY	$18.95	$4,547
	Bedding, 12" compacted #67 stone	38	CY	$77.47	$2,944
	Backfill, assume reuse excavated material	145	CY	$11.37	$1,648
	Disposal of spoil	95	CY	$61.47	$5,840
	Subtotal Division 31				**$25,526**
32	**Exterior Improvements**				
	Site Restoration	1	LS	$10,429.20	$10,429
	Subtotal Division 32				**$10,429**
	Total Chemical Building				**$880,662**
	Police Details	264	DAYS	$1,200.00	**$316,800**

Hazen

Opinion of Probable Construction Costs
Lowell Regional Wastewater Utility
Pevey Wet Weather Storage Facility

CSI Division	Description		Amount
01	General Conditions		$ 262,325
02	Existing Conditions		$ 28,982
03	Concrete		$ 255,713
11	Equipment		$ 86,068
17	Instrumentation and Control		$ 10,000
22	Plumbing		$ 39,978
26	Electrical		$ 15,000
31	Earthwork		$ 1,754,369
32	Exterior Improvements		$ 53,667
33	Utilities		$ 1,504,506
	Subtotal:		$ 4,010,609
	Value of Subcontracted Work		$ 802,122
	Subcontractor Overhead & Profit	21.0%	$ 168,446
	Subtotal:		$ 4,179,054
	Labor Escalation at 3.5% annually	13.12%	$ 265,337
	Material/Equipment Escalation at 5% annually	19.10%	$ 379,816
	Subtotal:		$ 4,824,208
	Prime Contractor Overhead	10.0%	$ 482,421
	Subtotal:		$ 5,306,629
	Prime Contractor Profit	10.0%	$ 530,663
	Subtotal:		$ 5,837,291
	Prime Contractor Profit On Subcontracted Work	5.0%	$ 48,528

CSI Division	Description		Amount
	Subtotal:		$ 5,885,820
	Bonds and Insurance	3.0%	$ 176,575
	Subtotal:		$ 6,062,394
	Design Contingency	20.0%	$ 1,212,479
	Subtotal:		$ 7,274,873
	Allowance for contaminated soil		$ 819,970
	Total (rounded):		**$ 8,100,000**

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
01	**General Conditions**				
	Project Manager	3	MO	$13,825.00	$41,475
	Superintendent	13	MO	$12,945.00	$168,285
	Field offices	13	MO	$1,834.00	$23,842
	Temporary fence	1285	LF	$7.50	$9,642
	Survey	10	DAYS	$1,908.04	$19,080
	Subtotal Division 01				**$262,325**
02	**Existing Conditions**				
	Test pit	30	CY	$279.08	$8,372
	Pavement demolition	1295	SY	$11.38	$14,739
	Haul pavement demolition	216	CY	$27.18	$5,871
	Subtotal Division 02				**$28,982**
03	**Concrete**				
	Form culvert weir walls 12" thick	288	SF	$12.68	$3,653
	Rebar culvert weir walls	1,163	LBS	$2.13	$2,473
	Place concrete	5	CY	$151.14	$756
	Culvert fill concrete	27	CY	$137.51	$3,687
	Junction Manhole				
	Junction MH fill concrete	3	CY	$213.41	$698
	Diversion Chamber				
	Form mat foundation 2' thick	184	SF	$12.68	$2,334
	Rebar mat foundation	6,764	LBS	$2.13	$14,381
	Place concrete	38	CY	$143.35	$5,447
	Waterstop	84	LF	$18.66	$1,567
	Form end walls	1,972	SF	$12.68	$25,010
	Rebar end walls	15,146	LBS	$2.13	$32,202
	Place concrete	85	CY	$143.35	$12,198
	Form side walls	3,132	SF	$12.68	$39,722
	Rebar side walls	24,055	LBS	$2.13	$51,144
	Place concrete	135	CY	$143.35	$19,373
	Form top slab	513	SF	$15.94	$8,179
	Rebar top slab	4,498	LBS	$2.13	$9,564
	Place concrete	25	CY	$143.35	$3,623
	Form weir wall	552	SF	$12.68	$7,001
	Rebar weir wall	1,820	LBS	$2.13	$3,869
	Place concrete	10	CY	$143.35	$1,465
	Form channel slab	72	SF	$15.94	$1,148
	Dowel channel slab	52	EA	$45.28	$2,355
	Rebar channel slab	475	LBS	$2.13	$1,009
	Place concrete	3	CY	$143.35	$382
	Fill concrete for sump	11	CY	$137.51	$1,467
	Fill concrete at oval pipe	7	CY	$137.51	$1,008
	Subtotal Division 03				**$255,713**

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
11	**Equipment**				
	Furnish Gate System, including gate, hydraulic cylinders, sea	2	EA	$33,454.65	$66,909
	Install Gate & Supports	2	EA	$7,631.91	$15,264
	Install Control Panel & HPU	2	EA	$1,947.31	$3,895
	Subtotal Division 11				**$86,068**
17	**Instrumentation & Control**				
	I&C Allowance	1	Allow	$10,000.00	$10,000
	Subtotal Division 17				**$10,000**
22	**Plumbing**				
	Sump pumps	2	EA	$17,960.88	$35,922
	Discharge pipe and supports	75	LF	$54.09	$4,057
	Subtotal Division 22				**$39,978**
26	**Electrical**				
	Electrical Allowance	1	LS	$15,000.00	$15,000
	Subtotal Division 26				**$15,000**
31	**Earthwork**				
	Erosion & Sedimentation Control	990	LF	$7.86	$7,782
	Clear and grub	1	AC	$6,809.55	$6,810
	Strip and stockpile soil	807	CY	$2.48	$1,998
	Dewatering	8	MO	$42,500.00	$340,000
	Excavate culvert	5,308	CY	$6.35	$33,690
	Haul surplus fill material	5,839	CY	$22.18	$129,507
	Excavate junction manhole	917	CY	$6.35	$5,820
	Haul surplus fill material	1,009	CY	$22.18	$22,373
	Excavate diversion chamber	1,012	CY	$6.35	$6,423
	Haul surplus fill material	1,113	CY	$22.18	$24,691
	Geotextile	582	SY	$3.03	$1,765
	12" thick structural fill - culvert	5,010	SF	$2.17	$10,890
	12" thick structural fill - manhole	784	SF	$2.17	$1,704
	12" thick structural fill - diversion chamber	608	SF	$2.17	$1,322
	Backfill culvert	3,251	CY	$42.32	$137,593
	Backfill manhole	115	CY	$42.32	$4,875
	Backfill diversion chamber	623	CY	$42.32	$26,381
	Steel Sheeting - Culvert				
	Steel sheets	8,957	SF	$48.43	$433,817
	W14x159 Whalers: lower level	400	LF	$108.16	$43,262
	W14x99 Whalers: upper level	400	LF	$94.81	$37,922
	W14x99 Braces: both levels, based on 5' width 8' oc	500	LF	$94.81	$47,403
	Cut off and dispose sheeting, 24" below grade	800	SF	$2.91	$2,329
	Vibration and Movement Monitoring	27	DAYS	$490.00	$13,214
	Steel Sheeting - Junction Manhole				
	Steel sheets	3,300	SF	$48.43	$159,830

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
	W14x159 Whalers: lower level	30	LF	$108.16	$3,245
	W14x99 Whalers: upper level	30	LF	$94.81	$2,844
	W14x99 Braces: both levels, based on 5' width 8' oc	38	LF	$94.81	$3,603
	Cut off and dispose sheeting, 24" below grade	120	SF	$2.91	$349
	Vibration and Movement Monitoring	6	DAYS	$490.00	$2,777
	Steel Sheeting - Diversion Chamber				
	Steel sheets	3,894	SF	$48.43	$188,599
	W14x159 Whalers: lower level	108	LF	$108.16	$11,681
	W14x99 Whalers: upper level	108	LF	$94.81	$10,239
	W14x99 Braces: both levels, based on 5' width 8' oc	135	LF	$94.81	$12,799
	Cut off and dispose sheeting, 24" below grade	216	SF	$2.91	$629
	Vibration and Movement Monitoring	9	DAYS	$490.00	$4,562
	42" DI Drain Pipe				
	Excavate trench	559	CY	$6.35	$3,548
	12" pipe bedding	520	SF	$2.17	$1,130
	Backfill, plus 15% compaction	297	CY	$12.99	$3,858
	Haul surplus fill material	23	CY	$22.18	$510
	Spread stockpiled loam	807	CY	$3.21	$2,594
	Subtotal Division 31				**$1,754,369**
32	**Exterior Improvements**				
	12" gravel pavement subbase	11,655	SF	$2.17	$25,335
	3-1/2" HMA pavement	1,295	SY	$19.03	$24,644
	Hydroseed	4,840	SY	$0.76	$3,689
	Subtotal Division 32				**$53,667**
33	**Utilities**				
	Existing 50"x33" Sewer Oval Pipe				
	Support pipe during installation of chamber	1	LS	$4,611.10	$4,611
	Cut and remove section of oval pipe	10	LF	$461.11	$4,611
	Temporary Bypass Pumping System	1	LS	$25,000.00	$25,000
	4' dia. manhole riser sections, 8 vlf each	6	EA	$2,347.35	$14,084
	Concrete Top Slab	6	EA	$938.68	$5,632
	Frame and cover, brick work	9	EA	$1,628.68	$14,658
	10' dia. Manhole base	1	EA	$13,254.48	$13,254
	10' dia. Manhole risers	26	VF	$1,121.33	$28,594
	Pipe Jacking under Railroad				
	Railroad Inspection	1	LS	$20,000.00	$20,000
	Pipe Jacking 54" Steel Casing	1	LS	$592,280.87	$592,281
	Pipe from Storage Structure to Junction Manhole:				
	30" DI pipe	30	LF	$337.50	$10,125
	30" 45 Deg Elbow	2	EA	$8,705.53	$17,411
	Pipe from Junction Manhole to Diversion Chamber:				
	42" DI pipe	150	LF	$472.89	$70,934
	Precast concrete, box culvert, 12' x 15'	330	LF	$2,070.64	$683,310
	Subtotal Division 33				**$1,504,506**

Hazen

Opinion of Probable Construction Costs
Lowell Regional Wastewater Utility
Redundant Transmission Main

CSI Division	Description		Amount
01	General Conditions & Traffic Control	15.0%	$ 704,413
02	Existing Conditions		$ 57,858
31	Earthwork		$ 524,565
32	Exterior Improvements		$ 516,005
33	Utilities		$ 1,215,486
		Subtotal:	**$ 3,018,327**
	Value of Subcontracted Work		$ 603,665
	Subcontractor Overhead & Profit	21.0%	$ 126,770
		Subtotal:	**$ 3,145,096**
	Labor Escalation at 3.5% annually	4.99%	$ 60,790
	Material/Equipment Escalation at 5% annually	7.16%	$ 78,486
		Subtotal:	**$ 3,284,372**
	Prime Contractor Overhead	10.0%	$ 328,437
		Subtotal:	**$ 3,612,809**
	Prime Contractor Profit	10.0%	$ 361,281
		Subtotal:	**$ 3,974,090**

CSI Division	Description		Amount
	Prime Contractor Profit On Subcontracted Work	5.0%	$ 36,522
		Subtotal:	**$ 4,010,612**
	Bond and Insurance	3.0%	$ 120,318
		Subtotal:	**$ 4,130,930**
	Design Contingency	20.0%	$ 826,186
		Subtotal:	**$ 4,957,116**
	Unit Price Work/Rock Excavation		$ 139,633
		Total (rounded):	**$ 5,100,000**

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
					$2,313,914
02	**Existing Conditions**				
	Test pits	25	CY	$418.02	$10,451
	Demolish pavement	2222	SY	$9.89	$21,970
	Hauling and disposal	1481	CY	$17.17	$25,438
	Subtotal Division 02				**$57,858**
31	**Earthwork**				
	Excavate trench	5185	CY	$9.82	$50,906
	Backfill trench	4259	CY	$9.94	$42,318
	12" pipe bedding	20000	SF	$2.17	$43,443
	8" pavement subbase	494	CY	$22.01	$10,868
	Sawcut trench	9600	LF	$3.02	$28,964
	Erosion & Sedimentation Control	8800	LF	$7.98	$70,234
	Dewatering	3	MO	$42,000.00	$126,000
	Clean fill for backfill	4259	CY	$30.67	$130,634
	Haul surplus material	1235	CY	$17.17	$21,198
	Subtotal Division 31				**$524,565**
32	**Exterior Improvements**				
	Temporary trench width pavement 4" thick	2222	SY	$73.85	$164,109
	Haul asphalt	244	CY	$17.17	$4,197
	Permanent pavement over trench, 4" thick	2222	SY	$73.85	$164,109
	Haul asphalt	244	CY	$17.17	$4,197
	Mill full width pavement	13500	SY	$3.03	$40,886
	Haul milled material	765	CY	$17.17	$13,136
	Full width overlay pavement 1-1/2" thick	13500	SY	$6.51	$87,871
	Haul asphalt	1485	CY	$17.17	$25,498
	Line Striping	4000	LF	$3.00	$12,000
	Subtotal Division 32				**$516,005**
33	**Utilities**				
	24" DIP water main	4000	LF	$226.07	$904,275
	Bends and fittings	55000	LBS	$5.34	$293,700
	Thrust blocks	50	CY	$350.22	$17,511
	Subtotal Division 33				**$1,215,486**

Hazen

Opinion of Probable Construction Costs
Lowell Regional Wastewater Utility
Walker Wet Weather Storage Facility

CSI Division	Description		Amount
01	General Conditions	15.0%	$ 1,532,260
02	Existing Conditions		$ 7,304
03	Concrete		$ 4,975,988
11	Equipment		$ 81,562
13	Special Construction		$ 250,000
17	Instrumentation and Control		$ 16,578
22	Plumbing		$ 39,497
26	Electrical		$ 58,146
31	Earthwork		$ 4,652,359
32	Exterior Improvements		$ 5,270
33	Utilities		$ 135,667
		Subtotal:	**$ 11,754,632**
	Value of Subcontracted Work		$ 2,350,926
	Subcontractor Overhead & Profit	21.0%	$ 493,695
		Subtotal:	**$ 12,248,327**
	Labor Escalation at 3.5% annually	0.00%	$ -
	Material/Equipment Escalation at 5% annually	0.00%	$ -
		Subtotal:	**$ 12,248,327**
	Prime Contractor Overhead	10.0%	$ 1,224,833
		Subtotal:	**$ 13,473,160**
	Prime Contractor Profit	10.0%	$ 1,347,316
		Subtotal:	**$ 14,820,476**

CSI Division	Description		Amount
	Prime Contractor Profit On Subcontracted Work	5.0%	$ 142,231
		Subtotal:	**$ 14,962,707**
	Bond and Insurance	3.0%	$ 448,881
		Subtotal:	**$ 15,411,588**
	Design Contingency	40.0%	$ 6,164,635
		Subtotal:	**$ 21,576,223**
	Contract Allowances		$ 2,137,885
		Total (rounded):	**$ 23,700,000**

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
02	**Existing Conditions**				
	Test pit	25	CY	$292.17	$7,304
	Subtotal Division 02				**$7,304**
03	**Concrete**				
	132'x270' Tank				
	Form mat foundation 24" thick	1645	SF	$13.59	$22,358
	Rebar base slab	333403	LBS	$2.16	$721,015
	Place concrete	2781	CY	$144.52	$401,868
	Waterstop	804	LF	$19.36	$15,565
	Form end walls 16" thick	6336	SF	$13.59	$86,096
	Rebar end walls	28137	LBS	$2.16	$60,848
	Place concrete	156	CY	$144.52	$22,553
	Form side and center walls 16" thick	77760	SF	$13.59	$1,056,628
	Rebar side and center walls	345312	LBS	$2.16	$746,769
	Place concrete	1915	CY	$144.52	$276,788
	Form top slab 12" thick	36444	SF	$13.59	$495,213
	Rebar top slab	316536	LBS	$2.16	$684,538
	Place concrete	1320	CY	$144.52	$190,769
	Form weir walls 12" thick	1584	SF	$13.59	$21,524
	Rebar weir walls	7034	LBS	$2.16	$15,212
	Place concrete	29	CY	$144.52	$4,239
	Fill concrete	37	CY	$138.39	$5,142
	17'x25' Diversion Chamber				
	Form mat foundation 24" thick	205	SF	$13.59	$2,790
	Rebar base slab	5710	LBS	$2.16	$12,349
	Place concrete	48	CY	$144.52	$6,883
	Waterstop	84	LF	$19.36	$1,626
	Form walls 16" thick	4032	SF	$13.59	$54,788
	Rebar walls	17905	LBS	$2.16	$38,721
	Place concrete	99	CY	$144.52	$14,352
	Form top slab 12" thick	509	SF	$13.59	$6,916
	Rebar top slab	3775	LBS	$2.16	$8,163
	Place concrete	16	CY	$144.52	$2,275
	Subtotal Division 03				**$4,975,988**
11	**Equipment**				
	Furnish Gate System, including gate, hydraulic cylinders, sea	2	EA	$33,454.65	$66,909
	Install Gate & Supports	2	EA	$5,911.55	$11,823
	Install Control Panel & HPU	2	EA	$1,414.94	$2,830
	Subtotal Division 11				**$81,562**
13	**Special Construction**				
	Odor Control	1	LS	$250,000.00	$250,000
	Subtotal Division 13				**$250,000**

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
17	**Instrumentation & Control**				
	I&C Allowance	1	LS	$16,578.11	$16,578
	Subtotal Division 17				**$16,578**
22	**Plumbing**				
	Sump pumps	2	EA	$17,840.64	$35,681
	Discharge pipe and supports	75	LF	$50.88	$3,816
	Subtotal Division 22				**$39,497**
26	**Electrical**				
	Electrical Allowance	1	LS	$58,145.66	$58,146
	Subtotal Division 26				**$58,146**
31	**Earthwork**				
	Erosion & Sedimentation Control	936	LF	$8.12	$7,601
	Clear and grub	1.4	AC	$7,176.37	$10,107
	Strip and stockpile soil	1136	CY	$3.38	$3,841
	Dewatering	21	MO	$42,500.00	$892,500
	Excavate tank	38475	CY	$6.57	$252,831
	Haul surplus fill material	21120	CY	$22.37	$472,520
	Excavate diversion chamber	1012	CY	$6.57	$6,650
	Haul surplus fill material	252	CY	$22.37	$5,635
	Geotextile	4356	SY	$3.12	$13,607
	12" thick structural fill - tank	39201	SF	$2.24	$87,907
	12" thick structural fill - diversion chamber	868	SF	$2.24	$1,946
	Backfill tank	17355	CY	$13.41	$232,671
	Backfill diversion chamber	760	CY	$13.41	$10,191
	Steel Sheeting - Tank				
	Steel sheets	44450	SF	$45.12	$2,005,683
	W14x159 Whalers: lower level	839	LF	$109.69	$91,992
	W14x99 Whalers: upper level	839	LF	$96.34	$80,795
	W14x99 Braces: both levels, based on 5' width 8' oc	1048	LF	$96.34	$100,994
	Vibration and Movement Monitoring	83	DAYS	$490.00	$40,670
	Steel Sheeting - Diversion Chamber				
	Steel sheets	6290	SF	$45.12	$283,820
	W14x159 Whalers: lower level	119	LF	$109.69	$13,018
	W14x99 Whalers: upper level	119	LF	$96.34	$11,433
	W14x99 Braces: both levels, based on 5' width 8' oc	148	LF	$96.34	$14,291
	Vibration and Movement Monitoring	12	DAYS	$490.00	$5,880
	42" DI Drain Pipe				
	Excavate trench	86	CY	$6.57	$565
	12" pipe bedding	80	SF	$2.24	$179
	Backfill, plus 15% compaction, assume reuse excavated mate	79	CY	$13.41	$1,059
	Haul surplus fill material	7	CY	$22.37	$157
	Spread stockpiled loam	1136	CY	$3.36	$3,814

CSI Division	Description	Quantity	Unit	Total Unit Cost	Total Amount
	Subtotal Division 31				**$4,652,359**
32	**Exterior Improvements**				
	Hydroseed	6816	SY	$0.77	$5,270
	Subtotal Division 32				**$5,270**
33	**Utilities**				
	Temporary Bypass Pumping System	1	LS	$25,000.00	$25,000
	4' dia. manhole riser sections, 8' long	6	EA	$2,422.69	$14,536
	Concrete Top Slab	6	EA	$976.34	$5,858
	Frame and cover, brick work	9	EA	$1,666.34	$14,997
	10' dia. Manhole base	1	EA	$13,509.90	$13,510
	10' dia. Manhole risers	26	VF	$1,131.15	$28,844
	Pipe from Storage Structure to Junction Manhole:				
	30" DI pipe	30	LF	$347.65	$10,430
	30" 45 Deg Elbow	2	EA	$8,857.80	$17,716
	Pipe from Junction Manhole to Diversion Chamber:				
	42" DI pipe	10	LF	$477.65	$4,776
	Subtotal Division 33				**$135,667**

Hazen

APPENDIX F

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 2 4 2014

MEMORANDUM

SUBJECT: Financial Capability Assessment Framework for Municipal Clean Water Act Requirements

FROM: Ken Kopocis
Deputy Assistant Administrator
Office of Water (OW)

Cynthia Giles
Assistant Administrator
Office of Enforcement and Compliance Assurance (OECA)

TO: Regional Administrators
Regional Water Division Directors
Regional Enforcement Division Directors

In May of 2012, we distributed the Integrated Municipal Stormwater and Wastewater Planning Approach Framework (Integrated Planning Framework). Since that time, we have made solid progress in promoting integrated approaches to meet Clean Water Act (CWA) obligations. Thanks to the hard work of regional and headquarters staff, and the active engagement of cities, many of our enforcement settlements now embody integrated planning principles in the structure and schedule for injunctive relief or explicitly include integrated planning as part of the settlement. We have also seen an increasing number of municipalities and local authorities moving towards developing integrated plans to support the development of their NPDES permits. We have been working with EPA Regions and States to assist in that process.

