BAYSIDE ADAPTS

PHASE 1

Sewer & Stormwater System Data Gap Analysis

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JEE Water Resources & Environmental Engineering

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BAYSIDE ADAPTS

How do we make our neighborhood more resilient to flooding?

Effective planning starts with good information.

Executive Summary

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WORKING TOWARD A RESILIENT BAYSIDE

Flooding has been a problem in Portland's Bayside area for decades. The low-lying neighborhood is already susceptible to flooding during high tides. When coupled with heavy rain, these conditions worsen. The City and its partners have been working to address flooding in Bayside and are identifying the key information and tools necessary to address today's issues and to adapt to tomorrow's changing climate.

With the right tools, collaboration, and planning, the City can select the most cost-effective, community-enhancing adaptation alternatives. This document summarizes the additional data collection needs which will serve as the foundation for adaptation planning in Bayside. In-depth detail on these topics is presented in a 2017 report entitled Bayside Adapts Phase 1 – Sewer & Stormwater System Data Gap Analysis.

EFFECTIVE ADAPTATION PLANNING REQUIRES GOOD INFORMATION AND THE RIGHT MODELING TOOLS

Coastal urban flooding is caused by several factors which must be collectively considered to properly plan for, predict, and identify effective flood management options. Factors include storm and sewer system pipe capacity, tide level, and precipitation rates, amongst others. Computer-based modeling tools are often used to simulate and assess the combined effects of these key factors on flooding. Modeling tools need quality information to produce useful results. Obtaining the appropriate amount of information and building an accurate model is key to enhanced, effective, and cost-efficient adaptation planning in Bayside.

DO WE HAVE GOOD INFORMATION AND THE RIGHT MODEL TOOLS?

Good information and a model exist. The City has:

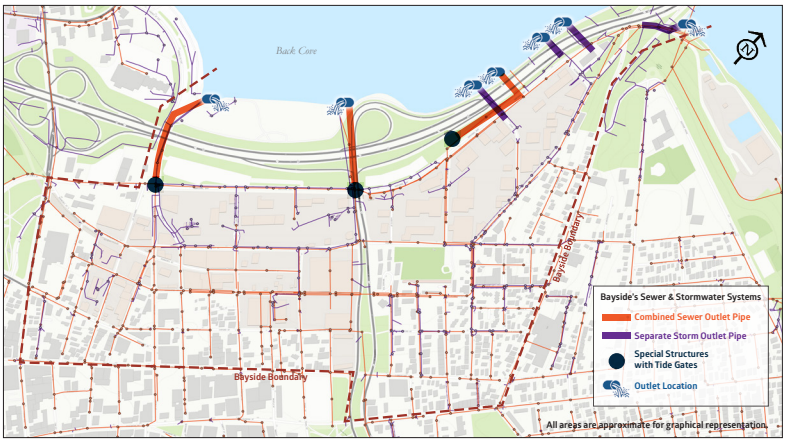
- Reasonably up-to-date information on the location of drainage and combined sewer pipes and structures (GIS data)
- High-resolution and recent surface elevation data
- Schematic drawings of Special Structures that currently control tide intrusion into the combined sewer
- Recent survey information covering most of the key sewer and combined sewer areas in Bayside and obtained as part of implementing the City's multi-million-dollar sewer infrastructure improvement program
- A hydraulic and hydrologic model of the major combined sewer drains (SWMM Model)

However, more information is required. The City needs:

- Compilation and extraction of recent survey information for integration into City GIS
- Targeted field surveys and condition assessments of critical drain pipes and structures
- Additional model expansion for surface flooding predication and adaptation decision support

BAYSIDE'S SEWER AND STORMWATER SYSTEMS

Bayside's sewer and stormwater system is made up of over 20 miles of pipe, over 950 structures and has 7 primary outlets into the Back Cove.



WHAT WE KNOW ABOUT THE FUTURE

The contributors to flooding in Bayside are rainfall, sea level (tides), and the adequacy and functionality of the drainage system. The following table includes current projections of Portland-specific sea level and climate change information to assist with flood and adaptation planning.

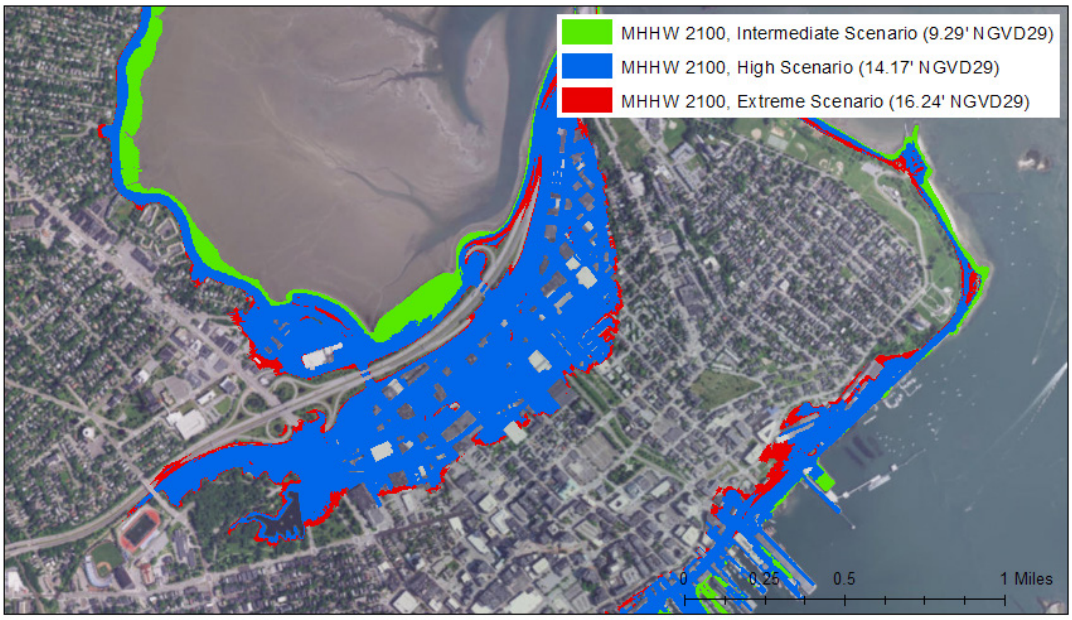
Year 2050		Year 2100	
	Rise in Sea Level		Rise in Sea Level
Commit to Manage	1.5 ft.	**Commit to Manage**	3.8 ft.
Prepare to Manage	3.4 ft.	**Prepare to Manage**	8.8 ft.
		Be Aware of	10.8 ft

**Source: The 'Rise in Sea Level' values are the Relative Sea Level rise values for the Intermediate, High, and Extreme scenarios for Portland, ME reported by a NOAA publication titled "Global and Regional Sea Level Rise Scenarios for the United States" (Sweet et al, 2017).*

Commit to Manage represents the most statistically likely to occur scenario. *Prepare to Manage* represents a less likely to occur scenario, but more consequential event if not managed appropriately. *Be Aware* of represents the 'Extreme Scenario', a very low probability, but high consequence event. In the years to come, Portland will continue to evaluate these numbers against the latest climate science data to determine if the 'High' or 'Extreme' scenarios increase in probability, and whether adjustments are needed to these sea level rise projections.

In addition to identifying the sea level rise projections, Portland-specific storm surge and precipitation tables have also been researched to aid in future modeling and planning. These climate change tables, combined with enhanced sewer and drain system information, ground surface information, and other model inputs, will provide the necessary information for flood predication modeling and the selection of the most cost-effective and community enhancing adaptation alternatives. One way the City can use this information today is establishing new design standards for development based on the projected precipitation and sea level information.

DAILY HIGH TIDE LEVELS IN 2100



Note: Daily high water levels are predicted using a base water level elevation of Mean Higher High Water (MHHW) for the Relative Sea Level rise values reported for Portland by Sweet et al (2017). MHHW is a tidal datum established by NOAA that represents the average high-water level reached daily. The figure is for illustrative purposes only as it is derived using a "bathtub" GIS analysis; it does not account for tidal flooding through the current stormwater conveyance system. Dynamic storm drain modeling is necessary to provide an actual detailed depiction of likely inundation areas.

THE STEPS TOWARDS A SAFER AND FLOOD RESILIENT BAYSIDE

Drainage System

More Information Needed

Good data exists, but there are key data gaps.

Rainfall, Tides, Sea Level

Good Information

Planning scenarios have been developed.

Ground Surface

Good Information

City has detailed ground surface elevation & land use data.

Flood & Adaptation Modeling

More Analysis Needed

The basis of a model exists, but it is not yet adequate for flood planning and decision making.

Deciding on the Best Adaptation Strategy

Cost effective implementation for a safer, flood resilient Bayside.

How can we adapt our Bayside neighborhood to make it more resilient to flooding? The Bayside Adapts Design Challenge submissions show us that there are lots of great ideas out there!

Once the final pieces of information are obtained and the right modeling tools are employed, these ideas can be simulated and evaluated to see if they are effective and cost-efficient. The model will help improve the ideas before they are constructed, saving time and resources for all and helping achieve the ultimate goal: A safer, resilient Bayside.