As the implementation of the Integrated Planning Framework has progressed and evolved, we have been actively engaged with stakeholders on ways to build on our efforts. Those discussions found a natural focus on issues related to the financial capability of permittees working toward our shared goals of clean water. One consistent theme that emerged was the benefit of more clearly articulating the flexibility available under the existing guidance. EPA continues to be guided by the 1997 "Combined Sewer Overflows – Guidance for Financial Capability Assessment

and Schedule Development" (FCA Guidance) that provides an aid for assessing financial capability as part of negotiating schedules for implementing CWA requirements for municipalities and local authorities. The FCA Guidance also encourages permittees "to submit any additional documentation that would create a more accurate and complete picture of their financial capability" that may "affect the conclusion" of the analysis described in the guidance.

As part of EPA's commitment to implementing CWA objectives in a sustainable manner, we have developed the attached "Financial Capability Assessment Framework" (FCA Framework). The FCA Framework has been greatly informed by the comments and experiences of a variety of stakeholders and financial experts. The FCA Framework identifies the key elements EPA uses in working with permittees to evaluate how their financial capability should influence schedules. In addition, the FCA Framework provides examples of additional information that may help some communities provide a "more accurate and complete picture" of their financial capability as is envisioned in the FCA guidance. We will be posting the FCA Framework to our website as an important next step in the pursuit of integrated planning approaches and in our ongoing work with municipalities and local authorities to achieve our shared goals of protecting our nation's waters. While this memorandum releases the FCA Framework, we know that we will continue to learn and refine our understanding of the issues surrounding financial capability assessments as we use it moving forward. We will continue to look for ways to improve the Framework as we gain new insights and additional information.

We look forward to continue working with the Regions on these important issues and encourage you to contact Deborah Nagle, Director, Water Permits Division (nagle.deborah@epa.gov) and Mark Pollins, Director, Water Enforcement Division (pollins.mark@epa.gov) with any questions you might have.

Attachment

cc: Regional Permit and Enforcement Liaisons

FINANCIAL CAPABILITY ASSESSMENT FRAMEWORK

November 24, 2014

Purpose

The Environmental Protection Agency (EPA) is committed to working with state and local government partners to assist local municipalities and local authorities to meet Clean Water Act (CWA) obligations in a manner that recognizes the unique financial challenges that local jurisdictions face. This financial capability assessment framework is intended to provide additional examples and greater clarity on the flexibilities built into existing guidance that local governments or authorities can use in assessing their financial capability, and the relationship between that assessment and consideration of schedules for permit and consent decree implementation. This framework builds on the progress already made in the May 2012 "Integrated Municipal Stormwater and Wastewater Planning Approach Framework," and the experience gained from talking with communities about their financial capability in actual, on the ground circumstances. Integrated Planning has been helping in identifying a permittee's relative priorities for projects based on the relative importance of adverse impacts on human health and water quality and the municipality's financial capability.

Background

Local governments and authorities want to provide clean water for their communities, and they play an essential role in providing wastewater and stormwater infrastructure and services for their citizens, businesses and institutions. These municipal functions have been an important part of implementing the CWA to protect public health and improve water quality in streams, lakes, bays, and other waters nationwide. However, significant water quality challenges remain. Public officials remain strong supporters of the CWA goals and objectives by directing the public investments that are necessary to comply with the Act and to provide clean water for their citizens. Many local governments face complex water quality issues that are heightened by the need to address population growth or decline, increases in impervious surfaces, source water supply needs, and aging infrastructure. In recent years, many local governments and authorities have increased investments in their wastewater and stormwater infrastructure through capital projects to rehabilitate existing systems, improve operation and maintenance, and address additional regulatory requirements. As programs are implemented to improve water quality and attain CWA objectives, many state and local government partners find themselves facing difficult economic challenges with limited resources and financial capability. We recognize these challenging conditions and are working with states and local governments to develop and implement new approaches that will achieve water quality goals at lower costs and in a manner that addresses the most pressing problems first.

Long-term approaches to meeting CWA objectives should be sustainable and within a local government or authority's financial capability. The financial capability of these entities and other relevant factors are important to consider when developing appropriate schedules for infrastructure projects in permits or enforcement actions to help protect human health and the environment. EPA's financial capability assessment guidance, "Combined Sewer Overflows:

Guidance for Financial Capability Assessment and Schedule Development" (FCA Guidance) (EPA 832-B-97-004) provides a reference point to aid all parties in negotiating reasonable and effective schedules for implementing CWA requirements, and the flexibility to take into account local considerations that may not be fully captured by the approach detailed in the guidance. As described in more detail in this Framework, the guidance provides for consideration of the impact on residential rate payers and the financial capability of the permittee using a suite of indicators, as well as allowing schedules to be responsive to circumstances unique to that community, while advancing the mutual goal to protect clean water. The FCA Guidance encourages permittees to provide any additional information that would be useful in understanding those unique or atypical circumstances and how they may affect CWA schedules, so that all relevant information presented by a community can be taken into account to ensure that a full understanding of financial capability guides the development of schedules.

Financial Capability Assessment

The following are key elements of EPA's approach to the evaluation of the financial capability of municipalities to inform implementation schedules, both in permits and enforcement actions. The elements are fully compatible with the FCA Guidance, integrated planning approaches, and the flexibility embodied in both.

1. **The 1997 FCA Guidance identifies a valuable assessment that provides a common basis for financial burden discussions between the permittee, EPA and state NPDES authorities. Permittees have the option of submitting additional information that would create a more accurate and complete picture of their financial conditions.** The financial capability assessment described in the 1997 FCA Guidance identifies information that provides a basis for a general comparison of financial conditions between communities across the country and provides a consistent assessment of basic financial indicators as part of the overall analysis. Additional information that the community provides on its unique financial circumstances will be considered so that schedules take local considerations into account. Where appropriate, this information can result in schedules that are different than the schedules suggested by the baseline analysis suggested in the 1997 FCA Guidance.

2. **Financial capability is on a continuum.** Although the FCA Guidance approach categorizes financial burden as "high, medium, or low," this does not mean that schedules will be rigidly set according to the break points between the categories. For example, two communities whose total residential share of costs are 1.1% and 1.9% of median household income (MHI) are both categorized in the FCA Guidance as having a "medium" burden for the Residential Indicator (RI). All other things being equal, the appropriate schedules for those communities are likely to be different. Similarly, all other things being equal, two communities whose residential share of costs are 1.9% and 2.1% of MHI would be more likely to have similar overall compliance timeframes, even though one community is ranked as having a "medium" burden and the other as having a "high" burden. Finally, additional information submitted by the community may affect the length of the schedule regardless of where the community is on the "high, medium, and low" continuum.

3. **EPA will consider all CWA costs presented in the analysis described in the FCA Guidance**. EPA originally published the FCA Guidance to assist in negotiating schedules for communities with combined sewer systems, as these typically represent the most expensive CWA compliance issues. The FCA Guidance has since been recognized as equally suitable for considering other municipal CWA obligations as well, such as those related to separate sanitary sewer systems. With the release of EPA's 2012 Integrated Planning Framework, the Agency clarified that the financial capability analysis could include costs of: stormwater and wastewater; ongoing asset management or system rehabilitation programs; existing, CWA related capital improvement programs; collection systems and treatment facilities; and other CWA obligations required by state or other regulators. Where the costs of multiple CWA obligations are included in an FCA, each of those costs should be enumerated separately, so as to provide an understanding of how each contributes to the overall analysis.

4. **When presented, Safe Drinking Water Act (SDWA) obligations will be considered, primarily as additional information about a permittee's financial capability.** EPA believes that the SDWA obligations of a community can be an important consideration in establishing schedules for implementing integrated plans. EPA recognizes that both clean water and drinking water costs are often covered through charges on a single rate base. One component of a financial capability assessment includes an evaluation of the residential indicator that is based on only CWA costs as this best reflects the intended use of the metric and allows for comparisons with other communities. Drinking water costs may be reflected in other components of a financial capability assessment. For example, the financial capability indicator includes consideration of bond rating of the entity that issues debt to fund the permittee's capital project, which can be impacted by both wastewater and drinking water obligations for a permittee that provides both services. If a community has incurred general obligation debt associated with the SDWA, these obligations would be considered in the indicator "overall net debt as a percent of full market property value." In addition, as discussed below, additional information, including information regarding drinking water obligations, may be submitted for consideration in analyzing financial capability. To the extent that drinking water costs are not fully addressed by these other components, communities are encouraged to provide additional information about these costs.

5. **Communities should demonstrate how the CWA work included as costs in the financial capability assessment will be implemented, including appropriate assurances that those expenditures will be made.**

The Financial Capability Assessment Guidance and Examples of Additional Information that are Relevant to a Consideration of Financial Capability

The specific approaches laid out in the FCA Guidance provide a good foundation for the assessment of financial capability. As stated in the guidance and outlined in this Framework, communities can build on that foundation to include additional relevant information. The FCA Guidance presents a two-phased approach to assessing overall financial capability. The first phase assesses the impact on residential customers, and the first step is to calculate the portion of

the annual costs that would be borne by residential households for both current and projected Clean Water Act related expenses. The residential share of the annual costs of CWA obligations is then compared to the MHI of the service area. MHI is calculated using current census data and may be adjusted based on the current Consumer Price Index. Finally, the CWA compliance costs per household are divided by the adjusted MHI to calculate the residential indicator (RI). The FCA Guidance then identifies various ranges of RI scores as "low, mid-range or high" levels of burden. In situations where there are unique circumstances that would affect the conclusion of the first phase of the assessment, additional information documenting unique financial conditions may be submitted.

The second phase of the financial capability analysis assesses the financial strength of the permittee. Six indicators are used to evaluate the debt, socioeconomic and financial conditions that affect a permittee's financial capability to implement CWA controls necessary for compliance with the Act. These include bond ratings, overall net debt as a percent of full market property value, unemployment rate, median household income, property tax revenue collection rate, and property taxes as a percent of full market property value. In the Guidance, EPA has established benchmarks for each of the six indicators showing whether the indicator reflects a "weak", "mid-range", or "strong" financial capability. These benchmarks are used to generate an overall score of a permittee's financial capability.

The residential indicator calculated in phase one and the permittee capability indicators analyzed in phase two are evaluated together in a Financial Capability Matrix to assess the level of financial burden. The level of burden is then used to inform discussions to establish an appropriate schedule for meeting CWA obligations in permits and enforcement actions. EPA uses these indicators, including the annualized costs as a percent of MHI, to help assess when costs are reaching levels that may represent a high burden on ratepayers and that longer compliance timeframes are likely to be appropriate to spread the cost over a longer period. EPA does not view or use the Financial Capability Matrix as a rigid metric that points to a given schedule length or threshold over which the costs are unaffordable.

Permittees have suggested and the FCA Guidance recognizes that the two step analysis may not provide a complete representation of financial capability. As noted above, other relevant financial or demographic information presented that illustrates the unique or atypical circumstances faced by a permittee will also be considered in evaluating financial capability. The presentation of additional information can be very valuable in analyzing financial capability, and the submission of this type of information has become fairly common practice. For example, in many consent decree negotiations, additional information has resulted in the establishment of schedules that differ from the ones suggested by the baseline analysis described in the FCA Guidance.

Some examples of information that may be relevant in negotiating schedules to be included in permits and consent decrees are given below. In order for such information to adequately illustrate that a permittee's situation is atypical, EPA encourages permittees to compare any additional information on their circumstances to national averages or to that of other permittees.

The examples given below are not intended to be a complete list, nor a list of factors that will be relevant in every community. Rather it provides an illustration of information that may prove useful in some instances.

Examples of Information Related to Residential Impacts:

1. Income distribution by quintile, geography or other breakdown, illustrating how income distribution in the service area differs from comparable data on the national level or for similar cities.

2. Where cities have adopted differential rates for low income customers, the income distribution that led to that rate structure.

3. Information about service area poverty rates and trends.

4. Projected, current and historical sewer, and stormwater fees as a percentage of household income, quintile, geography or other breakdown.

5. Information on sewer and water usage for various classes of ratepayers or by type of dwelling unit.

6. Information on the percent of households who own versus rent.

Examples of Information Related to Financial Strength:

1. Historical population trends or population projections.

2. Service area unemployment data and trends, or other labor market indicators, including unemployment on an absolute basis.

3. Rate or revenue models, including dynamic financial planning models showing the projections of impacts over the program period. All revenue sources tied to CWA obligations may be included as appropriate.

4. Rate determination studies used to develop and support recent rate increases.

5. Data and trends on late payments, disconnection notices, service terminations, uncollectable accounts, or revenue collection rates.

6. Historical increases in rates or other dedicated revenue streams.

7. State or local legal restrictions or limitations on property taxes, other revenue streams or debt levels.

8. Other costs or financial obligations, such as those that relate to drinking water or other infrastructure, that significantly affect a permittee's ability to raise revenue.

9. Circumstances that may affect a permittee's bond rating. For instance, incurring debt beyond certain thresholds may negatively impact the permittee's bond rating, thus reducing the ability to raise capital.

10. Financial plans that show the implications of incurring additional debt for a permittee's ability to secure financing, including projections of metrics such as debt ratios, debt service coverage, debt per customer, days of cash on hand, days

of working capital and other metrics used by rating agencies. Such data should be benchmarked to metrics such as rating agency medians and relative to similar entities. This will be especially relevant where the permittee does not have a bond rating.

11. Extraordinary stressors such as those from natural disasters, municipal bankruptcies, unusual capital market conditions, or other situations which impact a permittee's ability to raise revenue or acquire needed financing. When such stressors occur, they may also provide support for making changes to existing schedules.

Hazen

APPENDIX G

Lowell Water
Integrated Plan (1-801)
Public Meeting #1
SIGN-IN SHEET
June 14, 2019

NAME	AFFILIATION	EMAIL
Ben Agrawal	Hazen	bagrawal@hazenandsawyer.com
Chuck Wilson	Hazen	cwilson@hazenandsawyer.com
Greg Coyle	Lowell	gcoyle@lowellma.gov
John Macone	Merrimack River Watershed Council	JMacone@Merrimack.org
Karen Conard	Merrimack Valley Planning Commission	kconard@mvpc.org
Mike Sauer	Lowell Water	msauer@lowellma.gov
AARON FOX	Lowell	afox@lowellma.gov
MARK YOUNG	LOWELL	MYOUNG@LOWELLMA.GOV

Hazen

Lowell's Integrated Capital Plan:

Balancing CSO Control With Water Transport & Treatment

June 14, 2019

LOWELL WATER
Community ~ Health ~ Environment

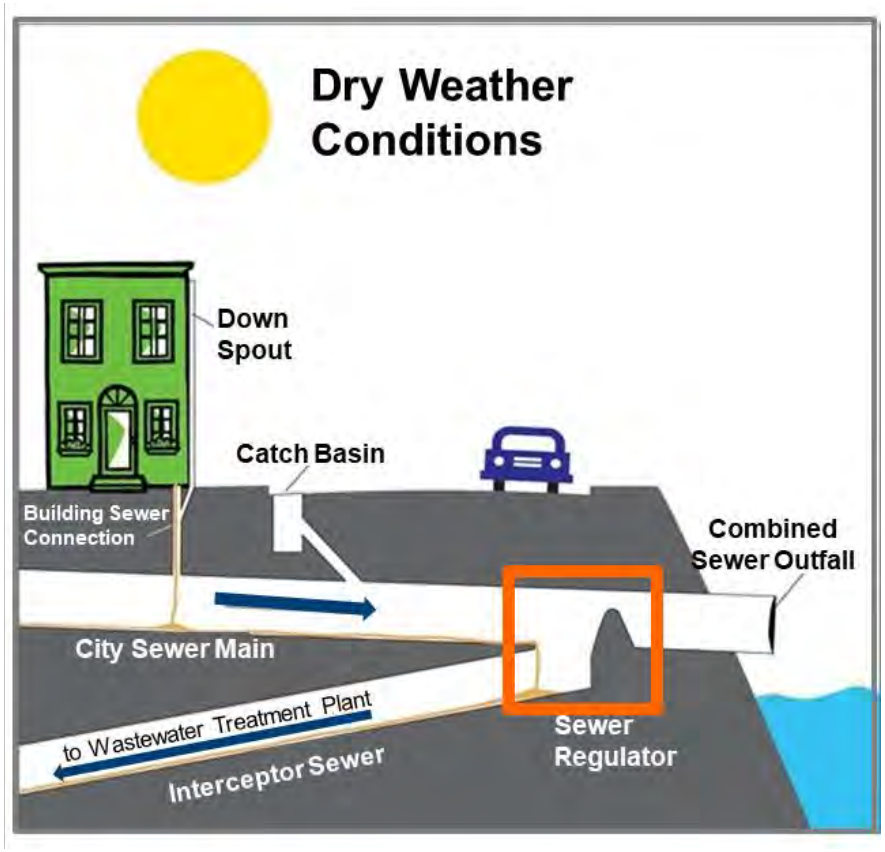
Agenda

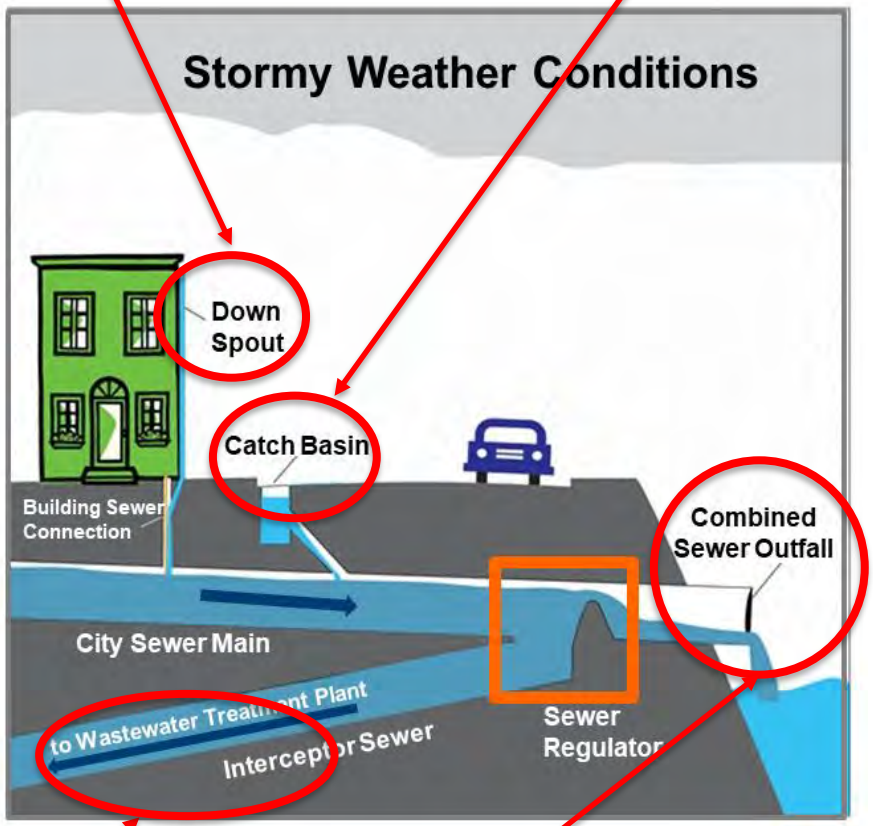
- Combined sewer systems – background
- Lowell's CSO control program history
- Integrated planning
  - Balancing CSO control with necessary water/wastewater transport and treatment improvements
- CSO control alternatives
  - Approach to CSO control alternatives analysis
  - North Bank Wet Weather Treatment Facility
- CSO control plan development

Combined Sewer System

Private Inflow

Public Inflow



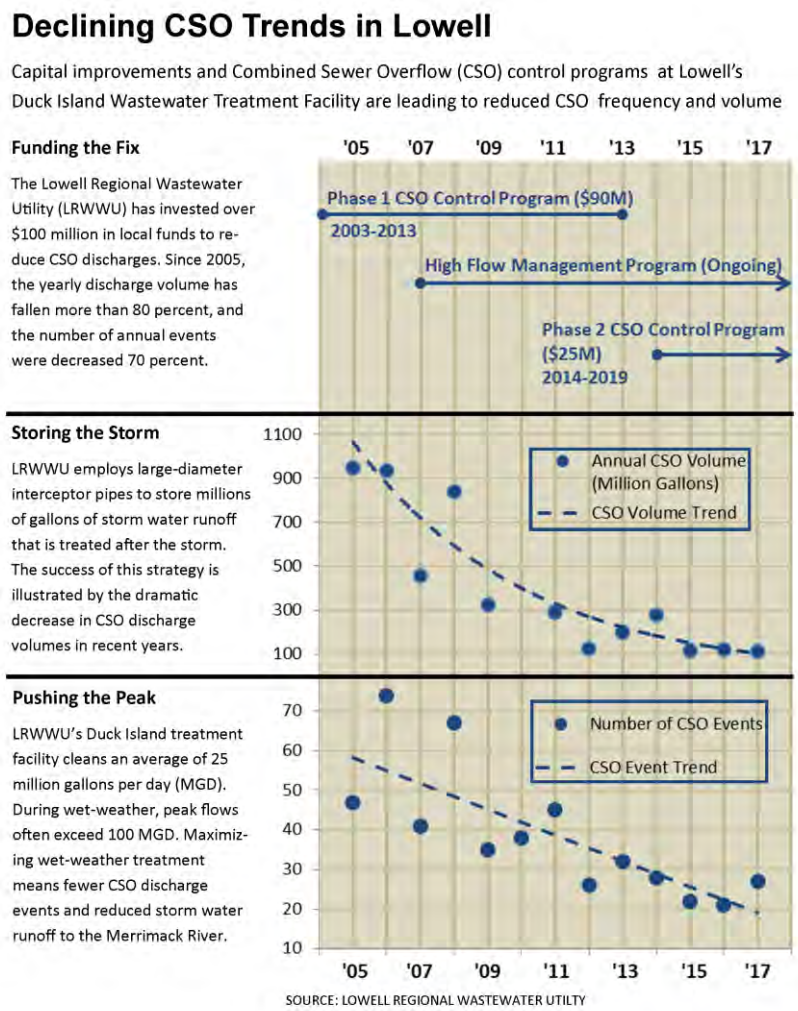


Sanitary flow AND stormwater conveyed for treatment

Untreated CSO discharge

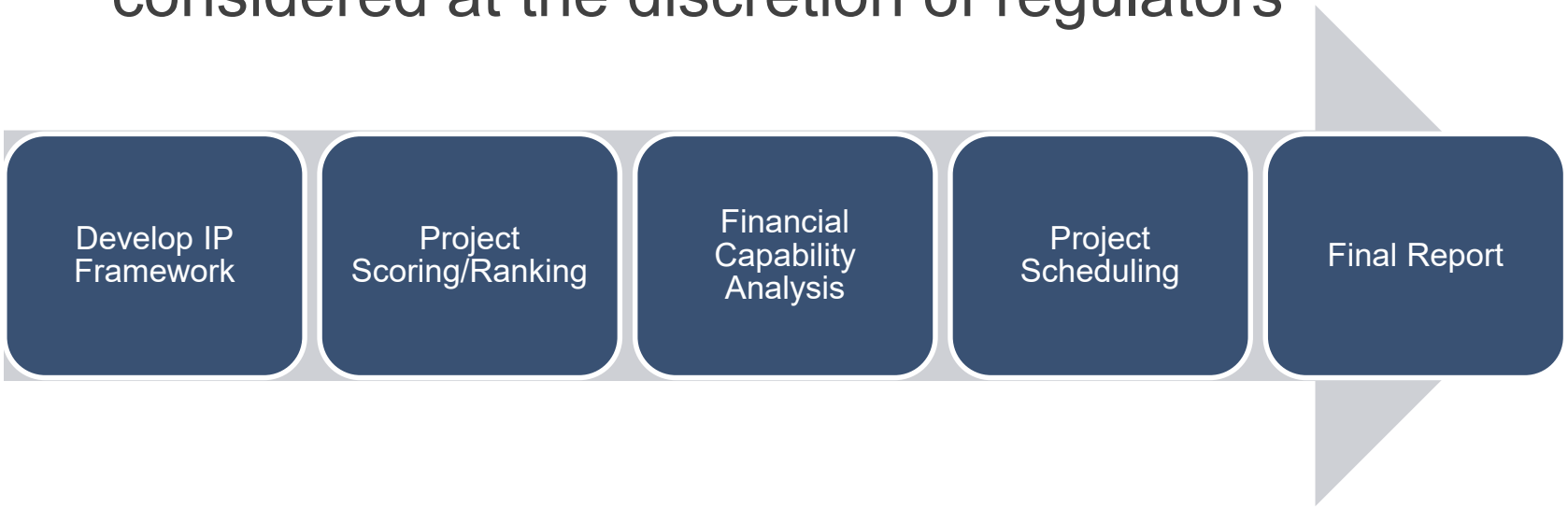
Lowell CSO Control Program History

- CSO control – more than $150M of local funds invested since 2003
- LTCP Phase I (2003-2013) - $120M
- LTCP Phase II (2014-2019) – $40M
- LTCP Phase III - TBD through Integrated Planning Process
- CSO Volume/Frequency – Dramatic Decrease in the past 15 years



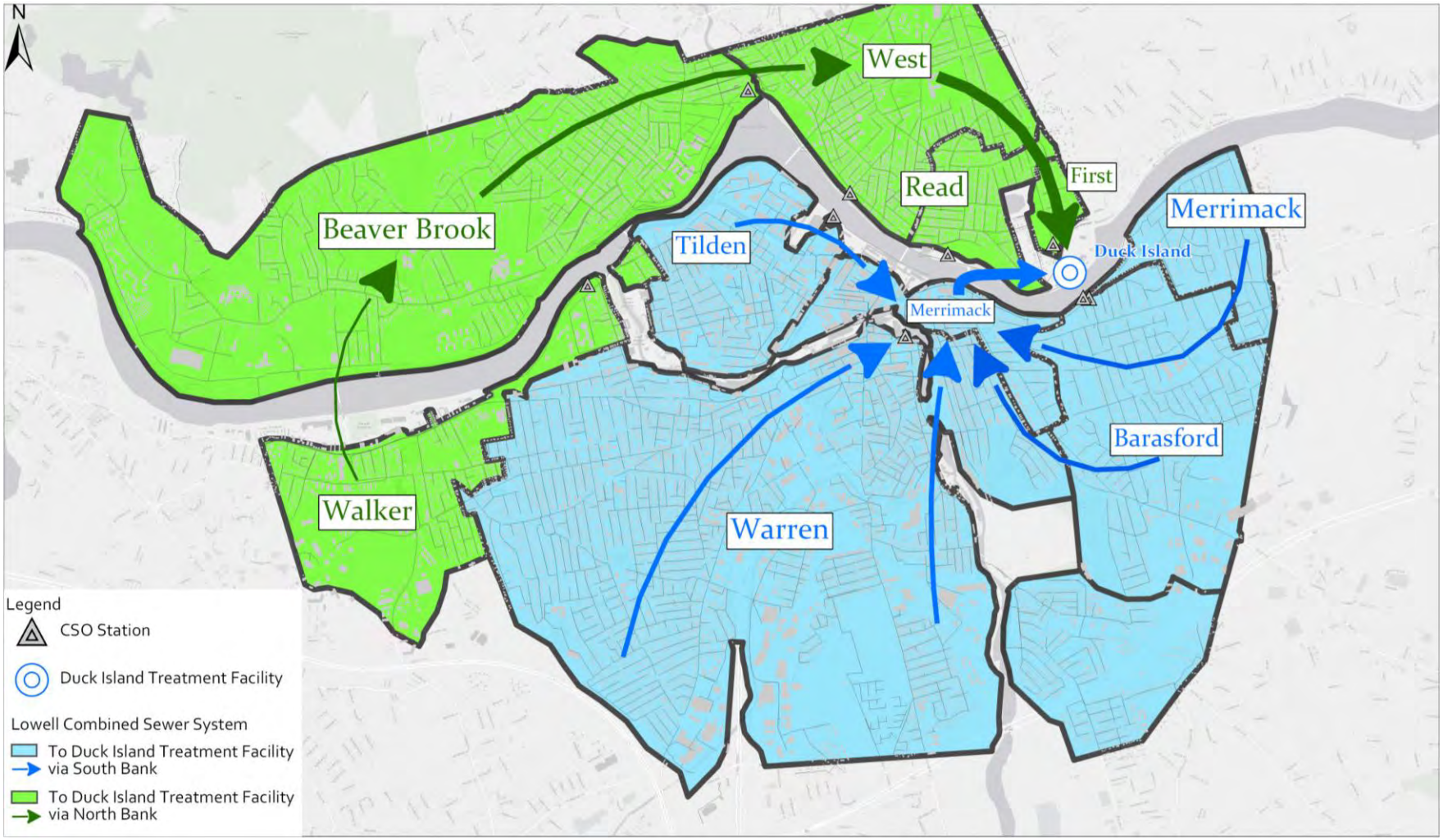
Why an Integrated Plan (IP)?

- Framework allows for plan to consider other community water needs, such as drinking water
- IP approach allows separate wastewater projects to be sequenced based on priority
- Other projects (drinking water) *may* be considered at the discretion of regulators



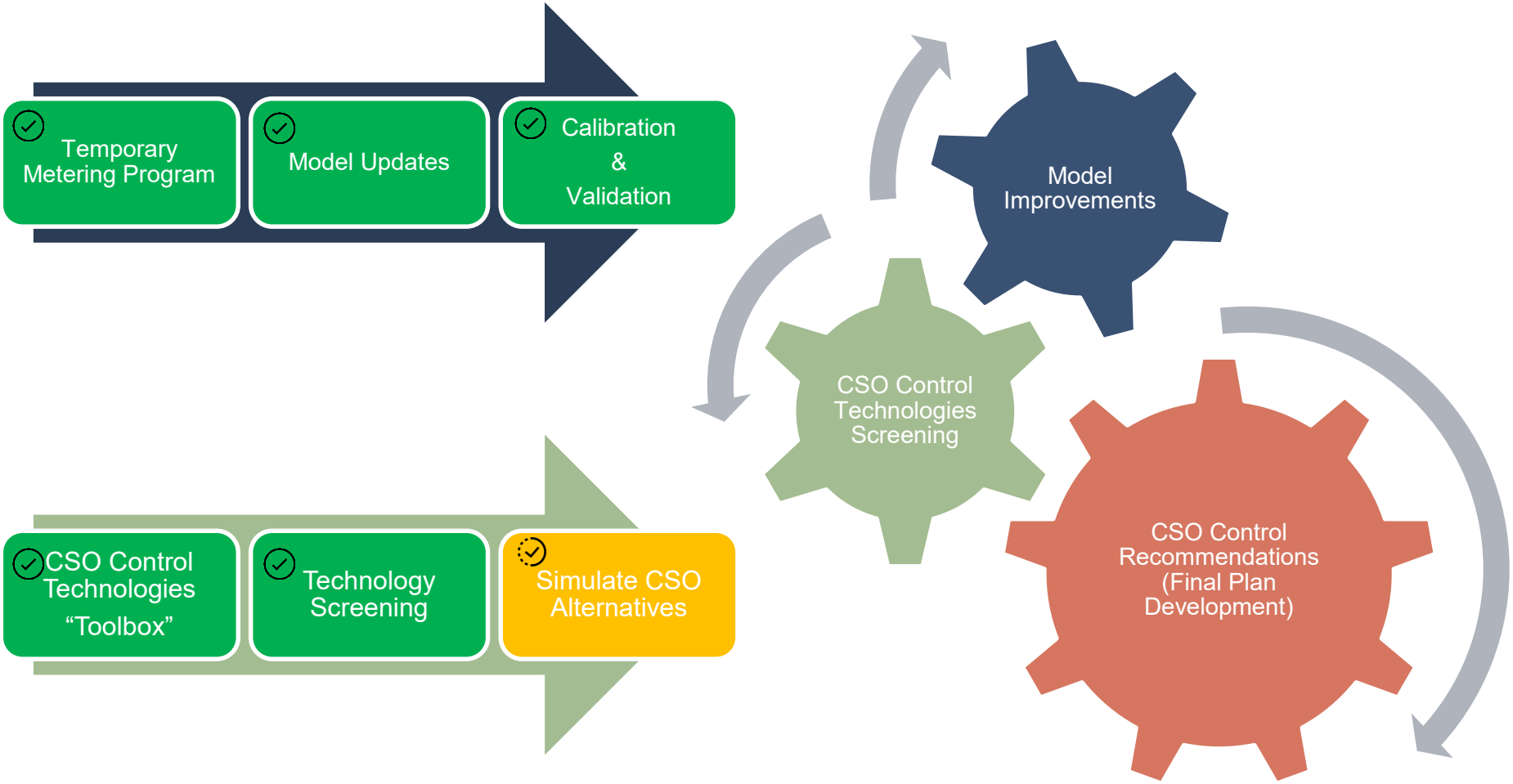
Lowell's Sewer Interceptor System

Wet Weather Transport and Treatment

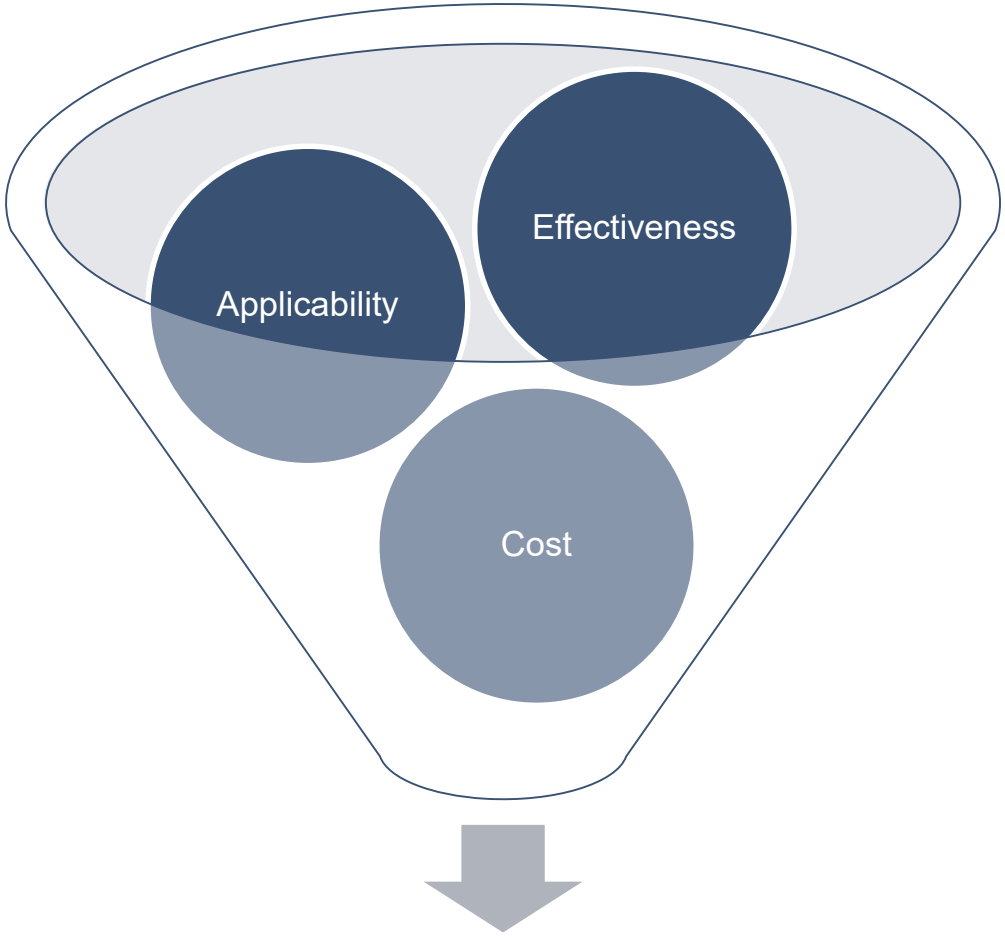


CSO stations in Lowell are subjected to "cumulative" flow from upstream sewersheds