In addition to helping identify the right construction projects to address flooding in the Bayside, the information and model can be used to: inform City planning and zoning ordinances, revise development design standards, inform City emergency response planning, help improve control of sewer overflows, and more.

Section 1
Introduction & Background Information

1. INTRODUCTION & BACKGROUND INFORMATION

In the fall of 2016, the City of Portland issued a request for proposals for planning and engineering services to facilitate climate change adaptation planning in the Bayside Neighborhood. Known broadly as Bayside Adapts, the Sewer & Stormwater System Data Gap Analysis project was framed to specifically improve the City's understanding of flooding caused by intense rainfall, extreme tides and sea level rise in this low-lying neighborhood both now and in the future.

Numerous initiatives, studies and processes have analyzed and projected the coastal impact of storm surge and sea level rise in the northeast region. The information available is from many different sources and not necessarily analyzed specifically for the City of Portland. To improve the City's understanding of this information and be able to utilize it effectively, the project team of Woodard & Curran, RPS ASA and Jordan Environmental Engineering collaborated with the City to use a multi-disciplinary approach to bring together the big picture potential changes to our City's climate with an in-depth look at what information the City needs to improve their knowledge of the sewer and stormwater infrastructure assets. This information together will help position the City to initiate a follow-on process – Bayside Adapts, Phase II.

1.1 Project Goals

For the Bayside Adapts, Phase 1 project, the City identified seven key goals which include:

- Assess the understanding of sewer, combined sewer and stormwater drainage areas in the study area,
- Define the validity and extent of existing information on system connectivity, functionality, performance and capacity,
- Define the data necessary to accurately model system performance and capacity for a range of rainfall, tide and sea level rise scenarios,
- Interview key department staff for operational and maintenance knowledge pertinent to areas of persistent system failures,
- Identify approaches the City is considering to address stormwater/wastewater management and flooding in Bayside and to what degree those approaches may be effective,

Photo: Bayside Area Working Group Meeting, December 2016

- Analyze historic extreme rain, tide and storm surge events incorporating predictable damage and community disruption, and
- Identify new (if any) immediate priority actions to lessen flooding risks and impacts discovered during the project.

1.2 Climate Change Adaptation Planning in Portland

In the City of Portland's recent Comprehensive Plan update (2017), it is acknowledged that climate change will have significant impacts on the City and there is a desire to mitigate and adapt. During the community engagement piece of the project, the City heard from participants their concern about climate change which helped guide the formation of the plan's overall vision. Climate change has been identified specifically as an environmental challenge faced by the City that will have local, regional and potential global implications and will also require collaboration and coordination to adequately and appropriately adapt to. Prior to the comprehensive plan, numerous studies and initiatives have been undertaken to inform the City of Portland about the projected coastal impact of storm surge and sea level rise. Many regional assessments provide valuable climate change predictions. The information from these studies was utilized in this data gap analysis as a first step in helping the City focus its adaptation efforts. Available information includes:

Local Plans, Studies, Resources

- Ocean Gateway Infrastructure Planning (2005)
- Sustainable Portland Report (2007-2009)
- Maine Climate Change Adaptation Task Force (2009 – 2010)
- City Council Resolution on Sea Level Rise Adaptation (2011)
- Bayside Vulnerability Assessment (2011)
- Commercial Street/Waterfront Vulnerability Assessment (2013)
- Urban Land Institute – Urban Resiliency Panel (2014)
- City of Portland Comprehensive Plan Update (2017)
- Flooding Response Protocols – Internal Staff Process (2015 – 2016)

While not all of these projects focus specifically only on Bayside, understanding the body of knowledge that exists helped inform the discussion for this project and provided a comprehensive, detailed investigation of approaches being considered throughout the City. To further understand the body of research available, the project team also referenced other relevant existing work, which is listed in Section 7.0.

1.3 Climate Change Implications in Portland

Climate change adaptation planning is an issue with wide ranging impacts and it knows no physical, social or political boundaries. The Bayside neighborhood has a unique history in that much of it is filled tidal flats which have been modified substantially over time since 1870 **(see Figure 1)**. Prior to the fill, Bayside was part of the Back Cove or tidal marsh. Bayside started to become upland area when it was partially filled with debris from the Great Fire of 1866. Subsequent filling of Bayside created more upland area, and transformed the landscape into a present day urban residential and industrial area of the City, home to warehouses, scrapyards, manufacturing and small businesses. Today, Bayside is seeing a significant interest and investment from commercial and residential developers as well as light industrial manufacturing uses and craft breweries. The residential nature of the neighborhood is another key factor in the need to determine next steps for improved flood control and climate change considerations.

Figure 1: Historic Fill in Bayside Neighborhood 1870 - 2003

During heavy rain events, particularly when they coincide with a high tide or astronomical high tide, parts of Bayside flood. The existing stormwater and combined sewer system in Bayside is stressed by these high tides, storm surge, and extreme precipitation events. During storm events with heavy precipitation, sewer, combined sewer and stormwater systems in Bayside can reach their capacity, resulting in wastewater discharges in the coastal receiving waters, which can be damaging to the environment and pose health risks. The potential for high precipitation events in low-lying coastal areas often coincides with storm surge events due to the characteristics of coastal storms. Understanding these events is an important aspect of scenario development. Understanding how the system responds to current and historical events is also key to predicting how it will respond to increasingly severe conditions in the future.

1.3.1 What is the City Currently Doing - CSO Abatement In Bayside

The City of Portland remains committed to Combined Sewer Overflow abatement within the Bayside neighborhood. Numerous projects have been completed, are ongoing, or are planned to separate stormwater from combined sewers. In addition, a major project (Back Cove South Combined Sewer Storage Conduit) that would temporarily store combined sewage and stormwater and then route this stored wastewater to the East End Wastewater Treatment Facility is in the design evaluation stage. While combined sewer overflow abatement is ultimately a stormwater management activity, the design objectives for these projects do not directly address flooding or flood control. The City is currently implementing improved tide inundation protection as a part of the installation of new stormwater drainage at Preble Street. Another mechanism the City is using to improve conditions is by requiring parcel developers to control stormwater runoff during redevelopment projects which will reduce the peak rate of runoff from an individual parcel.

1.4 The Data Gap Analysis

The City of Portland has many competing needs for operational and capital improvement budgets. It is challenging to identify and prioritize the funding and implementation of these projects. The decisions of investing to maintain and rehabilitate versus rebuild and redevelop are further complicated by considerations of climate change, which leaves coastal infrastructure with increased vulnerability. The exciting part of facing these complications is the potential for solutions that address not one, but multiple issues. This data gap analysis was prepared using a multi-disciplinary approach so that it can be applied widely, is repeatable, and is useful to address other needs.

While the City of Portland has already undertaken a tremendous amount of valuable work and developed related model improvements for the upland portions

of the Bayside drainage area, the influence of coastal water levels on the entire City of Portland, particularly Bayside, is having an impact that must be considered in future analyses of the system. One of the key issues for this project is understanding the influence of tides and storm surge on the stormwater system, now and into the future. To evaluate these impacts we have detailed how existing data and models currently used to manage the drainage system should be combined with tidal and storm surge predictions from ocean models to understand hydraulic limitations of the system. In this process we have flagged data gaps that must be filled before undertaking new modeling.

Conducting a technical data gap analysis of the sewer and stormwater drainage system will help the City to advance its understanding of the coastal influences and vulnerabilities (impacts) to the Bayside neighborhood, infrastructure, development, economic resources, cultural assets and natural systems, which is critical so decision-makers can continue to engage the public, identify funding, and move forward with informed adaptation planning and projects.

1.5 Collaboration With the Bayside Area Working Group

Woodard & Curran and our project partners RPS ASA and Jordan Environmental Engineering collaborated with the New England Environmental Finance Center (NEEFC) and the Bayside Area Working Group (BAWG); an essential component of public engagement during the Bayside Adapts planning effort.

The project team met with the NEEFC Project Manager and BAWG in March and June of 2017 to discuss the data gap analysis and receive feedback, in addition to attending other BAWG meetings to observe the public process. The BAWG was also involved in a Design Challenge which focused on developing concepts for adaptive approaches throughout Bayside to address rising sea levels. Illustrative design concepts were submitted from five applicants to help the community envision a viable future for Bayside and Woodard & Curran provided technical assistance for the event.

Section 2

The Sewer & Stormwater Systems in Bayside

2. BAYSIDE FLOODING AND DRAINAGE SYSTEM OVERVIEW

Frequent flooding in an urban environment is rarely caused by a single factor. Flood predicting and planning is complex as many key factors must be assessed. To provide a framework for this report, this Section provides an overview of basic definitions, a simple summary of Bayside's drainage system, and a synopsis of the challenges that complicate drainage and flood planning in this area of Portland. This Section also discusses the City's Combined Sewer Abatement (CSO) program and how it plays a role in the City's flood planning.

2.1 Drainage and Flood Planning

Flooding in urban areas is caused by several key hydrologic and hydraulic factors. These factors must be considered collectively to properly predict and plan for flooding.

Hydrologic factors influence how much and at what rate precipitation moves off the landscape as stormwater runoff. These factors include, but are not limited to, land use, rainfall intensity, rainfall duration and volume, soils and other factors. Hydrologic factors change as land use and climate change.

Hydraulic factors influence how water moves through pipes and channels. These factors include, but are not limited to, pipe size, pipe slope, configuration, structural condition, and whether a pipe is pressurized or not. Additionally, elements like tides and storm surge will greatly influence a pipe's hydraulics. How well and how fast a pipe system collects, redirects, conveys, stores, and ultimately discharges stormwater can greatly influence the flooding potential of the area.

2.1.1 Flood Planning is Complex – Requires Data and Modeling Tools

Hydrologic and hydraulic factors that are present in an area like Bayside combine to make planning a complicated task. Due to the complexity of the landuse and infrastructure systems, areas of interest are typically modeled using computer-based tools that help predict the locations and extent of flooding. Modeling tools need the right input information to produce useful results. Obtaining an adequate amount of the "right" information is key to initiating flood planning.

Identifying information that influences hydrologic and hydraulic factors for Bayside is the basis for this project. Where are the important data "gaps" that should be addressed to best adapt and enhance the area's resilience to flooding? **Sections 3, 4 and 5** provide an overview of drainage infrastructure, hydraulic and hydrologic information currently available and identify several gaps that will enhance future planning.

2.2 Bayside's Existing Drainage and Combined Sewer Infrastructure

For the purpose of this report, the combined sewer (pipes carrying both sewage and stormwater) and separate stormwater drainage system are called "drains" or the "drainage system". Throughout Bayside, these systems are interconnected. As this is essentially a flooding adaptation project, enhancing the stormwater drainage system inclusive of consideration for combined sewers is critical to resiliency.

The drainage system in Bayside has five key components that are necessary to understand when thinking about improvements to the existing conditions and future planning, they include:

- **Primary Drainage Discharge Conduits** –There are seven primary conduits or pipes that provide drainage system relief to Bayside. These pipes outlet to the ocean via Back Cove (**see Figure 2-1**). The largest three pipes accommodate sewage overflows during intense rain events, as most of the Bayside area is serviced by combined sewer systems. The remaining four pipes are separated stormwater drains that are intended to only carry stormwater runoff. Overall, the combined sewer and separated stormwater infrastructure in the Bayside area is made up of over 19 miles of pipe and over 900 structures. **Figure 2-1** is only a simplified rendering of the seven primary drainage system outlet locations in the Bayside area.

- **Tidal Intrusion** – Incoming tides can send seawater back into coastal drainage systems. This complicates hydraulics and can create backups for stormwater and combined sewer systems. Each of the primary drainage conduits are subject to tidal intrusion. Tide gates are a type of infrastructure that restrict the flow of tides back into a drainage system, but tide gates alone cannot protect upstream areas from precipitation-based flooding.

- **Combined Sewer System and Special Structures** – For the three combined sewer systems, there are

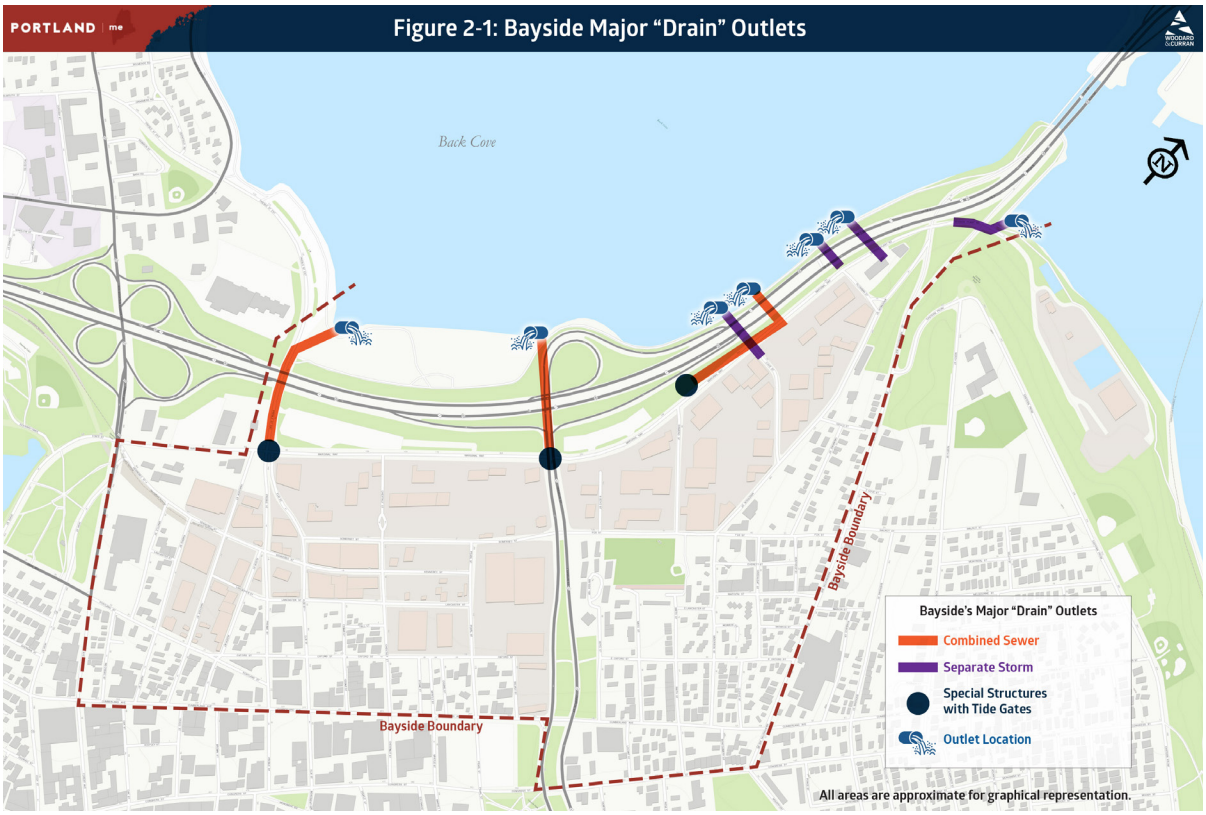


Figure 2-1: Bayside Major "Drain" Outlets

"Special Structures" that, if functioning properly, provide control of sewage overflows. These Special Structures, unlike other structures such as a typical manhole, contain various flow control devices such as weirs, orifices, tide gates, etc. Therefore, these Special Structures play a significant role in the overall system function. Structures that are referred to in this Report as "Special Structures with Tide Gates" have tide control features that are intended to protect upstream combined sewer systems from tidal intrusion. Each of the three combined sewer pipe systems have a critically important but aging "Special Structure with Tide Gate".

- **Separated Stormwater Drainage Systems** – The four fully separated stormwater drains are not currently protected from tidal intrusion, allowing inflow of ocean water during high tide. The City does not have full access or full responsibility over some of the separated stormwater drains. These drains are under Interstate-295 and are at least partially owned and operated by Maine DOT. Several additional stormwater drainage networks tie into the combined sewer conduits below the tide gates making them subject to tidal intrusion.

- **Known Flooding Areas in Bayside** – Illustrated in **Figure 2-2** are approximate areas in Bayside that flooded in 2016, based on the Flood Response Map provided by the City. These areas generally correspond to low-lying areas unprotected from tidal intrusion via separate stormwater drainage systems.

2.3 Computer-Based Modeling and the CSO Abatement Program

The stormwater drainage system in Bayside is complex which makes resolving flood and drainage issues challenging. To help manage the complexity and dynamic elements of the system, a computer-based tool is often used to model the entire system. Such software helps predict flooding and plan mitigation projects. The City is utilizing a computer-based model for assistance with decision-making on abatement of combined sewer overflows, as discussed in the **Section 3**.