CSO Control Alternatives Analysis



CSO Control Technologies Screening



LTCP Technology

CSO Control Technologies – Pros and Cons

Sewer Separation

Pros

- Reduces CSO frequency
- Reduces CSO volume
- Eliminates cost of treating stormwater

Cons

- Very costly
- Not 100% effective (private inflow removal difficult)
- Disruptive
- Time to implementation
- Untreated stormwater discharges & pollutant loading

Storage

Pros

- Reduce or eliminate CSOs in some locations

Cons

- Very costly
- Space required
- Property ownership
- Potential for disruptive construction

System Optimization

Pros

- Cost effective
- Maximize utility of existing infrastructure

Cons

- CSO control benefit may be small compared to other technologies

Green Infrastructure

Pros

- Public education
- Aesthetics
- Some stormwater treatment

Cons

- Costly
- Ineffective for CSO control
- Burdensome maintenance

Wet Weather Treatment

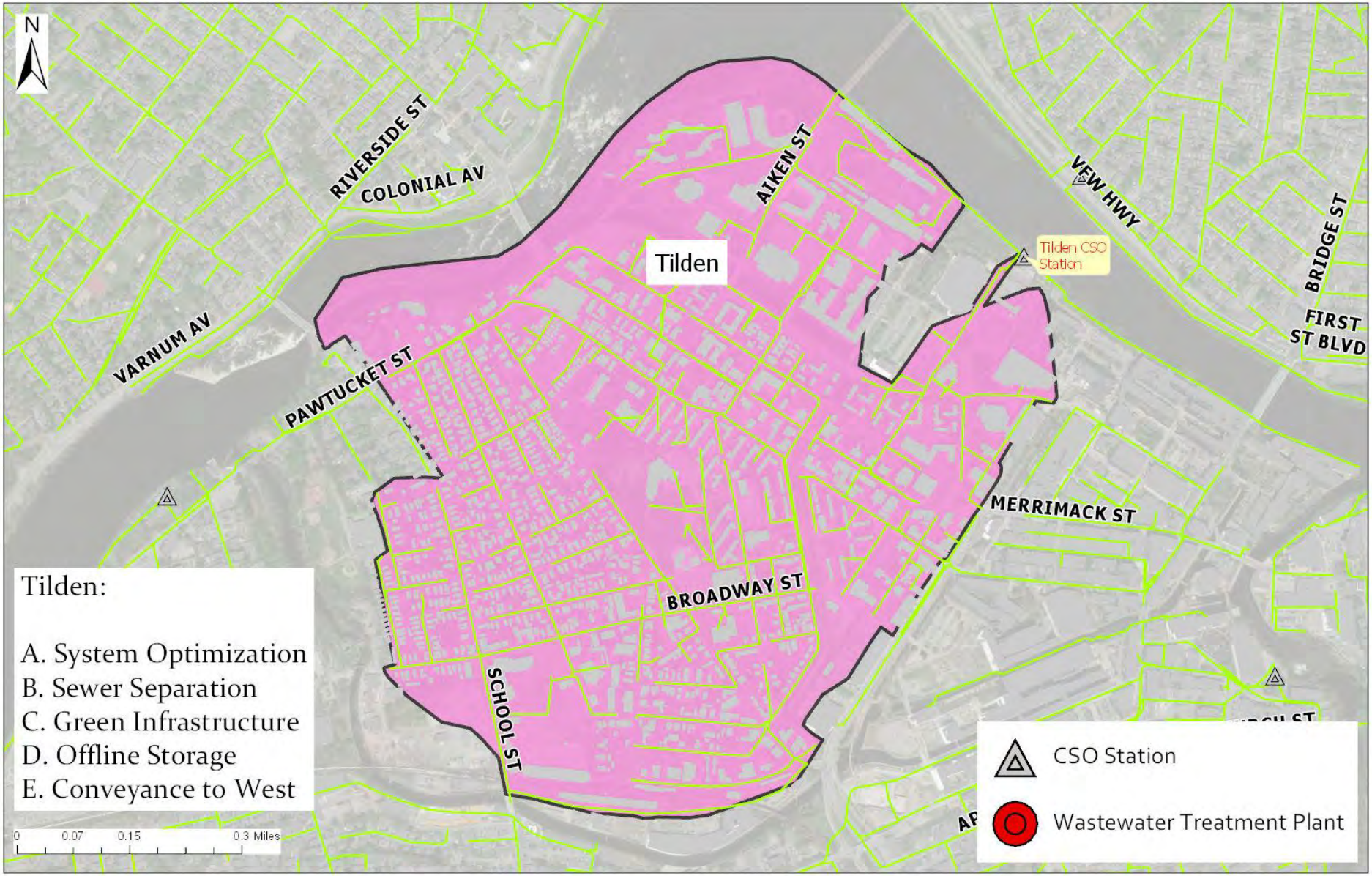
Pros

- Capture and treatment of potential CSOs
- Very cost effective
- May provide additional capacity at WWTP to further reduce CSOs elsewhere

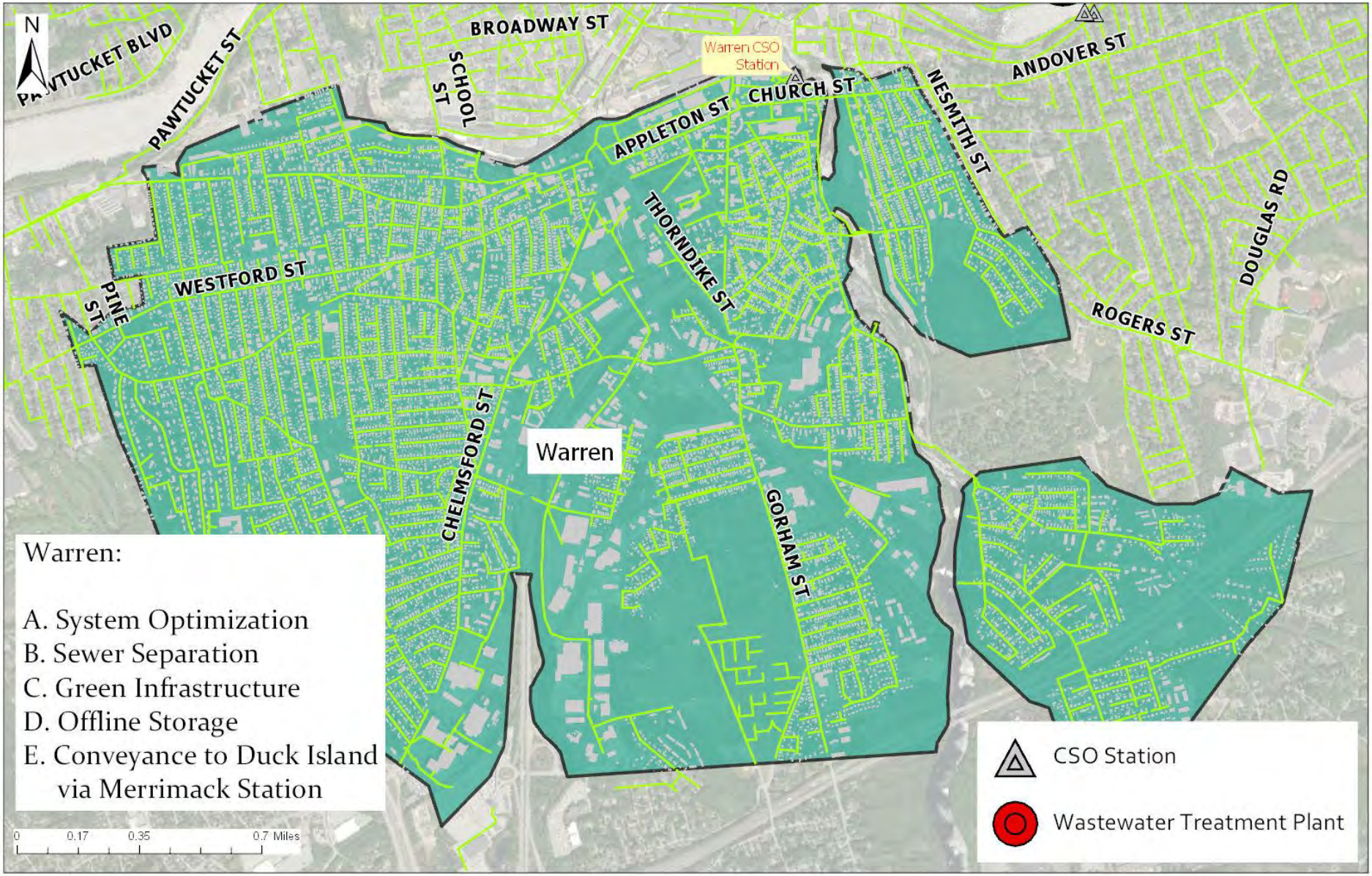
Cons

- CSOs may not be fully treated
- Pumping may be required

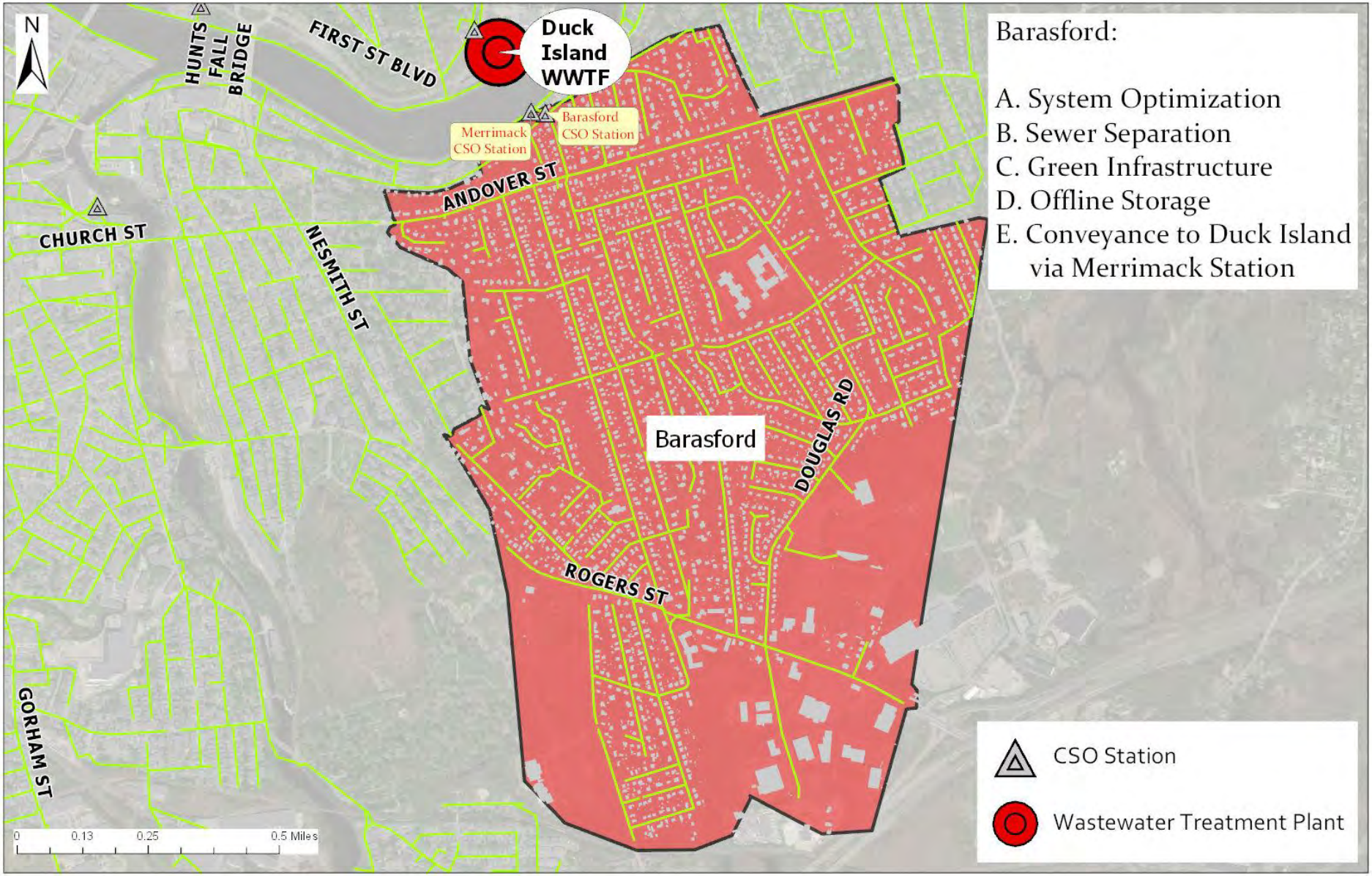
South Bank Sewershed CSO Control Alternatives



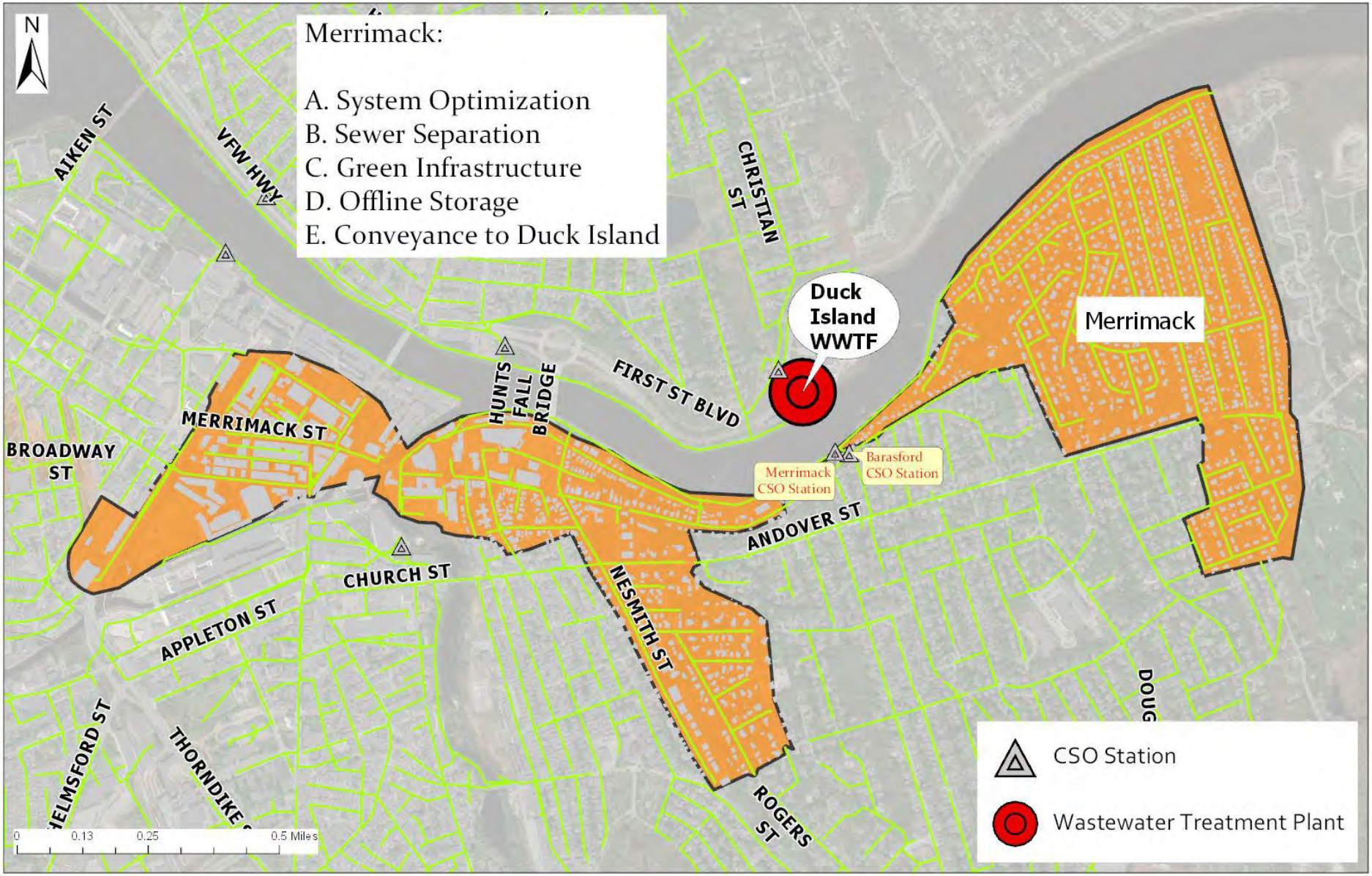
South Bank Sewershed CSO Control Alternatives



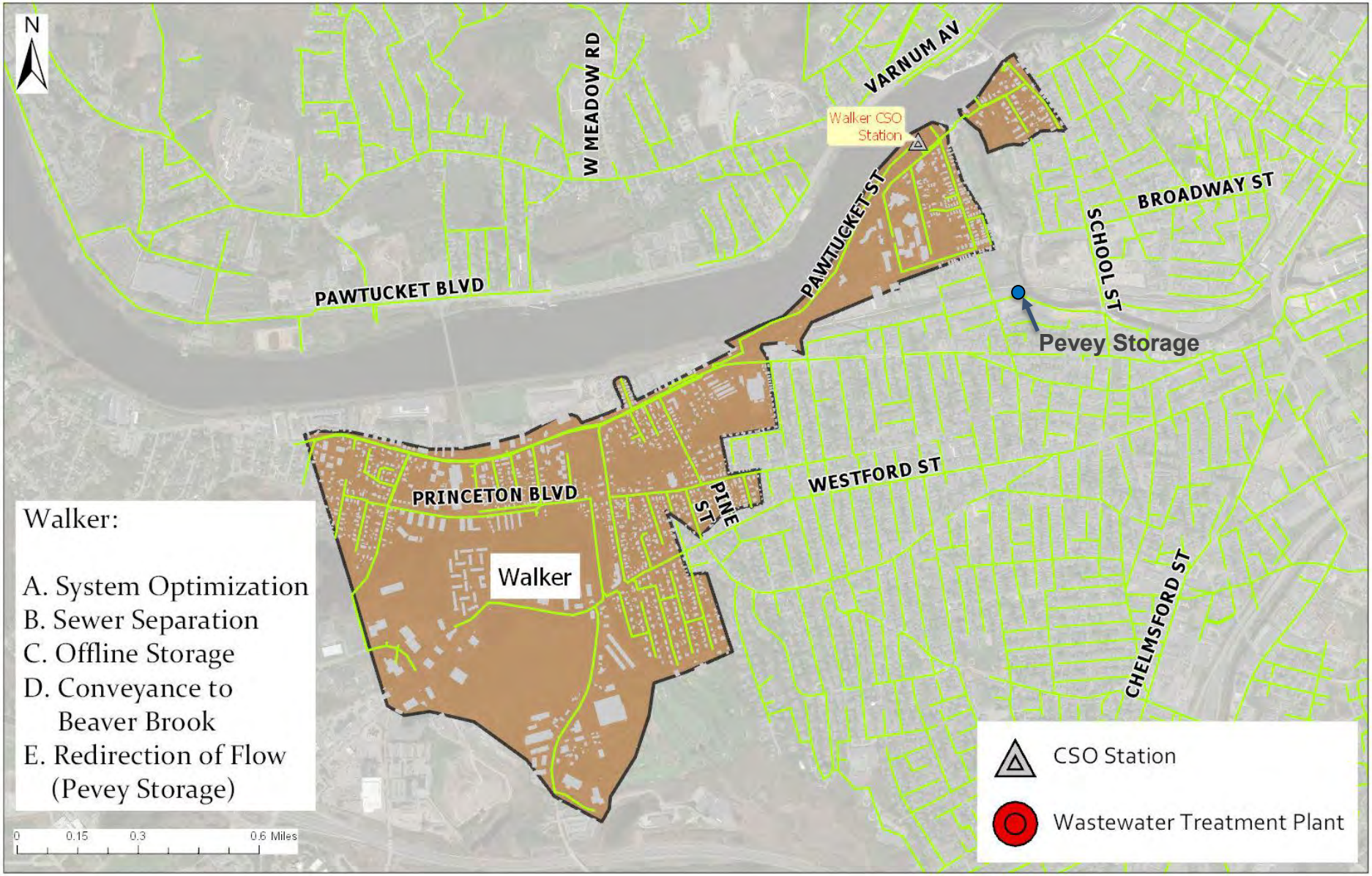
South Bank Sewershed CSO Control Alternatives