The existing computer-based model uses the EPA Storm Water Management Model software, and is therefore referred to as the "SWMM model." The model was built, and has been maintained by the Portland Water District, to support the City's multi-million dollar Combined Sewer Overflow (CSO) abatement program. The existing model excludes the separated stormwater

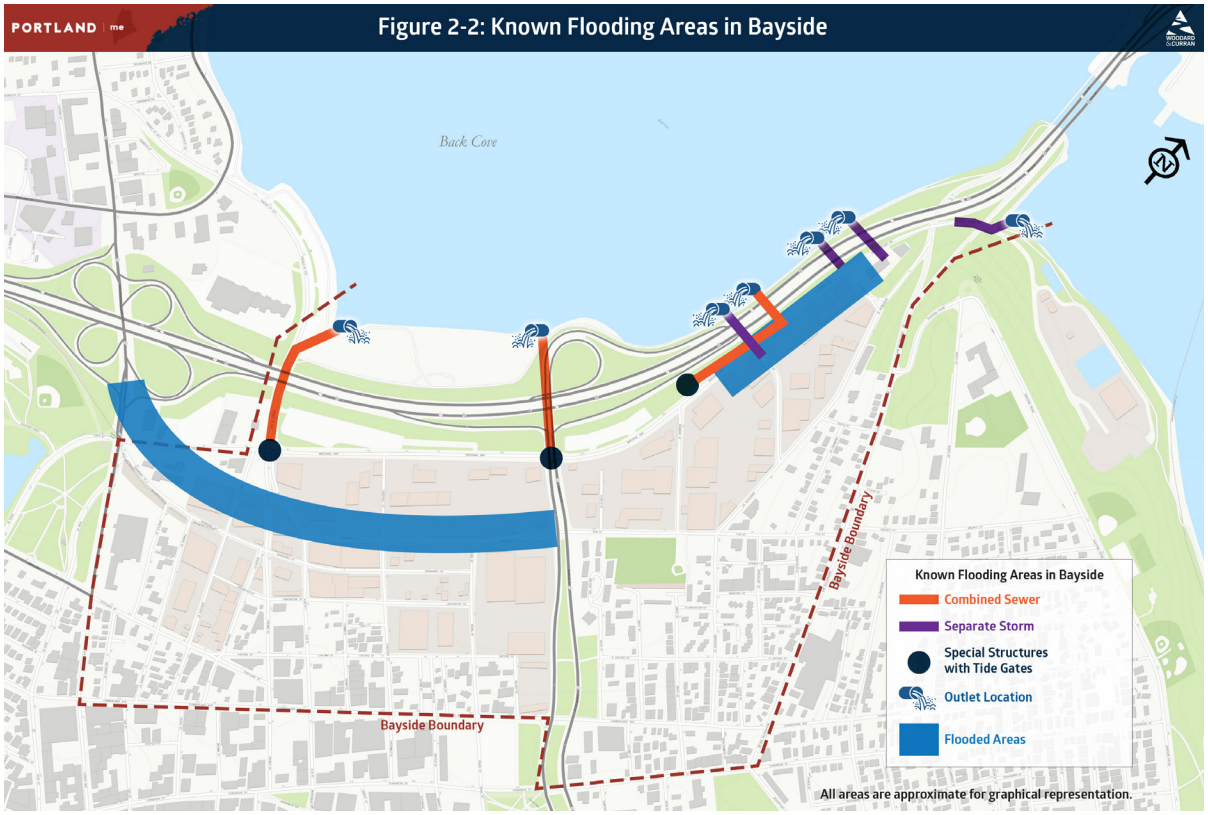


Figure 2-2: Known Flooding Areas in Bayside

drainage system because its primary intent is to address combined sewer overflows; it was not built with the intent of modeling local flooding. CSOs and flooding are linked because CSOs are caused by rainfall, and rainfall can cause or contribute to flooding.

2.4 Challenges Specific to the Bayside Area

Several challenges somewhat unique to Bayside should be considered during review of this report. These challenges are offered for context as several of these elements will complicate additional data collection and resiliency planning.

- The drainage system in the Bayside area was constructed over various periods of time that often coincide with the periods of fill, development, and urbanization in the area. The infrastructure is interconnected and not always well documented. Some areas may simply not be accessible for information gathering.
- Most of the drainage system is old with structural deficiencies, blockages and other impediments to hydraulics that are a function of condition defects which are challenging to assess and are changing in time.
- Portions of the drainage system, and particularly, the combined sewer system have and will continue to be modified due to increased development and efforts by the City to reduce Combined Sewer Overflows.
- I-295's location and ownership require coordination with a separate government entity MaineDOT with differing objectives for drainage system operations.

Section 3

Sewer & Stormwater System Data Gaps

3. SEWER & STORMWATER INFRASTRUCTURE DATA GAP ANALYSIS

Woodard & Curran worked with Jordan Environmental Engineering to conduct the following sewer and stormwater data gap analysis. Drainage infrastructure data and the existing SWMM model were reviewed to identify data "gaps" that may hinder adaptation planning in Bayside.

3.1 Summary of Infrastructure Data Gap Analysis Methodology

A variety of existing infrastructure and SWMM model data was provided to the project team by City staff and reviewed as part of this project. The review of City-provided data is discussed in **Section 3.2**. Upon completion of the initial review of the City's data, the project team interviewed several key City Department of Public Works staff. The information obtained from the interview is discussed in **Section 3.3**. Woodard & Curran was also able to use the experience of our staff who have a long-standing relationship with the City and who have background knowledge of the City's drainage and sewer infrastructure, particularly in Bayside. This knowledge was used extensively during this project.

3.2 City-Provided Data

Table 3-1 below summarizes the information provided by the City for our review in this data gap analysis.

Table 3-1: Summary of City Provided Data to Support Gap Analysis

Dataset (Received from City)	Format	Date Received	Description (Refer to Section 3.2 for more detail)
Stormwater and Sewer Infrastructure Data	GIS Geodatabase, Map Package	March 13, 2017	· Geographic and attribute information on sanitary sewer, combined sewer, and separate storm drain infrastructure. See Appendix A for representation of GIS data. · Sewer and stormwater pipes recently inspected for structural and operational condition.
I&I Maps (Infiltration-Inflow Analysis maps	PDF	2004	· 1970s & 1980s Infiltration-Inflow Analysis maps of Portland Sewer System. Refer to Appendix B for Bayside area I&I maps. · Approximate geographic locations and connectivity of pipes and structures. Including invert elevations. · Vertical datum: Anecdotally confirmed by City staff to be NGVD29. · Schematics of Special Structures in the drainage system. See Appendix B.
Surface Elevation Data (From 2015 LiDAR aerial survey)	Multiple: - GIS LiDAR (LAS) - GIS raster Digital Elevation Model (DEM)	March 28, 2017	· Detailed surface elevations for the entire Bayside area. · Vertical datum: NGVD29
SWMM Model	ASCII	March 17, 2017	· Hydraulic and hydrologic computer model of the sewer and combined sewer system servicing Bayside.

In addition to the information provided for this project listed in **Table 3-1**, the project team also obtained and reviewed the following documents for additional infrastructure information relevant to the gap analysis.

- City's 2016 Flood Response Map.
- Listing of flood event reports that occurred from 2013 to 2016.
- A report titled, "Separation and Green Projects for the Back Cove South Storage Conduit", dated November 2014, and prepared by Wright-Pierce. The report documents the results of a recent study that identified possible separation and/or green projects that would benefit the performance of the Back Cove South storage conduit.

The following provides additional detail on the City-provided data noted in **Table 3-1**:

GIS Database - The City has a well-developed GIS (Geographic Information Systems) database of sanitary sewer, combined sewer, and separate storm drain infrastructure. The geographic features of the database are depicted in **Figure A-1** in Appendix A. The City's GIS data appears reasonably up-to-date and it shows the locations of pipes, inlets and other drainage and combined sewer infrastructure which can all be referred to as "drainage system assets."

The information contained within the database and associated with these "drainage system assets", called "attribute data", are not completely populated in the GIS. Attribute information contains items like pipe size, material, slope, elevation, etc. Attribute data may be available in other data sources, but have not yet been integrated into the GIS. A null analysis of the City GIS was conducted which quantified how much of key attribute data fields are currently unpopulated. The results of the null analysis is provided in Appendix A. Updated and accurate attribute data is important for asset management and for hydraulic modeling of the system – both of which play a key role in flood mitigation planning.

The City also provided a GIS file that shows all the Bayside area sewer and stormwater pipes that have been inspected for structural and operation deficiencies since 2011. The data provided from the City only shows which pipes have been inspected, it does not provide the inspection results or condition assessment reports. It has been assumed that these reports are available for the segments of pipes that have been inspected.

The GIS database shows that the Bayside area, as delineated by the City and shown in Appendix A, has approximately 7.6 miles of stormwater pipe, 11.6 miles of combined sewer pipe, 1.1 miles of sewer pipe, 610 stormwater manholes and catch basins, and 365 sewer manholes. An additional 12 structures exist in the GIS under the label of "Sanitary Sewer Network Structures" (SSNS), but are referred to in this report as "Special Structures".

I&I Maps (Infiltration-Inflow Analysis Maps) - The City's I&I maps were developed in the 1970s and 1980s and depict the entire City of Portland sanitary sewer system, including combined sewer systems, but with limited information about separate storm drainage. I&I maps continue to provide generally helpful information because they show the approximate geographic connectivity of pipes and structures. In addition, I&I maps provide rim and invert elevation data, as well as schematics of important structures in the sewer system. The City's DPW staff have confirmed that the elevation data noted on the I&I maps are comparable to other survey data referenced to NGVD29; and therefore has considered these maps as referenced to NGVD29. Although the existing I&I maps are, in some cases, outdated, they are an especially important source of information wherever newer information is not available. It is our understanding that much of the City's GIS database and SWMM Model were constructed based on the I&I map data as their starting point, but have been largely updated as newer information was obtained. The four I&I Maps that cover the Bayside area are provided in Appendix B.

In addition to the typical components that make up a combined sewer system, the drainage system in the Bayside neighborhood also contains "Special Structures." As previously noted, the Special Structures, unlike other structures such as a typical manhole, contain various flow control devices such as weirs, orifices, tide gates, etc. and these structures play a significant role in the overall hydraulics of the stormwater drainage system. A summary document compiling both the I&I and GIS data available for each of Bayside's "Special Structures" was created and is provided in Appendix B. Note that the City's GIS refers to Special Structures as "Sanitary Sewer Network Structures" (SSNS).

Surface Elevation Data - Surface elevation data is another key piece of information used for flood planning. The City has detailed surface elevations for the entire Bayside area that was obtained from a 2015 aerial overflight LiDAR survey. The vertical datum of the data is NGVD29. Drainage infrastructure "rim" (street surface) elevations can be obtained from this surface elevation data due to its high resolution and accuracy. Also, the elevations of buildings and other major above ground structures can be extracted from these surface elevation data files, which will be needed for future flood modeling exercises.

Existing Bayside Hydraulic & Hydrologic Model - As previously noted, an extensive hydraulic and hydrologic model exists for the sewer and combined sewer system serving the Bayside neighborhood. The model is owned and managed by the Portland Water District, and was built in support of the City's CSO abatement program. The model was first developed in the early 1990's and has undergone numerous updates, as needed, for various CSO abatement projects.

The model is based on the EPA Storm Water Management Model software, version 5.x (SWMM5). The Bayside area portion of the City's SWMM model is called the Northeast Pump Station (NEPS) model. The existing model of the Bayside area includes selected sanitary sewer and combined sewer pipes (conduits) that are hydraulically connected to the Northeast Pump Station, which is one of the two pump stations that delivers flow to the East End wastewater treatment plant.

Separate stormwater drainage system pipes are excluded from the SWMM model because the primary intent of the model is combined sewer abatement, not flood management. The City is currently investigating and designing CSO abatement options for the Bayside area which has resulted in a recently updated version of the model for the Bayside area. However, the model not been completely calibrated and verified, particularly for flooding events. The target calibration and validation of the model is focused on the 1-inch 24-hour rainfall event and is not focused on higher precipitation depth or precipitation intensity events.

The current model does not have a geographic interface, but a schematic representation of the pipes and structures that are currently included in the Bayside model was developed by Woodard & Curran for this purposes of this report. The "Existing SWMM Model Schematic" figure is provided in Appendix C.

3.3 Stakeholder Interviews

An interview with City staff was conducted in April 2017, and is summarized in **Table 3-2**. The interview was conducted to better understand recently surveyed areas that are not represented in GIS, planned construction projects, maintenance activities on Special Structures, SWMM model updates and general confirmation of the functionality and connectivity of the drainage infrastructure in Bayside.

Table 3-2: Summary of April 2017 Interview with City Staff

Date	Staff Interviewed	Meeting Minutes
April 21, 2017	City (3): - Brad Roland - Justin Pellerin - Doug Roncarati	• Recent infrastructure surveys have been completed as part of City's roadway reconstruction and CSO abatement efforts. The City staff provided approximate locations of recently surveyed areas in Bayside. (See Appendix D) • Condition information is available for most of the sanitary and combined sewer. • City expressed that the following has been a source of concern: o Lack of information on DOT-owned stormwater infrastructure, including condition. o Servicing and maintenance needs for tide gates vary from year to year. City labor resources are often limited. More maintenance may be needed for tide gates and Special Structures. o Uncertainty on the functionality of existing tide gates. Structures may require updates to incorporate newer technologies/updates. o The SWMM model is managed by the Portland Water District, not the City. o The SWMM model as constructed is not a fully useful tool for flood planning. The SWMM model does not incorporate separate stormwater drainage systems and modeling, calibration and validation is done with the main goal of CSO abatement, not flood mitigation.

The following provides additional detail on the information noted in **Table 3-1**:

Recently Surveyed Areas in Bayside – Recent, ground-based surveys of much of the drain, sewer and combined sewer infrastructure exists for the Bayside area due to the City's aggressive roadway reconstruction and CSO abatement efforts. City staff also identified that several City projects are anticipated to move forward with design and construction in the near future and these projects will also be preceded by extensive surveying. The areas with recent or upcoming survey information are shown in the figure in Appendix D.

Condition Assessment Data – The City conducts regular inspections of their combined and sanitary sewer infrastructure following the recommendations of their Sewer Capacity, Management, Operation, and Maintenance (CMOM) Plans. Additionally, the City is in the middle of an ongoing sewer infiltration and inflow reduction study, which includes a multi-year flow and pipe condition data collection effort. Based on discussions with City staff during our interview process, it is likely that much of the Bayside sanitary sewer and combined sewer have undergone recent condition inspections as part of these aforementioned efforts. Condition inspection data includes video of pipe and manhole assets and generally include infrastructure attribute information in addition to identifying structural defects and operational defects (clogging, root intrusion, etc).

Very limited condition assessment data is available for separated storm pipes. Given tidal intrusion in the separate storm drain, the inspection data may be poor due to partial tidal inundation of the pipes at the time of inspection.

Maintenance, Ownership and Functionality of Infrastructure – The Bayside area includes infrastructure owned by the Maine Department of Transportation (DOT). The maintenance and condition status of DOT infrastructure is often unknown to the City. The City does not have free access or responsibility over DOT infrastructure. Staff indicated the necessity to increase collaboration with DOT, as it will be needed for flood planning in Bayside.

The City also expressed the need for increased frequency of tide gate maintenance. City labor resources are often not sufficient to meet the regular maintenance requirements of tide gates, as these structures need to be periodically inspected and/or cleaned after significant tidal cycles or precipitation events. Maintenance of these structures is complicated by their location in busy intersections, such as the intersection of Preble Street and Marginal Way and the intersection of Fanklin and Marginal Way.

There is also uncertainty regarding the current and future functionality of the aging tide gates. City staff have expressed interest in upgrading or replacing the tide gates with newer technologies to reduce maintenance and increase reliability.

3.4 Identified Data Gaps

Upon a review of City-provided data and the information collected from interviews with City staff, Woodard & Curran has identified data gaps that should be filled for the City to improve flood and adaptation planning. The gaps are categorized as "infrastructure-related" and "modeling-related," however, they are all closely linked. Infrastructure-related gaps may be resolved by review of existing survey and inspection reports, additional infrastructure surveys, condition assessments, and collaboration with DOT. Modeling-related gaps can be resolved by closing infrastructure data gaps, migrating data to a single repository, such as City GIS, and updating the model to accommodate additional planning objectives, which will require commitments to dedicated staff and/or consultants, software advancements, and calibration.

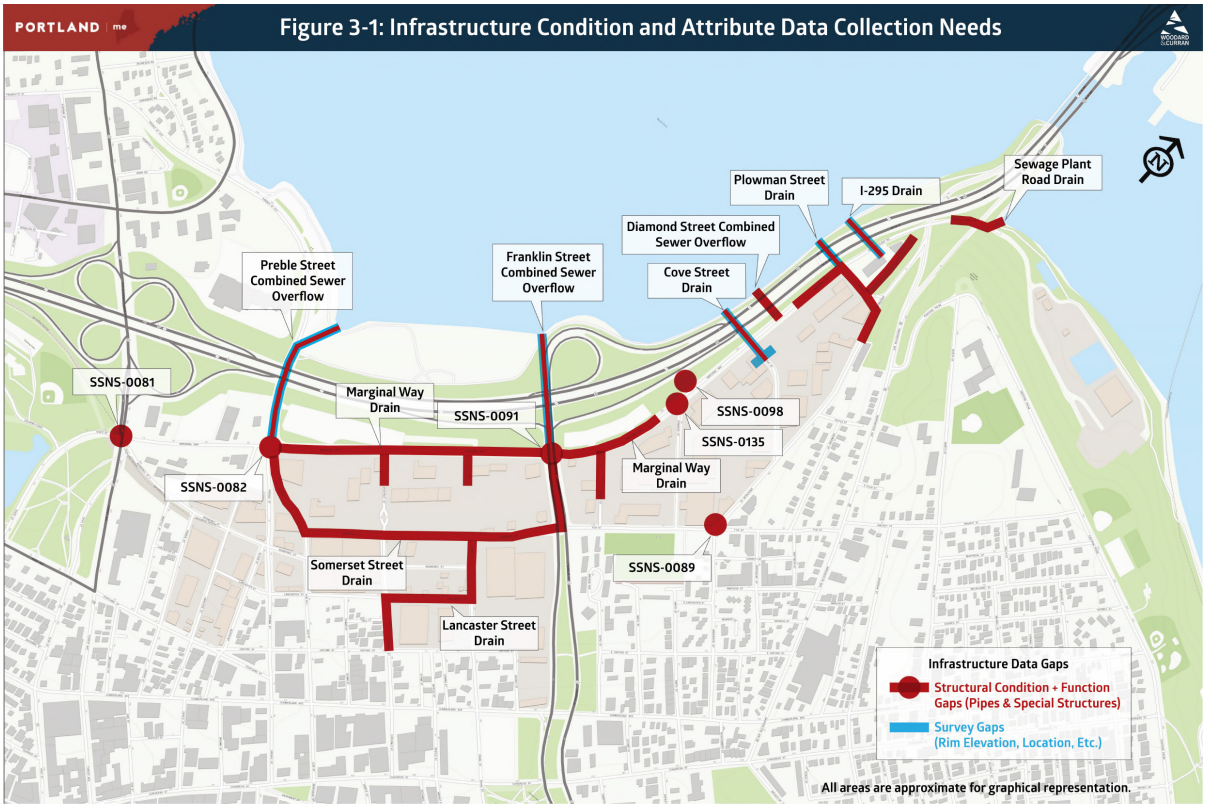
3.4.1 Infrastructure-Related Gaps

Table 3-3 provides a summary listing of the important flood-planning data and resources that the City has available, as well as the infrastructure data and maintenance gaps that have been identified. No data gaps were identified pertaining to surface elevations. Detailed surface elevations for the entire area of Bayside were obtained via recent aerial overflights (2015 LiDAR Survey) and the data is high quality. **Figure 3-1** provides graphical representation of infrastructure-related data gaps.