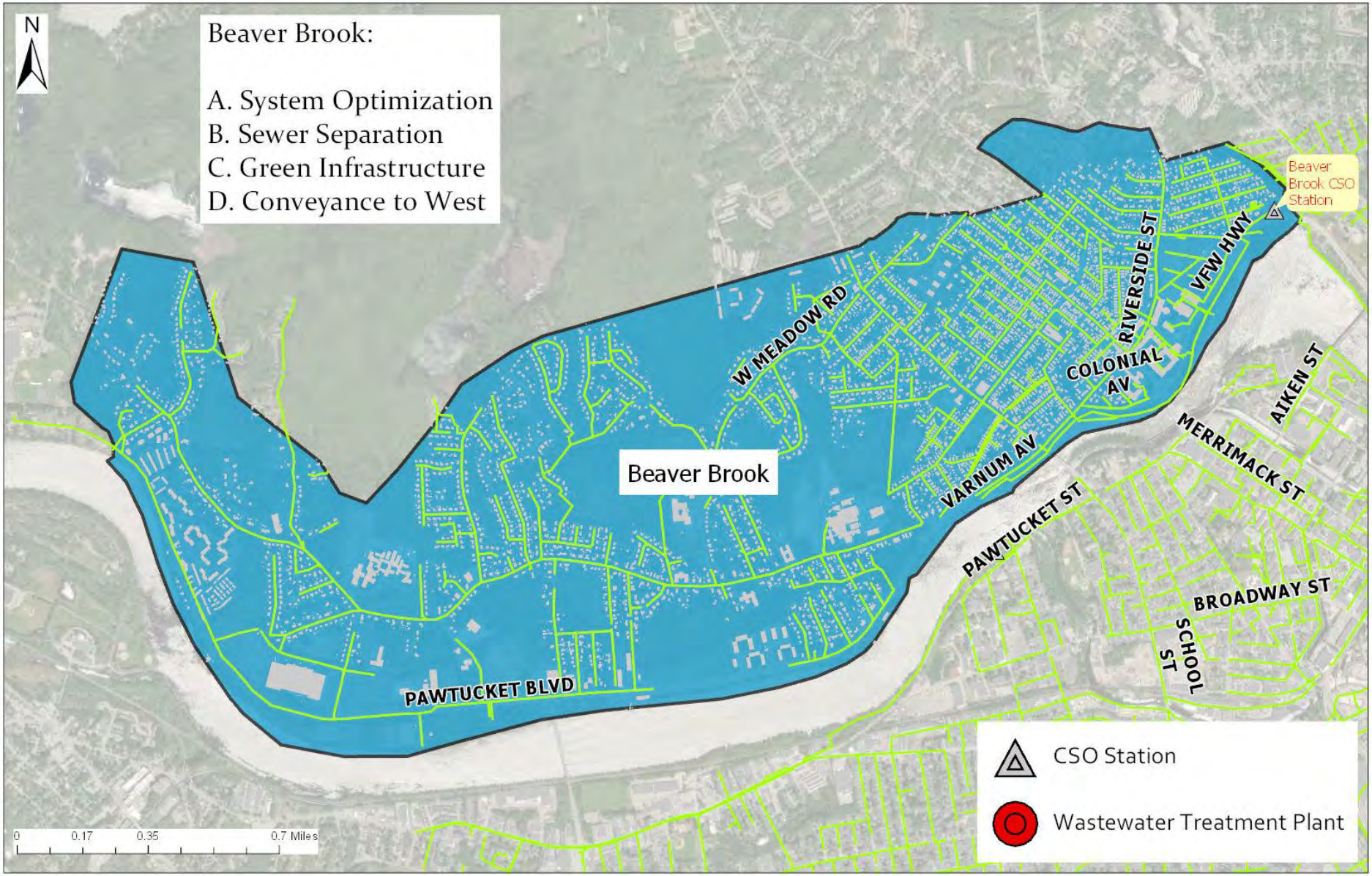
South Bank Sewershed CSO Control Alternatives



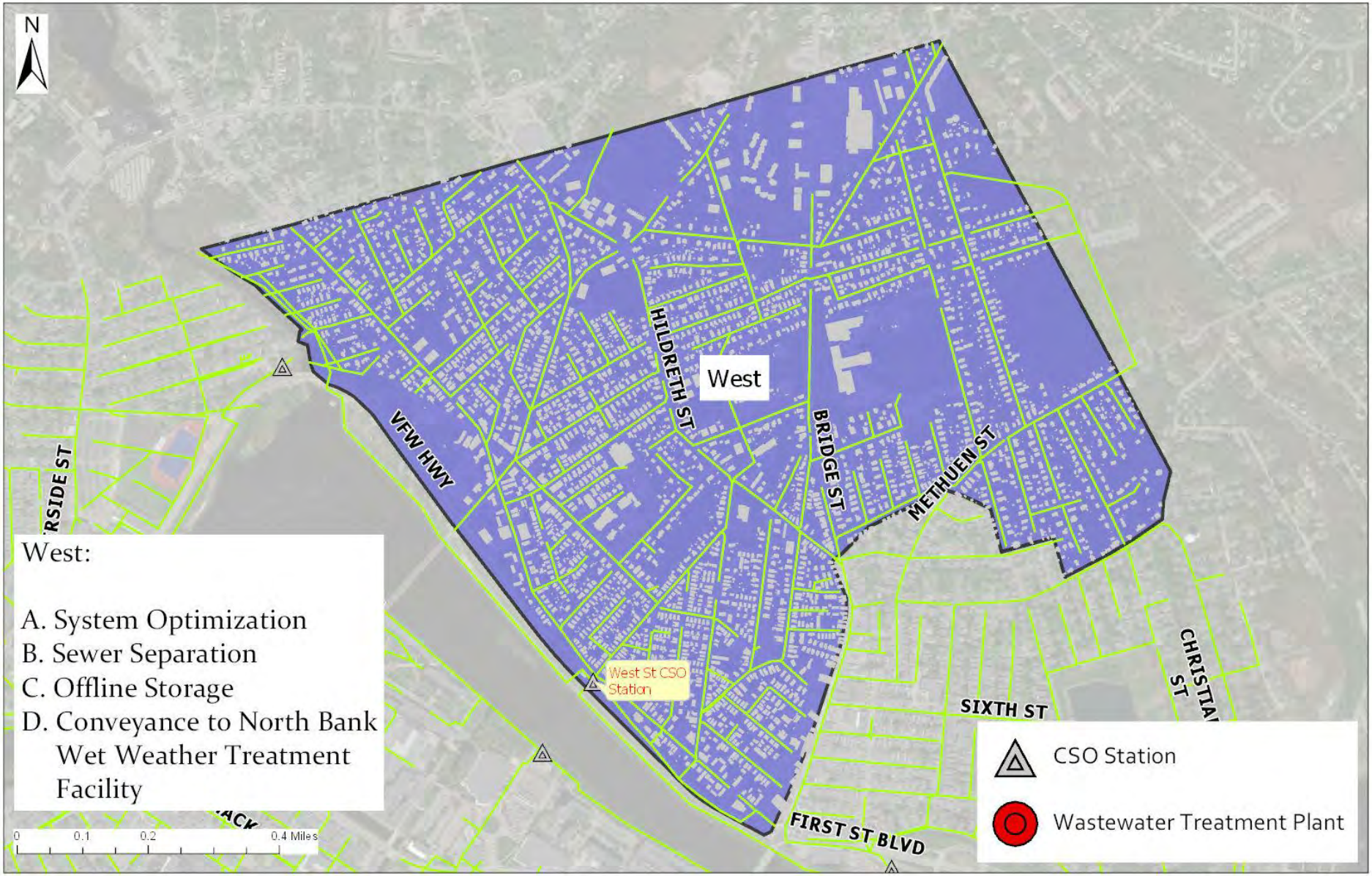
North Bank Sewershed CSO Control Alternatives



North Bank Sewershed CSO Control Alternatives

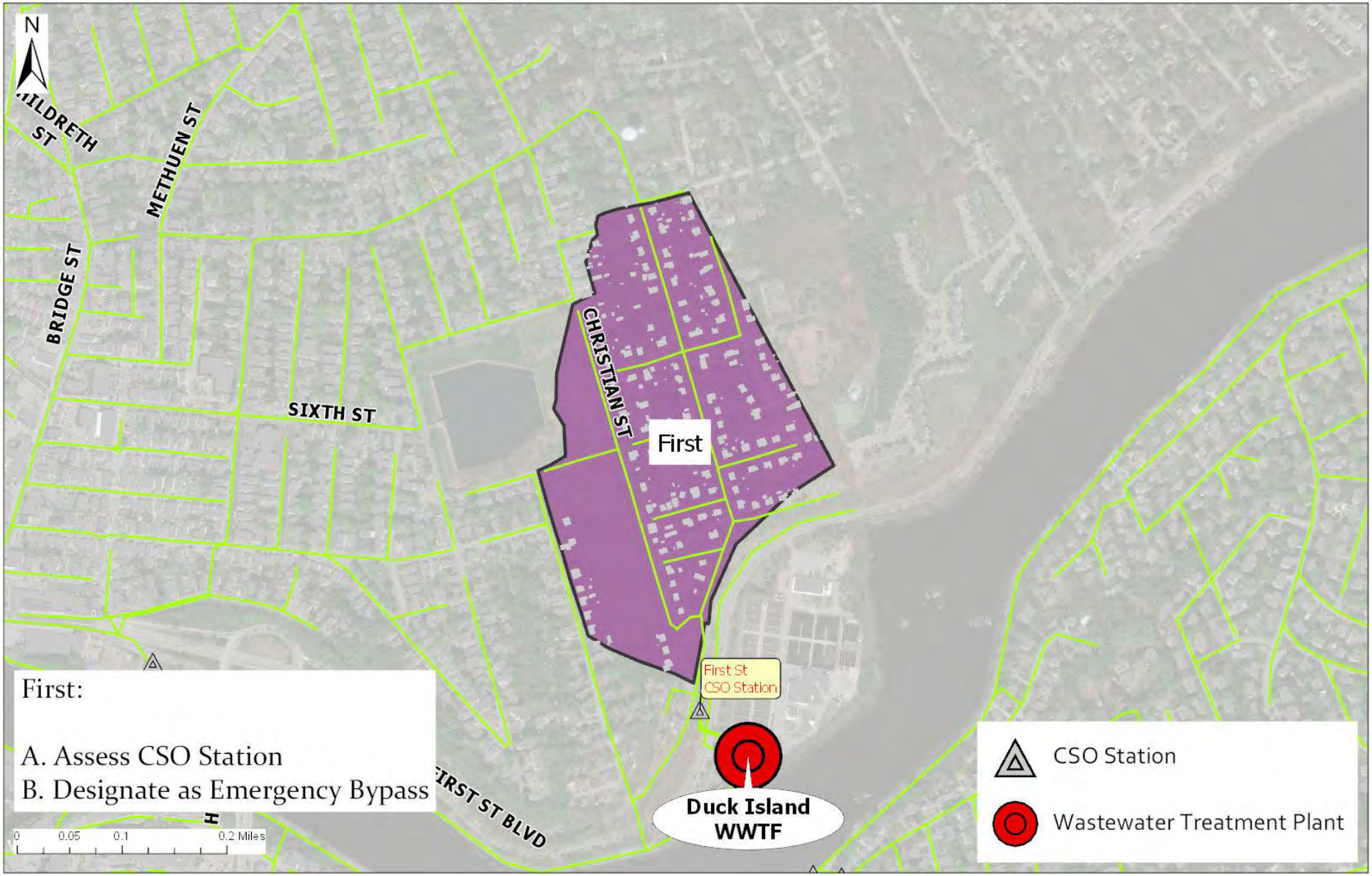


North Bank Sewershed CSO Control Alternatives

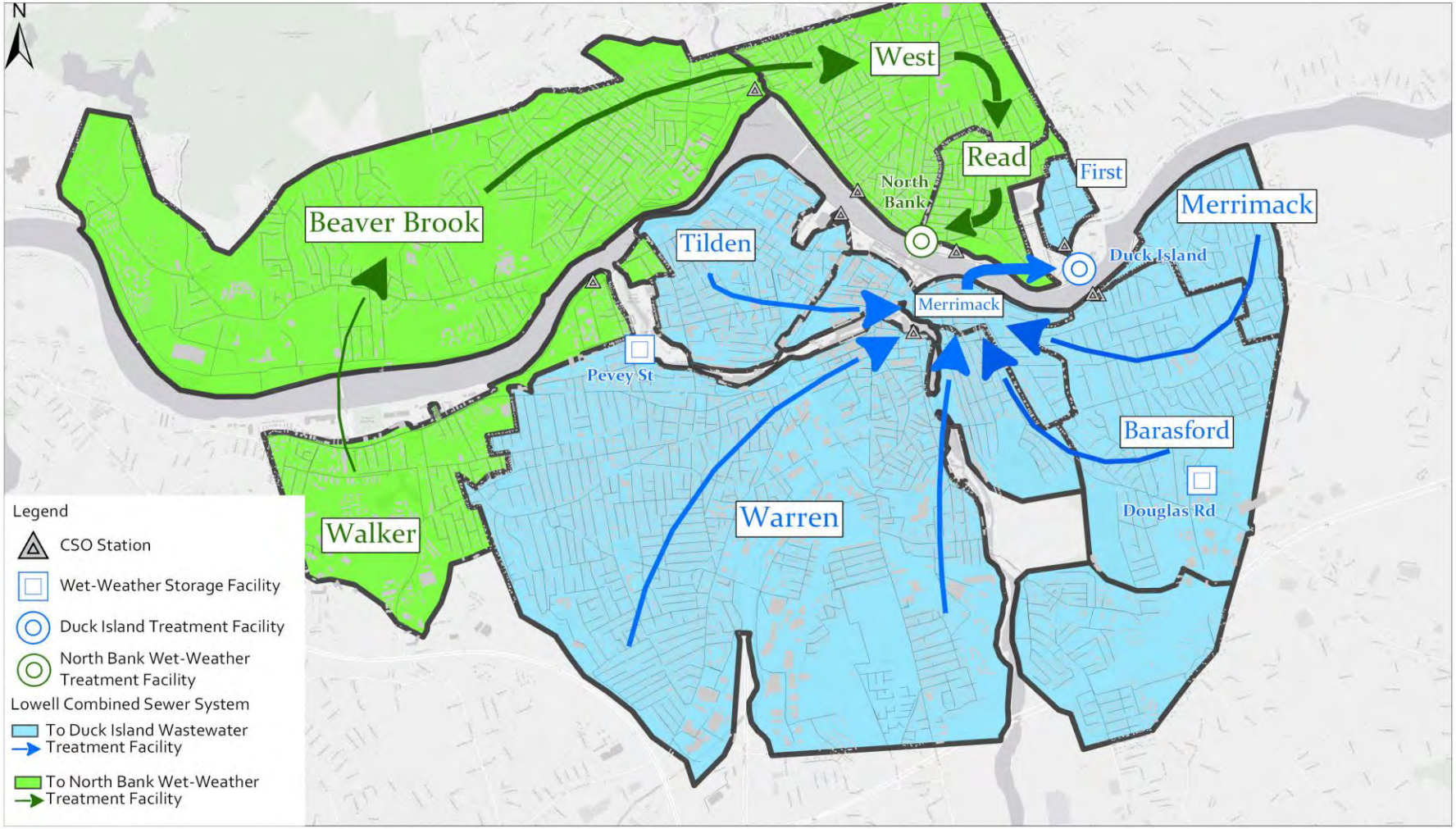


North Bank Sewershed CSO Control Alternatives

North Bank Sewershed CSO Control Alternatives



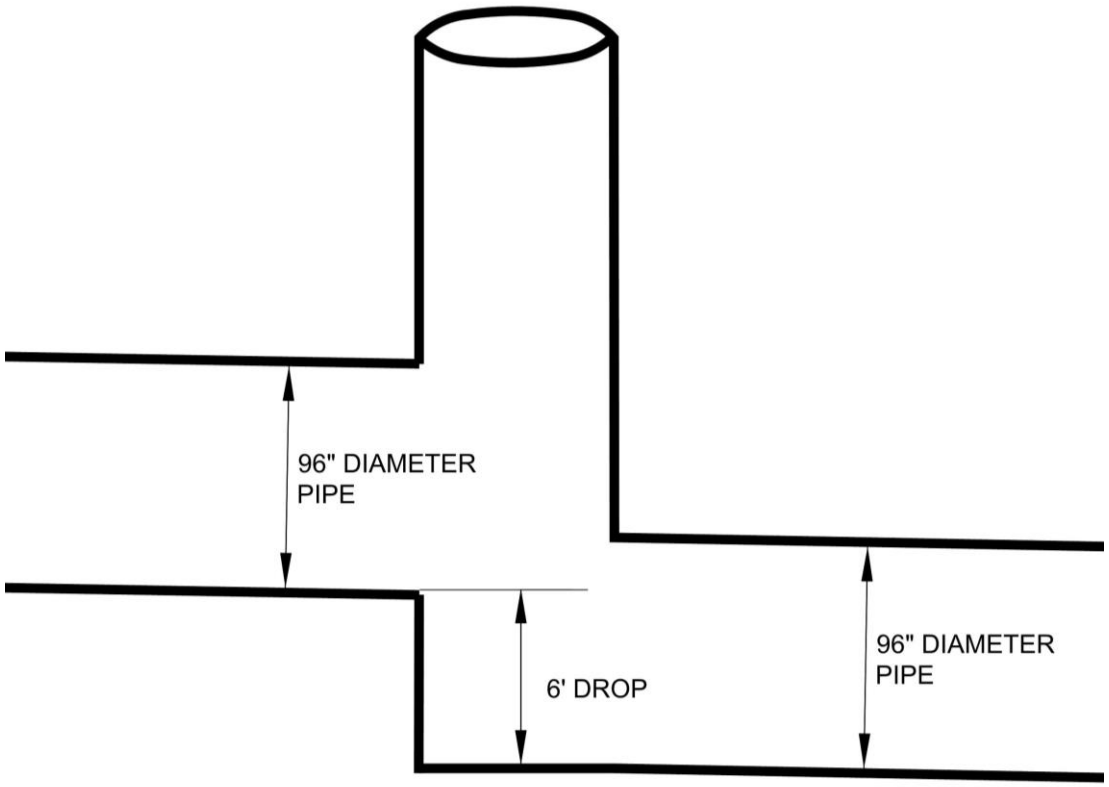
System Wide CSO Control Alternative – North Bank Wet Weather Treatment Facility