Table 3-3: Summary of Infrastructure Data Gaps

Existing Data	Data Gaps	Refer to:
City's GIS Database Gaps		
· Reasonably up to date Geographic Information System (GIS) data shows the locations of pipes, inlets and other drainage and combined sewer infrastructure. · The associated information (size-shape-depth,etc) with these drainage system assets, although not completely populated in the GIS, largely exists in surveys or other locations. · The City currently utilizes ESRI's Local Government Information Model (LGIM) for attribute data schema.	· Recent survey data has not been integrated into the GIS. · Important attribute data, although largely available, is not completely populated in the GIS. · The database organization under LGIM must be able to accommodate future data collection for Bayside adaptation planning.	Figure: Available Sewer and Stormwater Infrastructure GIS Data, Appendix A Table: Null Analysis of GIS Attribute Data, Appendix A
City Infrastructure Data Gaps: Surveys		
· Extensive ground-based survey data for most of the key drain, sewer and combined sewer infrastructure exist in the area due to the City's CSO abatement and roadway reconstruction efforts.	· Recent survey data does not exist for some critical drainage infrastructure and may require additional field survey. Approximately 3,000 linear feet of this infrastructure have been identified for survey.	Figure: Areas Recently Surveyed, Appendix D Figure: Infrastructure Condition and Attribute Data Collection Needs, Figure 3-1
City Infrastructure Data Gaps: Condition Assessments		
· Condition assessment data (since 2011) is available for approximately half of the sewer and combined sewer system.	· Limited condition information is available for separate stormwater drainage. Approximately 35,000 linear feet of separate stormwater drainage is within the study area and condition information may be unknown.	Figure: Infrastructure Condition and Attribute Data Collection Needs, Figure 3-1

Existing Data	Data Gaps	Refer to:
City Infrastructure Data Gaps: Condition, Form & Function of Special Structures		
· Schematics for Special Structures are available in I&I maps, and potentially available from recent CSO storage conduit planning and design efforts (not received or verified by Woodard & Curran)	· I&I maps and schematics were developed in the 1970s and 1980s and may not be accurate given recent reconstruction. · Special Structures in Bayside have not been recently assessed for condition and functionality.	Figure: I&I Maps covering Bayside, Appendix B Figures/Tables: Summary of Special Structures, Appendix B Figure: Infrastructure Condition and Attribute Data Collection Needs, Figure 3-1
Maine DOT Infrastructure Gaps		
· DOT owned or operated drainage infrastructure locations are mapped in GIS.	· Attribute data, condition and location of drainage infrastructure needs to be verified with input from DOT. · Collaboration and partnership between the City and DOT regarding maintenance and rehabilitation of drains that pass under I-295.	Figure: Infrastructure Condition and Attribute Data Collection Needs, Figure 3-1



3.4.2 SWMM Model-Related Gaps

The key SWMM model gaps identified in this study are summarized in **Table 3-4** below. **Figure 3-2** provides graphical representation of model-related data gaps. An overview of the model fundamentals and limitations is discussed below:

Overview on How the Existing Model Works

As previously mentioned in **Section 3.2**, the portion of the existing SWMM model that covers the Bayside area includes selected sanitary sewers, combined sewers and storm drains that are hydraulically connected to the Northeast Pump Station. The SWMM model can be thought of as a network of pipes and nodes. Some nodes represent simple pipe junctions, while other nodes represent Special Structures or other sewer point features. The data files required to run the model consist of a combination of hydraulic parameters and hydrologic data, including information on infrastructure, precipitation, groundwater, tides, and other factors.

The existing SWMM model utilizes long-term and actual precipitation, tide, and groundwater input data to run simulations. It is not an event-based model. To ensure that the results are reliable, the model needs to be calibrated and validated with actual pipe flow during simulated events to match results with simulated flows. Although the software currently being used does not have a geographic interface, a schematic representation of the pipes and structures that are incorporated in the existing model was developed by Woodard & Curran for this purposes of this Study. The "Existing SWMM Model Schematic" figure is provided in Appendix D. Upon running the model, the EPA SWMM5 software can identify which structures (at modeled nodes) will overflow onto the street surface.

Model Gaps:

Model Components – The primary intent of the existing model is combined sewer abatement and the model has never been modified with the specific intent of modeling local flooding. The model does not currently contain much of the separate stormwater drainage system that may be influencing local flooding.

Within the Bayside area that is likely to be subject to flooding, the sanitary and combined sewers required to model flood scenarios are for the most part already included in the model. The one sanitary and combined

sewer area that does not have enough detail within the SWMM model is the intersection of Forest Ave, Kennebec Street, and Brattle Street, which has been highlighted in **Figure 3-2**.

Data Sources – The portion of the model that describes the combined sewer pipe network and the Special Structures was originally constructed using information from the I&I maps, developed in the 1970s and 1980s. The source of most of the infrastructure data (manhole inverts, pipe lengths, etc.) within the existing Bayside model is not documented on a point-by-point basis. Historically, there was a very limited effort to identify source information or changes to the model and embed it into the model. Most source and change data has been lost during various model updates.

Data Accuracy – Data was intentionally input into the model incorrectly because, at the time, the software was less advanced and required limited manual manipulation for calibration. For example, the manhole and special structure rim elevations along Somerset Street and Lancaster Street are set several feet above the actual street elevation. These elevations made sense for the original model, in that prior to SWMM5, the SWMM model math engine had some numerical instabilities associated with surcharging manholes. To get accurate CSO volume estimates at the overflow weirs (the original objective of the model), the rim elevations for the nodes likely to surcharge were set artificially high to prevent them from surcharging. The numerical methods used in the current version of the SWMM5 math engine are superior to those used in the original model, therefore, the concerns related numerical instabilities and surcharging no longer exist.

Model Calibration and Validation – To accurately calculate which nodes will surcharge (i.e., which manholes will overflow and result in local flooding), the model needs to be calibrated, and the calibration needs to be verified. Calibration/validation requires depth and velocity data from key locations within the pipe network. For example, Wright-Pierce and the City of Portland used a network of 27 monitors at 23 locations to collect data to calibrate and verify the SWMM model for flows within the Bayside area. These monitors collected data from October 2013 to January 2015. Wright-Pierce used this data to calibrate the hydrologic parameters for the catchments within the Bayside area. The focus of the calibration were flow rates generated by a 1-inch 24-hour rainstorm for both the metered locations and at the Preble Street and Franklin Street combined sewer overflow weirs.

Model Capabilities – The model, when run in the SWMM5 environment, is only capable of predicting which nodes (drainage structures) surcharge. It is not capable of predicting the extent of flooding (depth and coverage area). From a practical standpoint, a surcharged node is a manhole or special structure that is causing some degree of local flooding. From a modeling standpoint, a surcharged node is identified when the local hydraulic grade-line has an elevation that is greater than the manhole's or special structure's rim elevation. In the Bayside area, a node's hydraulic grade-line elevation is a function of the CSO piping network, the tide elevation in Back Cove, and during rain events, a combination of total rainfall, rainfall intensity, and the operational status of the Franklin Street and Northeast pump stations. The hydraulic grade-line is the elevation that the water would rise to if it was contained within a very tall manhole. The depth and extent of flooding can be determined from the local hydraulic grade-line and a surface elevation model.

Table 3-4: Summary of SWMM Model Gaps

Description of Existing Data	Description of Gap
Model Components	
· Within the Bayside area that is likely to be subject to flooding, the sanitary and combined sewer pipe systems that would be required to model the flooding are for the most part already included in the SWMM model.	· The model lacks many separate pipe systems in Bayside that are likely to contribute to local flooding. · Figure 3-2 provides an illustration of general areas that contain separate stormwater system infrastructure. It is estimated that up to 10,000 linear feet of separate stormwater drainage pipe and nodes would need to be included in an updated model; much of which has recently surveyed.
Data Sources	
· Data sources for Special Structures and model junction nodes are outdated and uncertain.	· Special Structures condition, form and function identified in Figure 3-1 are likely outdated given data sources from 1961.
Data Accuracy	
· The accuracy of most data in the model is assumed to be good given numerous updates and calibrated flows for small precipitation events.	· Selected rim elevation infrastructure data was historically input incorrectly to account for calibration needs.
Model Calibration and Validation	
· The model has been calibrated and validated for combined sewer overflow abatement design criteria. The design storm of interest in the 1" 24-hour event.	· Calibration and validation for a range of storm events and flow conditions that are focused on flood, tide and storm surge condition design criteria.
Model Capabilities	
· SWMM5 environment is a common and extensively utilized hydraulic evaluation and simulation model.	· SWMM5 does not account for surface flooding evaluation but can be updated and integrated with other modules that can account for surface flooding.

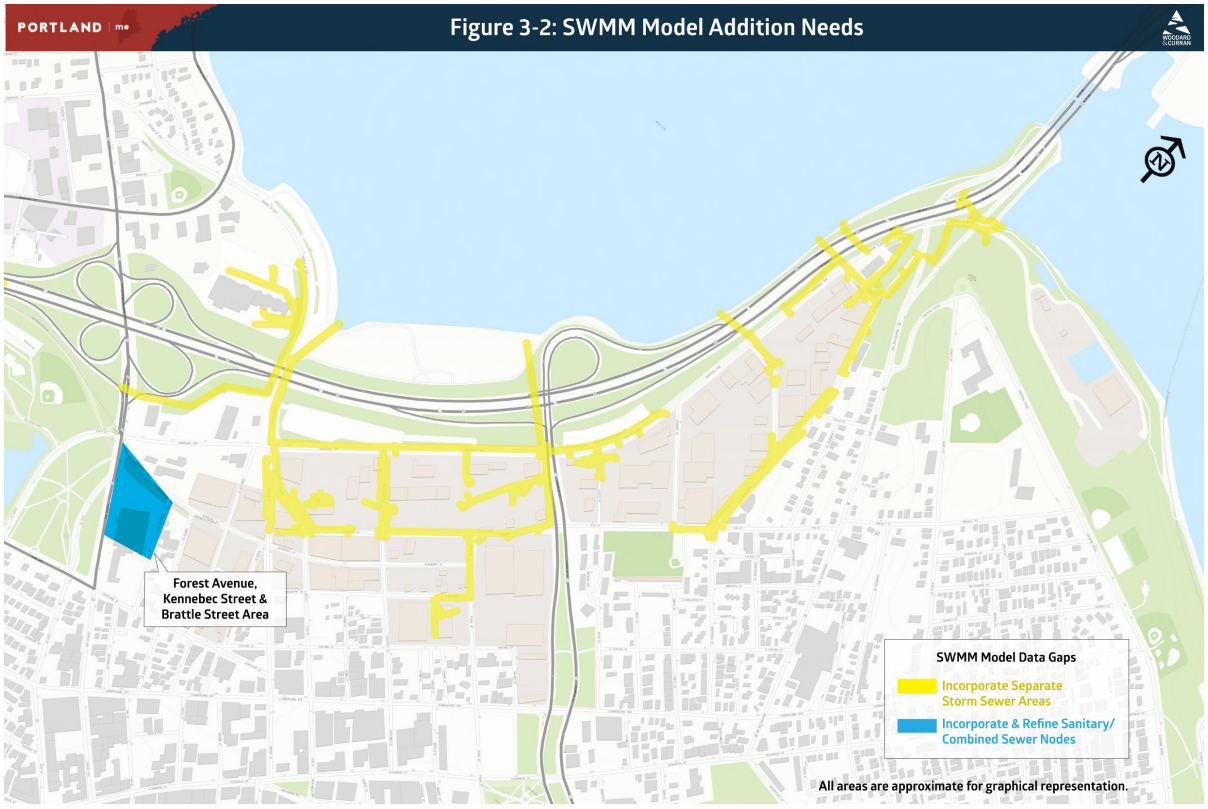

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Figure 3-2: SWMM Model Addition Needs
Forest Avenue, Kennebec Street & Brattle Street Area
SWMM Model Data Gaps
Incorporate Separate Storm Sewer Areas
Incorporate & Refine Sanitary/ Combined Sewer Nodes
All areas are approximate for graphical representation.

Section 4

Sea Level Rise & Climate Change Evaluation

4. SEA LEVEL RISE AND CLIMATE CHANGE EVALUATION

In the following sections describing sea level rise, storm surge, and precipitation, a scenario-based approach is taken when defining ranges of potential changes. Planning for a series of potential scenarios is important for managing uncertainty and ensuring continuity of critical systems. Such an approach is valuable when planning at the municipal level where mid-range projections are important for nearer-term planning needs. This approach is also prudent because it considers a broader range of outcomes that address the widening uncertainty in predictions, including those scenarios that are low-probability but high-consequence and may be important for planning of long-life critical infrastructure upgrades or construction. Use of a scenario based approach is consistent with both national and international best practices and with the recent Urban Land Institute study on strategies for creating resilient waterfronts in Portland and South Portland (ULI, 2014), which recognizes that recommendations must account for both uncertainty in future projections and risk tolerance.

4.1 Sea Level Rise

A recent review of sea level rise (SLR) literature conducted by NOAA (Sweet et al, 2017) provides a full range of global and regional SLR scenarios based on both current scientific literature and various future greenhouse gas (GHG) emissions scenarios. These GHG scenarios are known as Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011) and were used in the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC, 2013) to represent possible future GHG concentrations. Sweet et al. (2017) use three RCPs :

1. **RCP 2.6**: strong GHG mitigation resulting in net-negative emissions at the end of the 21st century; likely increases in global mean temperature of 1.9 to 2.3 degrees Celsius in the period from 2081 to 2100 relative to the period from 1850 to 1900 (IPCC, 2013)

2. **RCP 4.5**: moderate GHG mitigation resulting in a stabilization of emissions by 2050, a subsequent decline in emissions, and likely increases in global mean temperature of 2.0 to 3.6 degrees Celsius in the period from 2081 to 2100 relative to the period from 1850 to 1900 (IPCC, 2013)

3. **RCP 8.5**: often referred to as a 'business as usual' scenario with continued intensive use of fossil fuels and likely increases in global mean temperature of 3.2 to 5.4 degrees Celsius in the period from 2081 to 2100 relative to the period from 1850 to 1900 (IPCC, 2013)

Based on recent literature, NOAA concluded that global projections of SLR in the range of 2.0 to 2.7 meters by 2100 are not only physically plausible, but becoming more likely given new research on Antarctic ice-sheet instabilities. As such, NOAA has revised its extreme upper-bound SLR scenario for 2100 to 2.5 m, which is an increase of 0.5 m from the previous extreme scenario used in the third National Climate Assessment (Mellilo et al., 2014). The lower-bound scenario was also increased from 0.1 m to 0.3 m based on analysis of recent water level observations and review of new climate model results (Sweet et al., 2017). Several intermediate scenarios were defined between the upper and lower bounds, for a total of six global mean sea level (GMSL) rise scenarios:

1. Low: 0.3 m

2. Intermediate Low: 0.5 m

3. Intermediate: 1 m

4. Intermediate High: 1.5 m

5. High: 2.0 m

6. Extreme: 2.5 m

While the range of GMSL scenarios provides a starting point for defining sea level rise scenarios for the City of Portland, it must be adjusted for regional factors and then reviewed relative to the City's planning horizons and risk tolerance. Regional factors are discussed in **Section 4.1.1** below. It is also important to note that these scenarios are relative to the year 2000 (a non-standard 1991-2009 epoch) instead of 1992 (the National Tidal Datum Epoch of 1983-2001). Since most of the U.S., including Portland, uses the National Tidal Datum Epoch an adjustment is necessary. Details of this adjustment are also provided in **Section 4.1.1**.

In consideration of risk tolerance and following the guidance provided by Sweet et al. (2017), the SLR scenarios presented for Portland strive to account for both "what is most likely to occur" as well as a "how bad can things get". Thinking in these terms will allow the City to prepare for the most probable outcome, while also ensuring that there is a general awareness of lower-probability, but higher consequence events. Sweet

et al. (2017) provide guidance for choosing scenarios by associating probabilities of exceedance for each GMSL scenario. For example, there is a 94% to 100% chance that by 2100 GMSL will have increased more than 0.3 m (the low scenario) but only a 0.05% to 0.1% chance that it will have increased more than 2.5 m (the extreme scenario). It is important to note that recent research on the Antarctic ice sheet could significantly increase the probabilities of higher-end scenarios and attention should be paid to the literature on this subject. A summary of the GMSL scenarios and probability of exceedance for each is shown in **Table 4-1**. Each scenario is assigned a range of probabilities, based on the three emissions scenarios used in the study.