North Bank Screening and Disinfection Facility

System-Wide CSO Control Strategy – Wet Weather Treatment at Read Station

- Add a second treatment facility to Lowell sewer system
- Utilize a unique system feature at Read Station
  - 6’ drop, 96” pipe
  - Opportunity for gravity operation
- Benefit other CSO control alternatives by reducing excess wet-weather flows in system



North Bank Screening and Disinfection Facility

System-Wide CSO Control Strategy – Wet Weather Treatment at Read Station

Gravity only operation – no pumping required

Flow control gate regulates flow in North Bank Interceptor – flow from South Bank is maximized

Excess flow goes over weir (screened) and into North Bank WWTF

WWTF functions as storage tank until tank size is exceeded

Excess flow (previously screened) is disinfected before discharge to the Merrimack River

Remaining volume is returned to the interceptor after the event ends

CSO Control Benefits – North Bank WWTF

	Existing Conditions		North Bank WWTF	
CSO Station	**Volume (MG)**	**Frequency**	**Volume (MG)**	**Frequency**
West Street	121.8	34	13.1	12
Merrimack	115.2	21	57.7	12
Warren	48.8	20	49.5	20
Tilden	22.0	18	21.9	18
Read Street	8.1	17	0.0	0
Walker	7.0	8	6.8	8
Beaver Brook	5.7	5	3.0	3
Barasford Avenue	3.1	6	2.8	3
First Street	0.0	0	0.0	0
North Bank WWTF	N/A		168.6	
Untreated CSO Total Volume (MG)	331.7		154.9	

Key Points:

- **53% reduction in untreated CSO volume**
- Significant reduction in frequency of untreated CSO events
- Benefits are magnified when paired with other CSO control technologies
- Readily implementable system wide CSO control strategy – benefits fully realized immediately

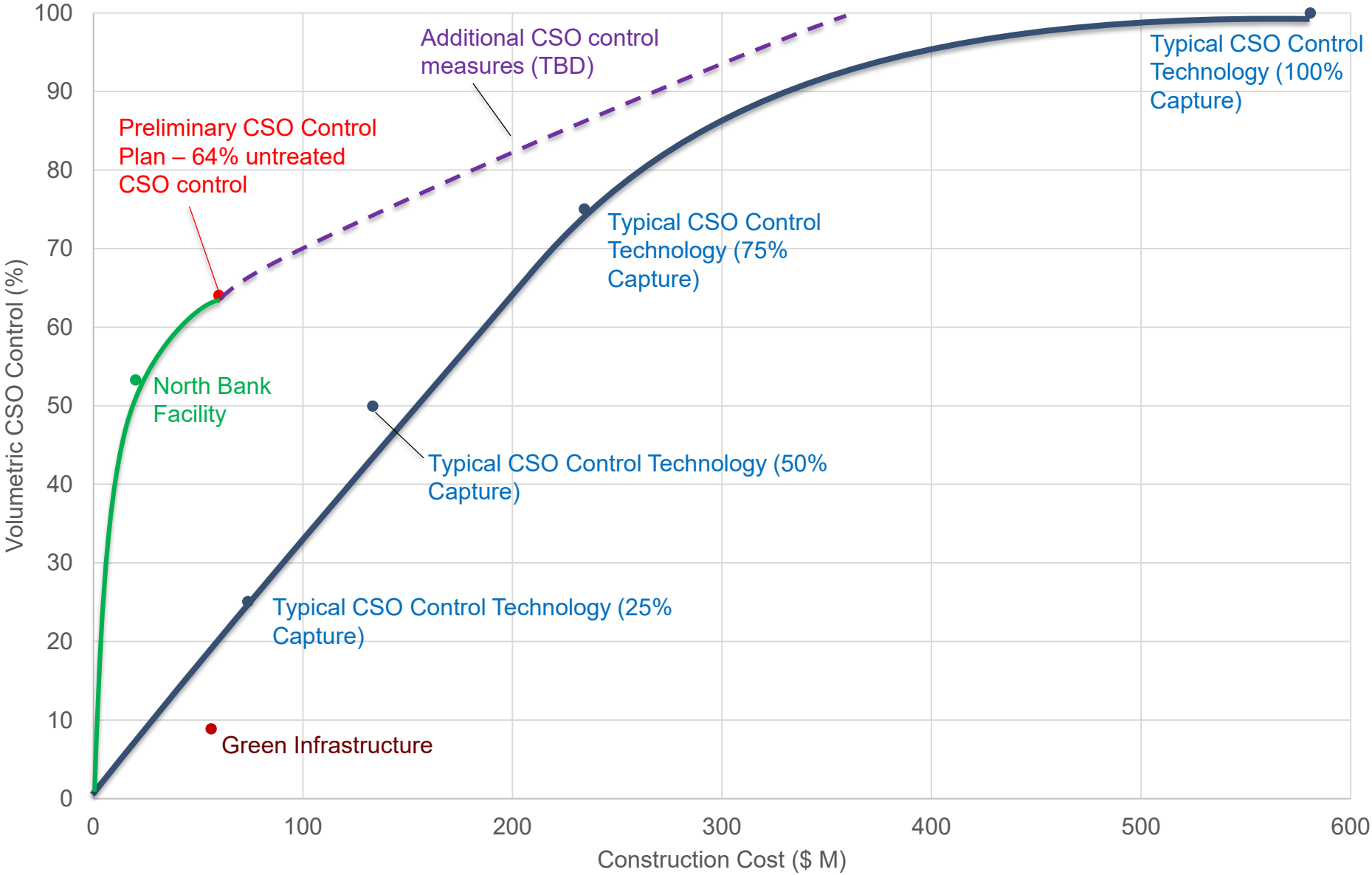
CSO Control Benefits – Preliminary Plan

- North Bank WWTF at Read Station (system-wide improvement)
- Beaver Brook Sewershed - additional conveyance (new siphon)
- Tilden Sewershed – sewer separation and green infrastructure
- Walker Sewershed – offline storage tank
- System optimization

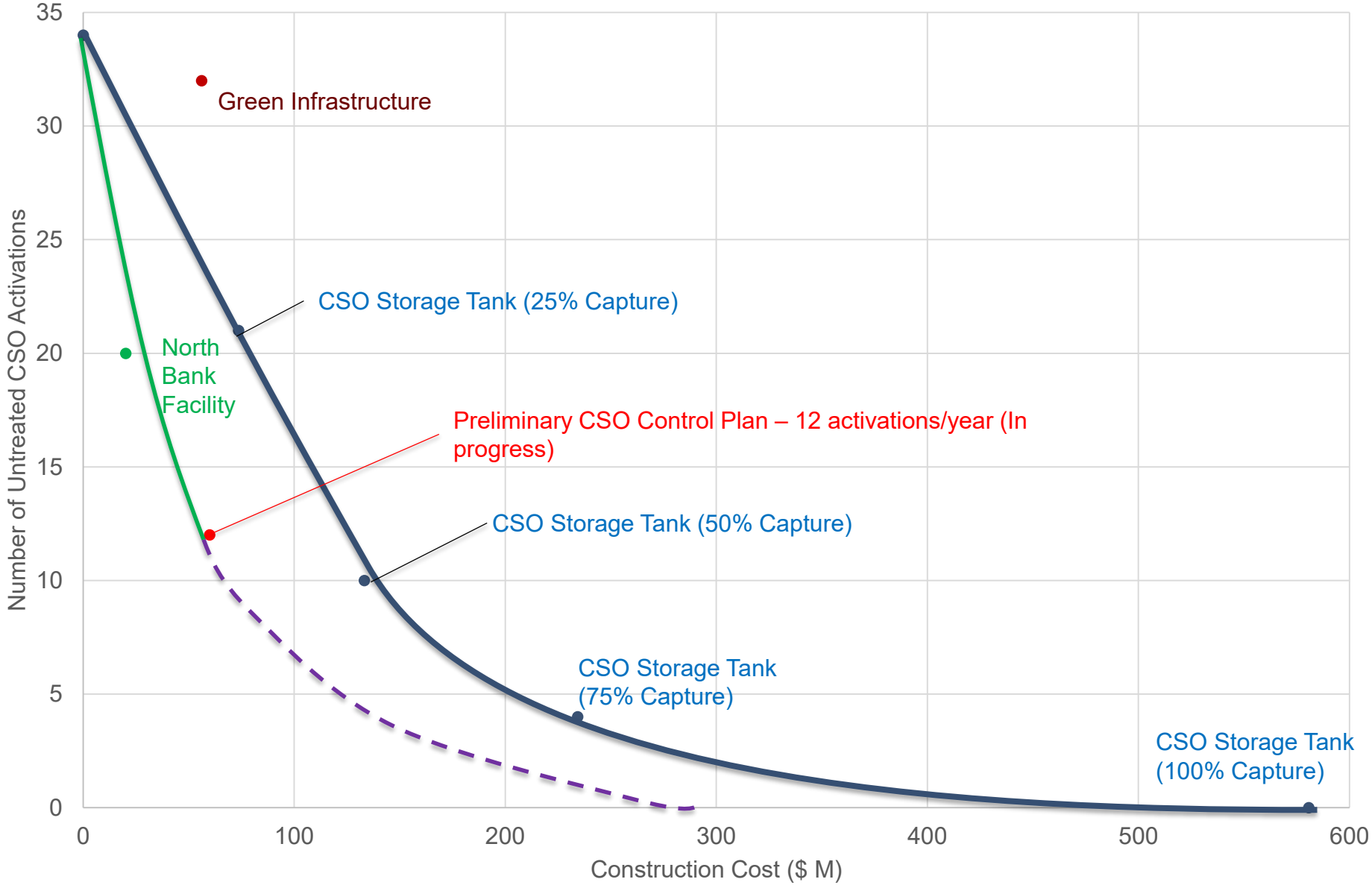
CSO Station	Volume (MG)	Frequency
Walker	6.5	8
Beaver Brook	3.0	3
West Street	12.9	12
Read Street	0.0	0
First Street	0.0	0
Warren	25.3	10
Tilden	10.3	9
Barasford Avenue	2.9	4
Merrimack	61.4	8
Total Untreated CSO	**122.2**	
North Bank WWTF	**165.8**	

- Untreated CSO volume reduced by 64%
- Activations reduced from 34 → 12

Construction Cost vs Volumetric Reduction of CSOs (Volume)



Construction Cost vs No. of Untreated Activations (Knee-of-Curve)

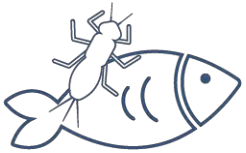


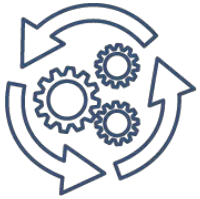
Lowell Water
Integrated Plan (1-801)
Public Meeting #2
SIGN-IN SHEET
October 23, 2019

NAME	AFFILIATION	EMAIL
Charles Wilson	Hazen and Sawyer	cwilson@hazenandsawyer.com
Ben Agrawal	Hazen and Sawyer	bagrawal@hazenandsawyer.com
Gabby Queenan	Mass Rivers Alliance	gabbyqueenan@massriversalliance.org
John Macone	Merrimack River Watershed Council	JMacone@Merrimack.org
Christina Eckert	Merrimack River Watershed Council	executivedirector@merrimack.org
Beverly Woods	Northern Middlesex COG	bwoods@nmcog.org
MARK YOUNG	LOWELL	MYOUNG@LOWELLMA.GOV
Aaron Fox	Lowell	afox@lowellma.gov
Greg Cayle	"	gcayle@ "
EVAN WALSH	LRWWU	ewalsh@lowellma.gov
Cathy Crumbley	MRWC	ccrumbley@merrimack.org
Mike Stuer	Lowell Water	mstuer@lowellma.gov

Hazen

Lowell's Integrated Capital Plan





October 23, 2019

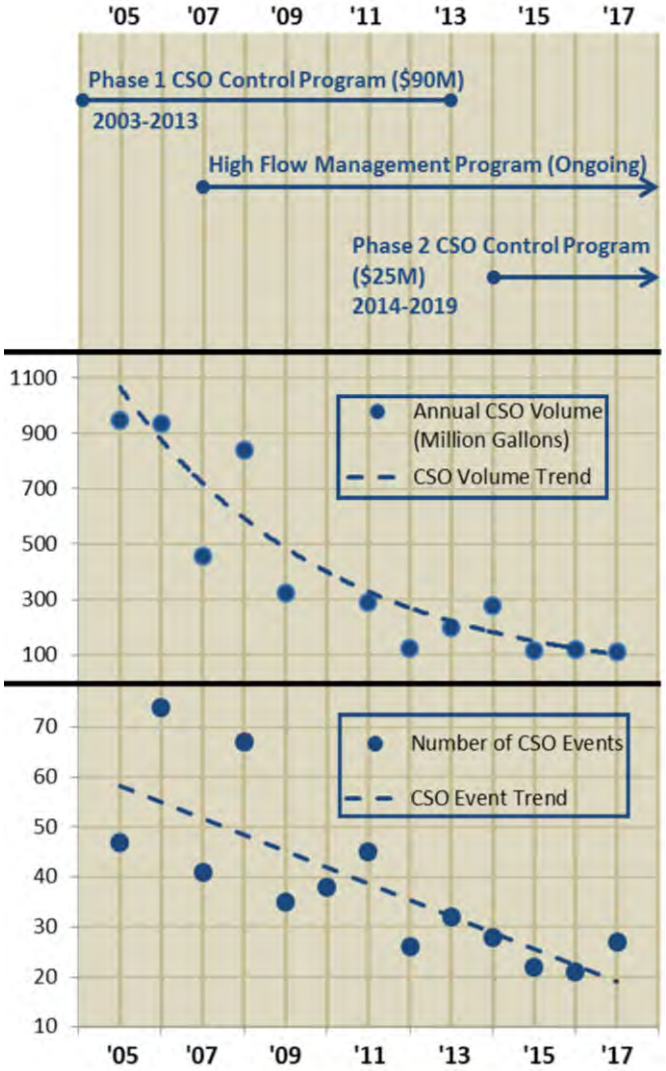
LOWELL WATER
Community ~ Health ~ Environment

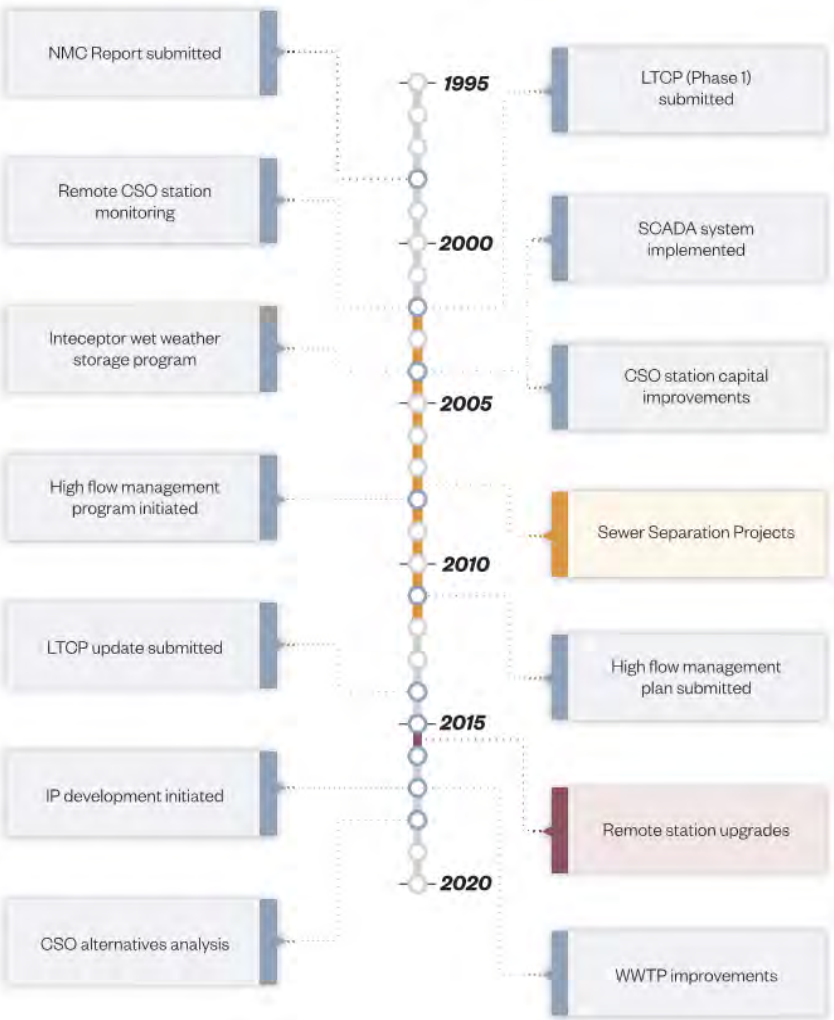
Agenda

- Lowell's CSO control program history
- What is integrated planning?
- CSO control alternatives
  - CSO control alternatives analysis
  - North Bank Wet Weather Treatment Facility
- Draft Integrated Plan
  - Cost-benefit analysis
  - Draft plan benefits

Lowell's CSO Control Program History

- CSO control – more than $150M of local funds invested since 2003
- LTCP Phase III - TBD through Integrated Planning Process

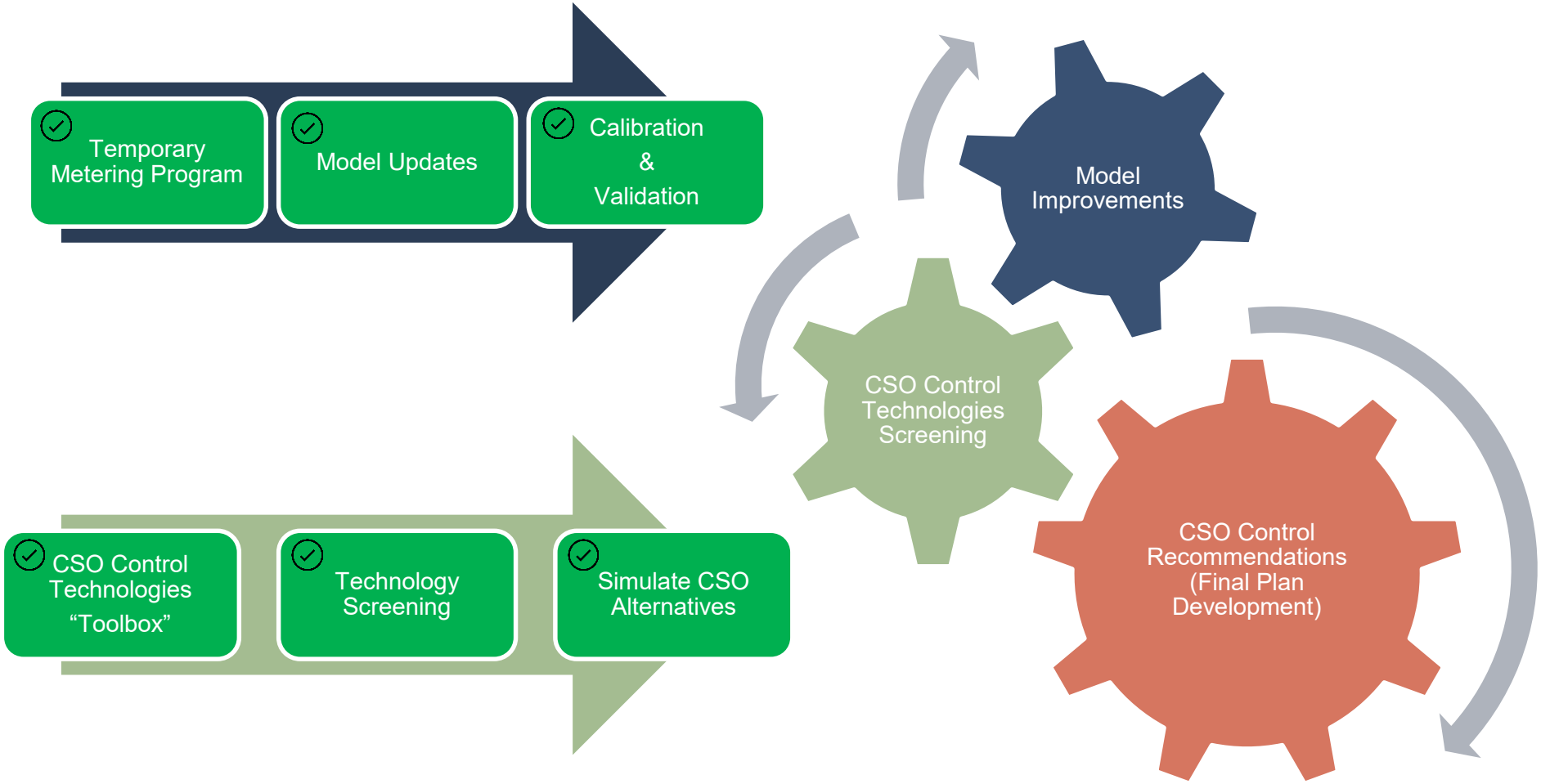




What is an Integrated Plan (IP)?

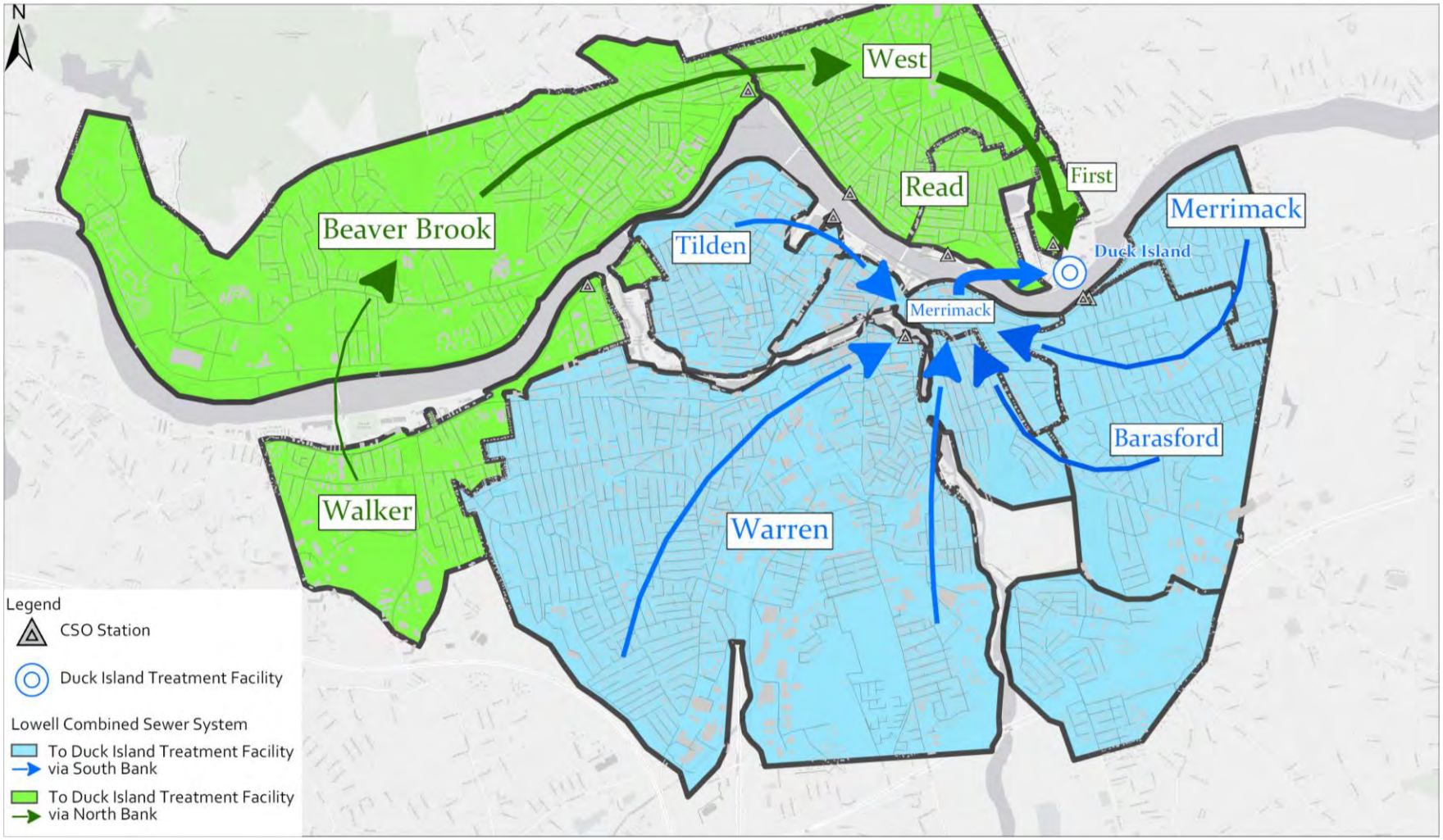
- An LTCP that also considers other water needs, such as drinking water
- Process allows ranking of CSO, wastewater, and drinking water projects according to the same criteria
- Environmental & community benefits and protection of public health considered

CSO Control Alternatives Analysis



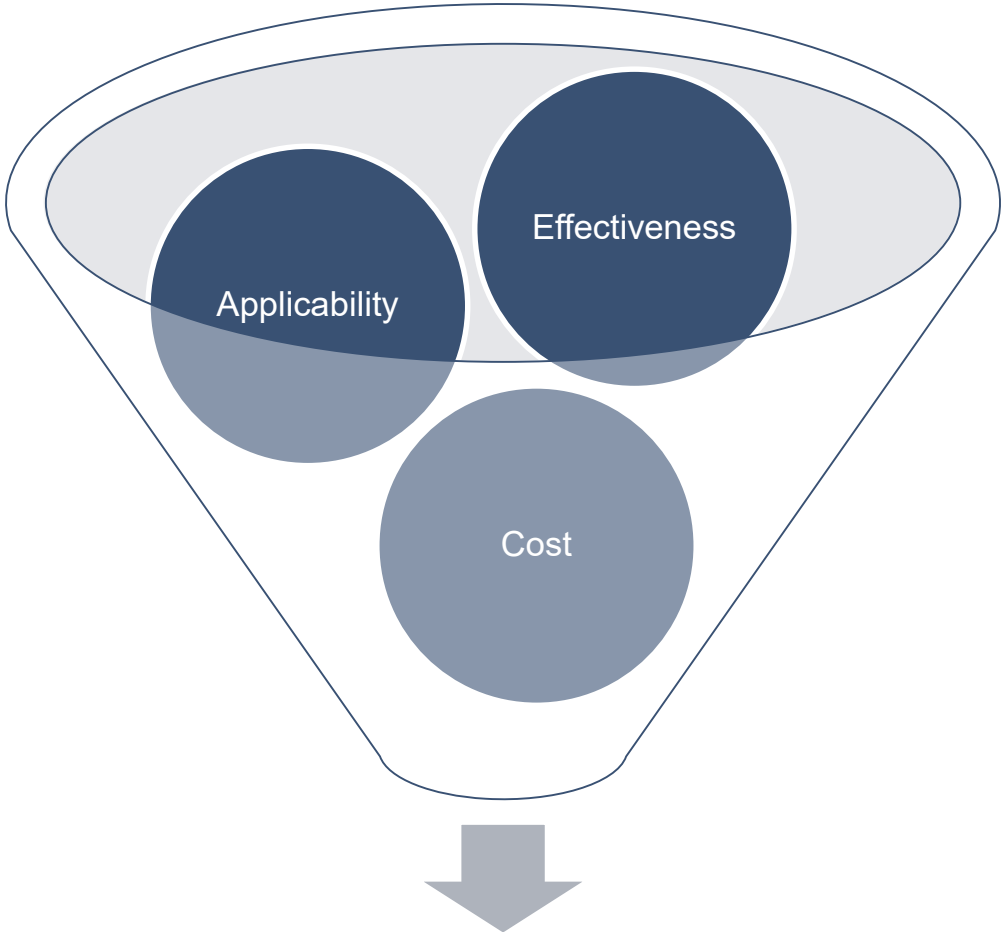
Lowell's Sewer Interceptor System

Wet Weather Transport and Treatment



CSO stations in Lowell are subjected to "cumulative" flow from upstream sewersheds

CSO Control Technologies Screening



LTCP Technology

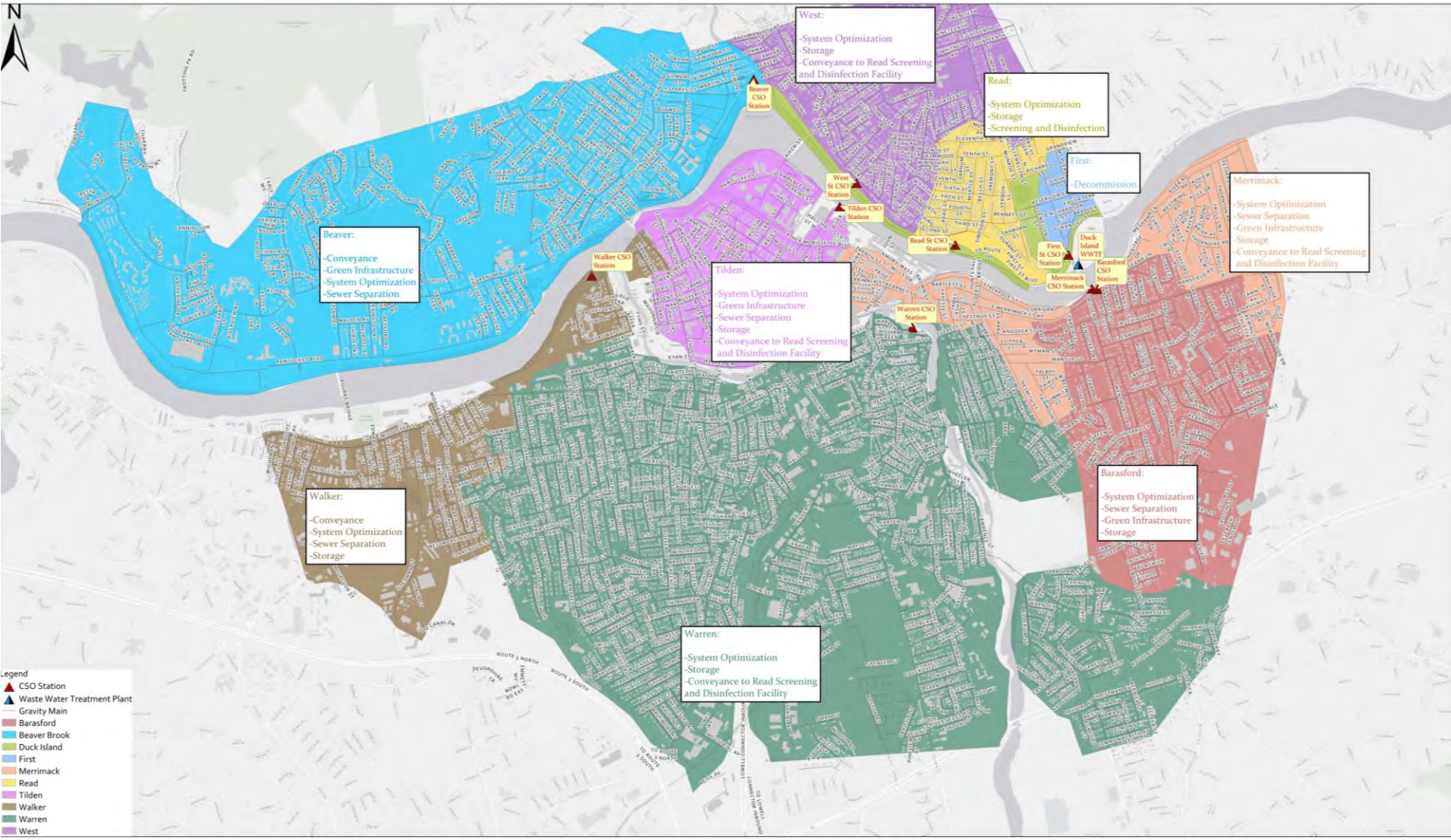
CSO Control Alternatives Screening

CSO Control Technology	Technology Not Widely Applicable or Appropriate	Continue Current Practice	Update/ Initiate Practices	LTCP Technology
Quantity Source Controls – Green Infrastructure				
Porous Pavement				X
Flow Detention/Retention			X	
Area Drain and Roof Leader Disconnection/Rain Barrels			X	
Utilization of Pervious Areas for Infiltration			X	
Quality Source Controls – Best Management Practices				
Air Pollution Reduction	X			
Solid Waste Management		X		
Fat, Oil, and Grease Control Programs (FOG)			X	
Street Sweeping		X		
Fertilizer/Pesticide Control		X		
Snow Removal and Deicing Practices		X		
Soil Erosion Control		X		
Commercial/Industrial Runoff Control		X		
Animal Waste Removal		X		
Catch Basin Modifications			X	
Catch Basin Cleaning		X		
Sewer Cleaning/Flushing		X		

CSO Control Alternatives Screening

CSO Control Technology	Technology Not Widely Applicable or Appropriate	Continue Current Practice	Update/ Initiate Practices	LTCP Technology
Collection System Controls				
Existing System Management			X	
Regulator Modifications			X	
Sewer Separation				X
Infiltration/Inflow Control			X	
Polymer Injection	X			
Regulating Devices and Backwater Gates		X		
Remote Monitoring and Control/Flow Diversion			X	
Relocation of CSO Outfalls & Flow Tipping/Conveyance				X
Storage Facilities				
In-Line Storage				X
Off-Line Storage				X
Surface Storage		X		
Treatment Technologies				
Wastewater Treatment Plant Improvements				X
Screening				X
Sedimentation				X
Enhanced High-Rate Clarification	X			
Chemical Flocculation	X			
Dissolved Air Flotation	X			
Swirl Concentrators	X			
Biological Treatment	X			
Filtration	X			
Disinfection				X

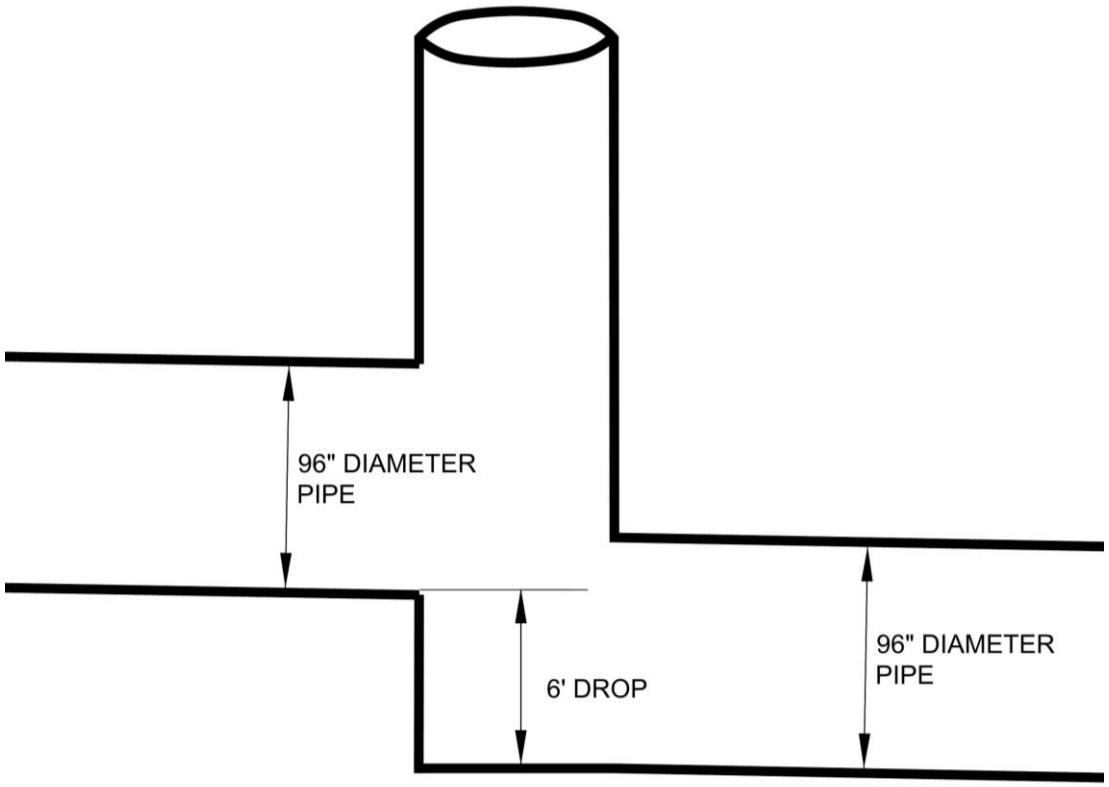
Sewershed CSO Control Alternatives (Handout)



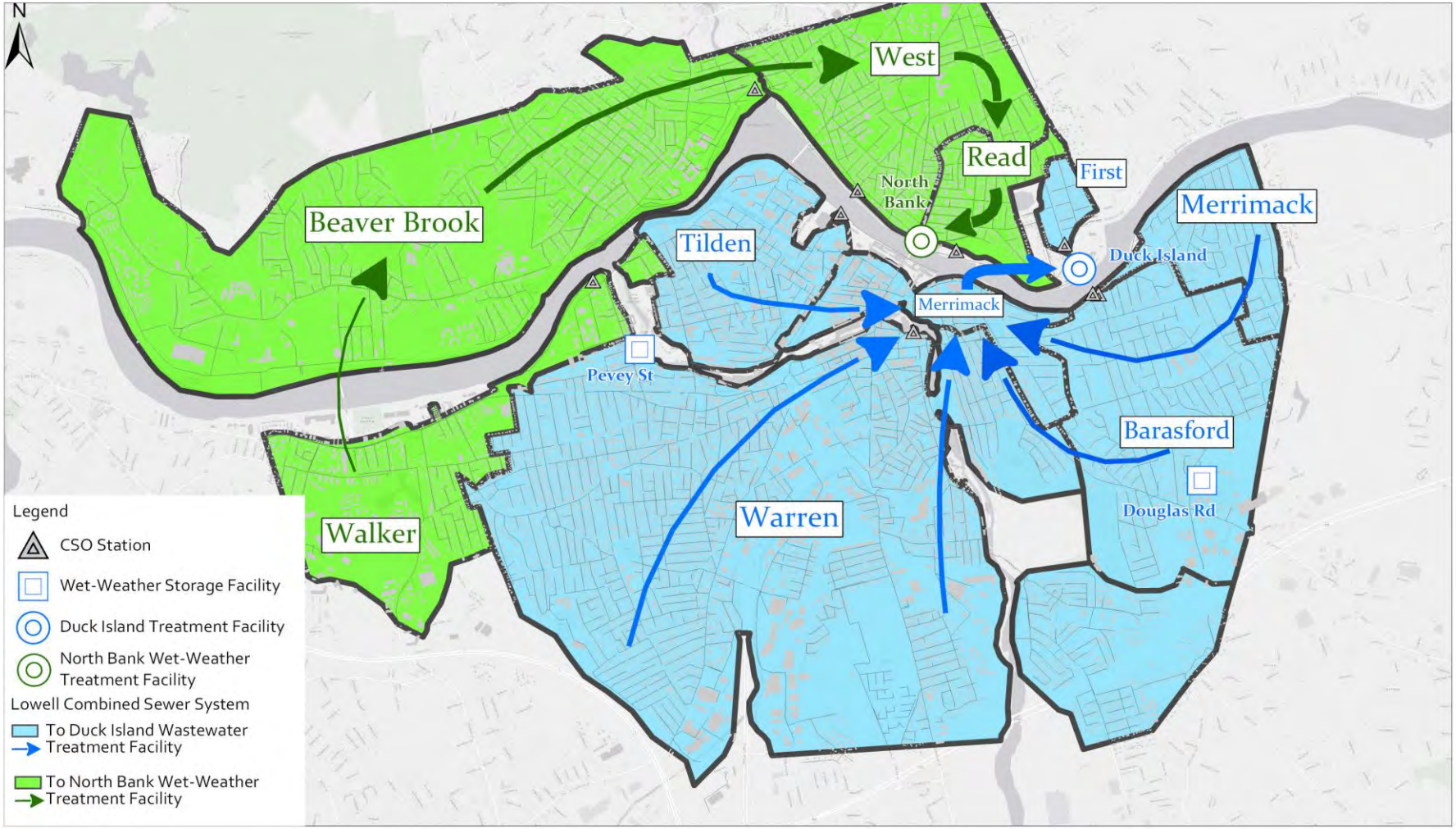
North Bank Screening and Disinfection Facility

System-Wide CSO Control Strategy – Wet Weather Treatment at Read Station

- Add a second treatment facility to Lowell sewer system
- Utilize a unique system feature at Read Station
  - 6’ drop, 96” pipe
  - Opportunity for gravity operation
- Benefit other CSO control alternatives by reducing excess wet-weather flows in system



System Wide CSO Control Alternative – North Bank Wet Weather Treatment Facility



North Bank Screening and Disinfection Facility

System-Wide CSO Control Strategy – Wet Weather Treatment at Read Station

Gravity only operation – no pumping required

Flow control gate regulates flow in North Bank Interceptor – flow from South Bank to Duck Island is maximized

Excess flow goes over weir (screened) and into North Bank WWTF

WWTF functions as storage tank until tank size is exceeded

Excess flow (previously screened) is disinfected before discharge to the Merrimack River

Remaining volume is returned to the interceptor after the event ends

Screening and Disinfection - Background

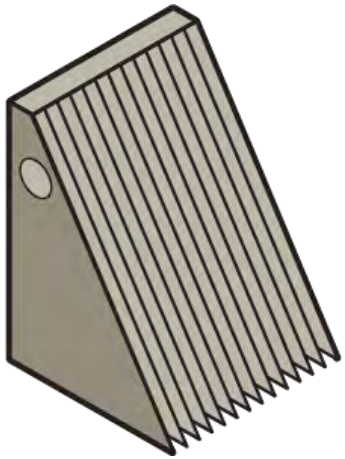
Influent → **Effluent**

- Bacteria
- Solids
- Sediment
- Water

Combined sanitary & stormwater flow

Screening

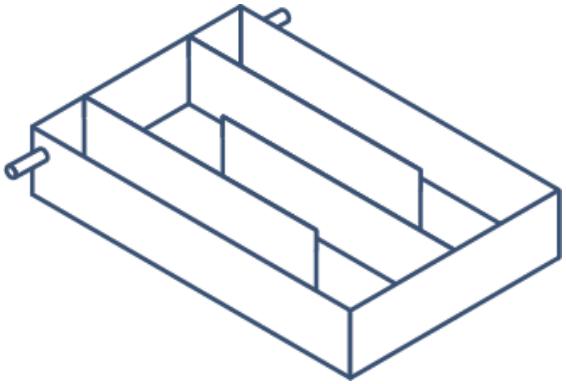
- Bacteria
- Sediment
- Water



Solids remain in the sewer

Disinfection

- Sediment
- Water



99% bacteria removal & partial solids (TSS) removal

- Reduced Sediment
- Water

Treated combined flow

CSO Control Benefits – North Bank WWTF

	Existing Conditions		North Bank WWTF	
CSO Station	**Volume (MG)**	**Frequency**	**Volume (MG)**	**Frequency**
West Street	121.8	34	13.9	11
Merrimack	115.2	21	58.0	11
Warren	48.8	20	49.3	20
Tilden	22.0	18	22.6	18
Read Street	8.1	17	0.0	0
Walker	7.0	8	6.7	8
Beaver Brook	5.7	5	2.9	3
Barasford Avenue	3.1	6	3.1	3
First Street	0.0	0	0.0	0
Untreated CSO Total Volume (MG)	**331.7**		**156.6**	

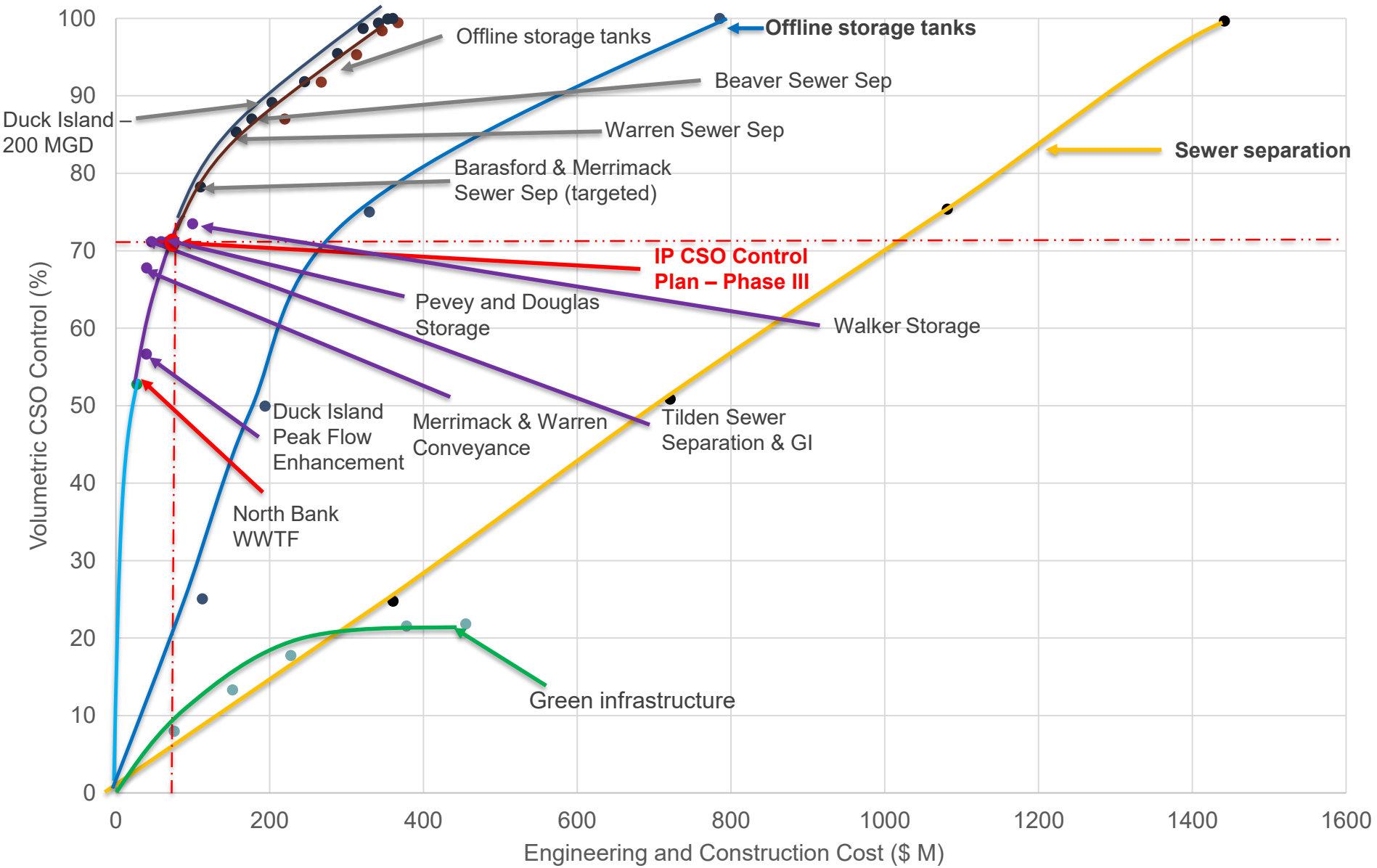
Key Points:

- **53% reduction in untreated CSO volume**
- Significant reduction in frequency of untreated CSO events
- Benefits are magnified when paired with other CSO control technologies
- Readily implementable system wide CSO control strategy – benefits fully realized immediately

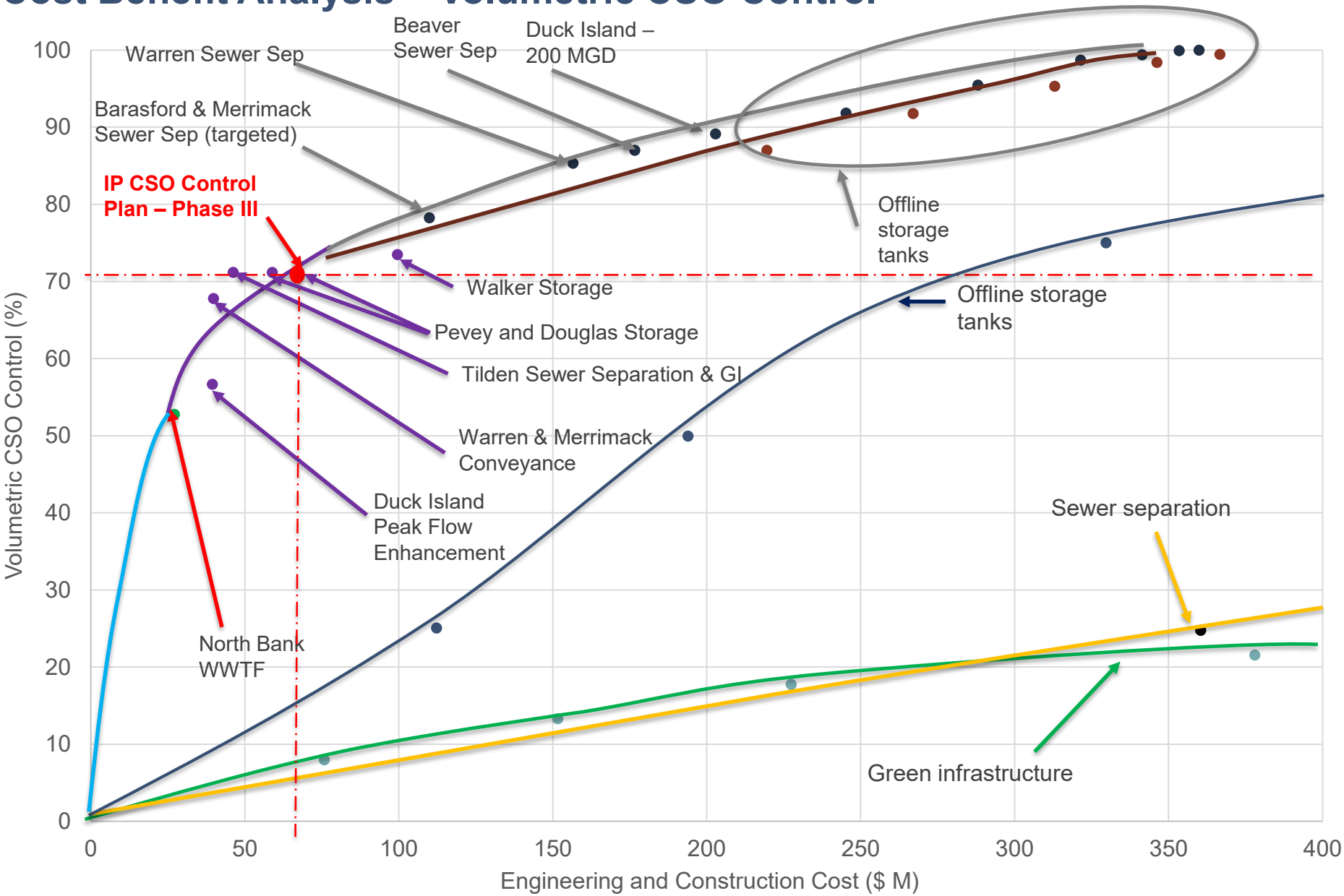
Other CSO Control Strategies Simulated

- Additional wet weather treatment at Duck Island
- Sewer separation (systemwide and targeted)
- Green infrastructure
- Offline storage tanks
- Conveyance improvements & optimizations

Cost Benefit Analysis - Volumetric CSO Control



Cost Benefit Analysis – Volumetric CSO Control



Phase III CSO Control Plan

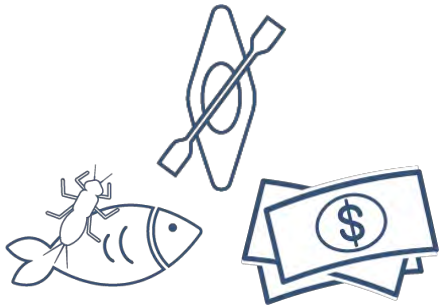
	Existing Conditions		Phase III CSO Control Plan	
CSO Station	**Volume (MG)**	**Frequency**	**Volume (MG)**	**Frequency**
West Street	121.8	34	15.8	12
Merrimack	115.2	21	45.7	8
Warren	48.8	20	11.9	5
Tilden	22.0	18	10.2	9
Read Street	8.1	17	0.0	0
Walker	7.0	8	7.1	8
Beaver Brook	5.7	5	1.8	2
Barasford Avenue	3.1	6	3.1	3
First Street	0.0	0	0.0	0
Untreated CSO Total Volume (MG)	331.7		95.6	
Wet Weather Capture	83.7%		94.8%	

Full IP Project List

Project Name

- Redundant Transmission Main
- Lead Service Replacements
- North Bank WWTF
- Douglas Wet Weather Storage Facility
- Pevey Wet Weather Storage Facility
- Drinking Water Backflow & Meter Improvements
- Duck Island Peak Flow Optimization
- Diversion Stations: Wet Weather Conveyance
- Duck Island WWTF Upgrades
- Duck Island Phosphorus Removal Project
- Drinking Water Treatment Facility Upgrades
- Tilden Sewer Separation and GI
- Satellite Station Upgrades
- Distribution System Improvements
- Finished Drinking Water Storage Tank

IP Scoring & Ranking Process



Develop Criteria → Weight Criteria→ Score Projects → Maximize Benefits Early

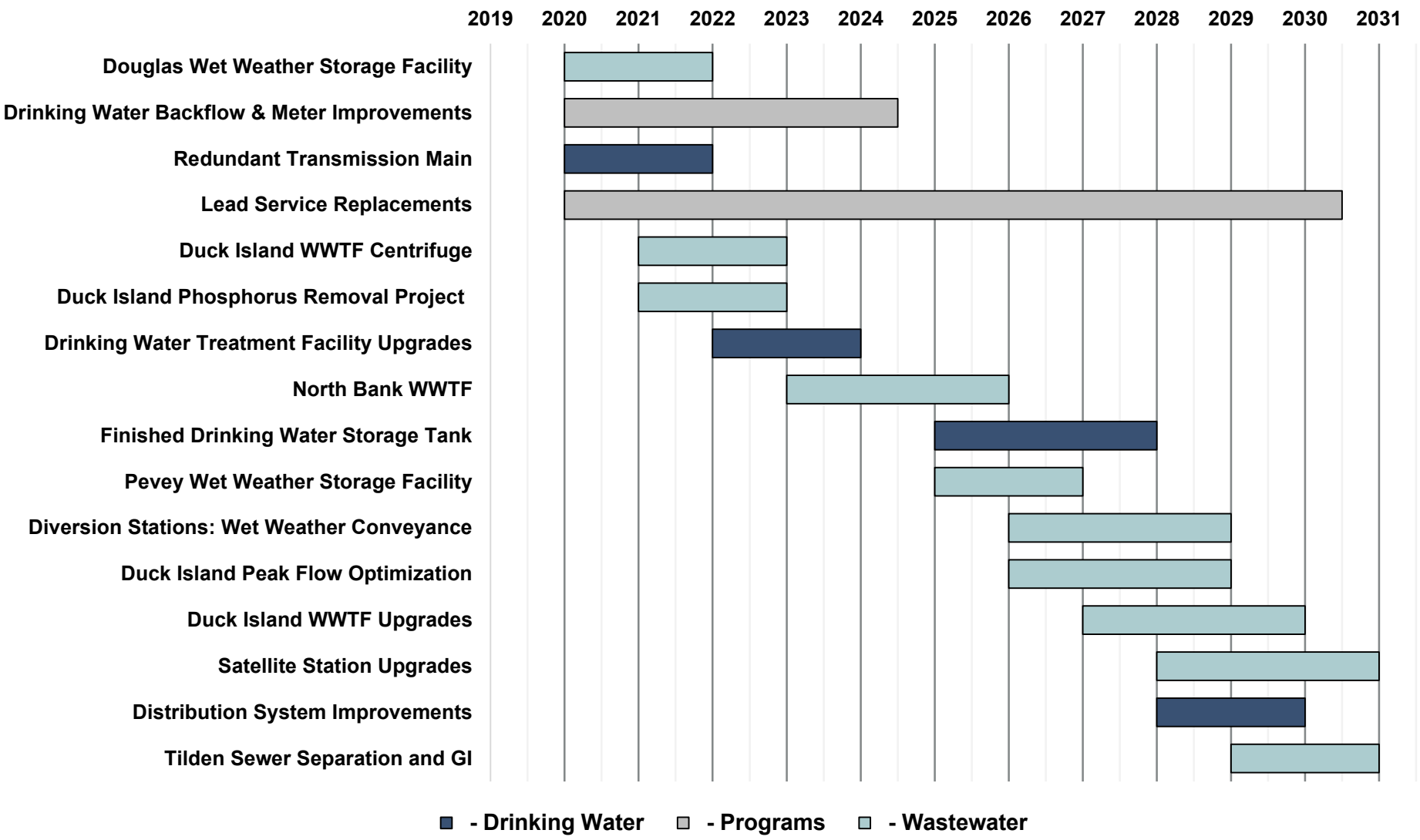
Financial Capability Analysis

- Estimated Plan Cost: $145.3M
- Wastewater: $86.5M
- Water: $58.8M

Income Level	RI	RI w/ COLI
MHI	2	2.5
1st Quintile	6.4	7.8
2nd Quintile	2.8	3.4

Permittee Financial Capability Indicators Average Score	**Residential Indicator (Cost Per Household as a Percentage of MHI)**		
	Low (Below 1%)	Mid-Range (Between 1 and 2%)	**High (Above 2.0%)**
Weak (Below 1.5	Medium Burden	High Burden	High Burden
Mid-Range (Between 1.5 and 2.5)	Low Burden	Medium Burden	**High Burden**
Strong (Above 2.5)	Low Burden	Low Burden	Medium Burden

Draft Project Schedule



Hazen and Sawyer
24 Federal Street, 5th Floor • Boston, MA 02110