Table 4-1: Global Mean Sea Level Rise Scenarios for 2100 with corresponding exceedance probabilities (Sweet et al., 2017)

Scenario	GMSL (m)	Probability of Exceedance
Low	0.3	94-100%
Intermediate Low	0.5	49-96%
Intermediate	1	2-17%
Intermediate High	1.5	0.4 to 1.3%
High	2	0.1 to 0.3%
Extreme	2.5	0.05 to 0.1%

4.1.1 Regional Sea Level Rise Estimates for the City of Portland

Regional factors that influence GMSL projections include:

- Shifts in regional oceanographic processes (e.g., circulation patterns)
- Changes to the Earth's gravitation field and rotation
- Vertical land movement (subsidence or uplift)

When adjusted for regional factors, Sweet et al. (2017) found that the relative sea level (RSL) rise along the Northeast Atlantic coast is expected to exceed global projections significantly. This is illustrated by recent observations of sea level trends. Over the last several decades the rate of regional sea level rise in the Northeast has outpaced the global rate and Portland has seen the largest change in sea levels in the eastern U.S. (Goddard et al. 2015); this regional acceleration in sea level rise is likely attributable to changes in the Gulf Stream (Yin and Goddard, 2013; Ezer, 2013; Kopp, 2013; Kopp et al., 2015). These changes include both an offshore shift and weakening north of Cape Hatteras (Ezer et al., 2014).

In addition to changing oceanographic processes, the impacts of Antarctic and Greenland Ice Sheet and glacial and ice cap melting are amplified along most U.S. coastline due to static-equilibrium processes. Finally, non-climatic contributions such as the regional influence of vertical land movement (VLM) also play an important role. In the Northeast, subsidence is occurring at a rate of 2 to 5 mm/yr (Sweet et al. 2017).

To facilitate use of the GMSL rise scenarios regionally, NOAA (Sweet et al., 2017) has derived regional relative sea level (RSL) rise projections from the GMSL scenarios on a 1-degree grid covering U.S. coastlines as well as

for tide gauges around the country, including Portland, Maine (Station 8418150). RSL rise scenarios for 2050 and 2100 in Portland are summarized in **Table 4-2**. As expected due to regional factors, the Portland-specific RSL values are higher on average than the global sea level rise scenarios presented in **Table 4-1** from Sweet et al., 2017. **Table 4-2** also shows the projected mean sea level for 2050 and 2100 relative to NGVD29 (the City's preferred vertical datum).

The following steps were necessary to perform this conversion to NGVD29:

1. Convert the RSL values from a reference year of 2000 (1991 to 2009 epoch) to a reference year of 1992 (National Tidal Datum Epoch) by calculating the difference between average MSL for 1983-2001 and 1991-2009 at the Portland Tide Station (8418150) and adding it to the RSL value relative to 2000. This difference in Portland is 0.014 m (0.046 ft.).

2. Convert the RSL (1992) rise values to MSL relative to NAVD88 using the datum offsets available from the Portland Tide Station (8418150). At this location NAVD88 is 0.095 m (0.312 ft.) above MSL.

3. Convert the MSL (1992) values from NAVD88 to NGVD29 using the values available from the National Geodetic Survey for Portland Tide Station (8418150). At this location NAVD88 is 0.222 m (0.728 ft.) above NGVD29.

4. Thus, for Portland, to convert from RSL change (2000) as reported by Sweet et al. (2017) to MSL relative to NGVD29 one must add 0.014 m, subtract 0.095 m, and add 0.222 m to the RSL change (2000) values for a total offset of 0.14 m (0.46 ft.) between RSL (2000) and mean sea level relative to NGVD29 (1992).

Sea level rise curves (in ft.) for the 2000 to 2100 period are shown in **Figure 4-1**, represented as projected mean sea level relative to NGVD29. The curves clearly indicate that the projections are not linear and that differences in sea level scenarios become larger over time.

Based on the probabilities of exceedance defined for the GMSL rise scenarios, scenarios that have exceedance probabilities for 2100 significantly lower than 50% are used to narrow the range of possible scenarios. Thus, we define "What is most likely to occur" as the intermediate scenario (probability of exceedance 2-17%) and "How bad can things get" as the extreme scenario (probability of exceedance 0.05 to 0.1% - a low probability and high consequence event).

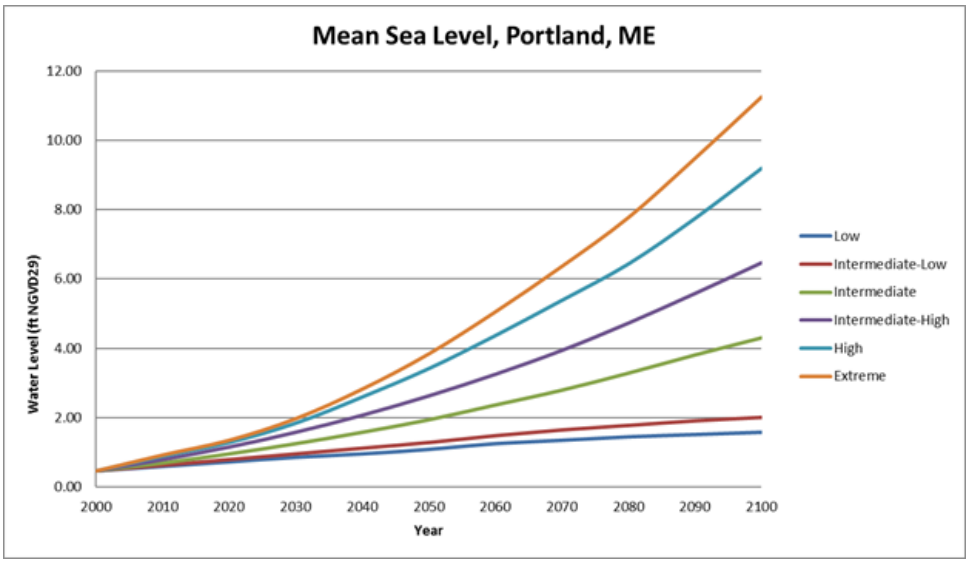
As such, we recommend that Portland commit to managing the intermediate mean sea level of 1.9 ft. (NGVD29), but be prepared to manage the extreme mean sea level of 3.8 ft. (NGVD29) in 2050. In the latter half of the century scenario planning is more complicated because the four sea level rise scenarios bounded by the intermediate to extreme envelope in 2050 deviate from each other significantly between 2050 and 2100; the range increases from 1.9 ft. in 2050 to 7.0 ft. in 2100 **(Figure 4-1, Table 4-2)**. Our recommendations for the 2100 planning horizon are that Portland commit to managing the intermediate mean sea level of 4.3 ft. (NGVD29) by 2100, be prepared to manage the

Table 4-2: Summary of Sea Level Rise Scenarios for 2050 and 2100, Portland, Maine

Scenario	2050: RSL, ft. / Mean Sea Level, ft. relative to NGVD29	2100: RSL, ft. / Mean Sea Level, ft. relative to NGVD29
Low	0.62 / 1.08	1.12 / 1.58
Intermediate Low	0.82 / 1.28	1.53 / 2.00
Intermediate	1.48 / 1.94 – commit to manage	3.84 / 4.30 – commit to manage
Intermediate High	2.16 / 2.63	6.00 / 6.46
High	2.95 / 3.41	8.72 / 9.19 – prepare for
Extreme	3.38 / 3.84 – prepare for	10.79 / 11.25 – be aware of

Note: The first value is the RSL rise in ft., as originally reported by Sweet et al (2017). The second value is the RSL converted to Mean Sea Level relative to NGVD29 following the methodology presented in Sweet et al., (2017).

Figure 4-1: Predicted MSL elevations from 2000 to 2100 for Portland, Maine



Note: The predicted elevations in Figure 4-1 are in feet and relative to NGVD29 for all RSL rise scenarios.

high mean sea level of 9.2 ft. (NGVD29), and be aware of and monitoring for any indication that mean sea levels could approach the extreme scenario of 11.3 ft. (NGVD29).

Figure 4-2 illustrates what daily high water levels may look like in 2050 and 2100 for the range of scenarios chosen. Daily high water levels are predicted using a base water level elevation of Mean Higher High Water (MHHW) for the RSL rise values reported for Portland by Sweet et al. (2017). MHHW is the average of the higher high water elevation of each tidal day observed over the National Tidal Datum Epoch (NOAA, 2017) and thus represents the high-water level reached daily. To generate the projected daily high water levels for 2050 and 2100, the process followed in Steps 1 through 4 above was repeated for MHHW to determine MHHW elevations for 2050 and 2100 relative to NGVD29. The total offset between RSL (2000) and MHHW (1992) relative to NGVD29 is 5.45 ft. **Table 4-3** shows the MHHW elevations relative to NGVD29 for the recommended 2050 and 2100 scenarios.

To create the maps, a GIS analysis was performed, using high resolution elevation data (2015 City of Portland, Maine LiDAR). This figure is a GIS-based 'bathtub' style analysis, which assumes a static base water level elevation (MHHW relative to NGVD29) from the Portland, ME tide station (8418150) for all of Portland, and should be used for illustrative purposes only as it does

Table 4-3: Summary of MHHW Elevations Under Various Sea Level Rise Scenarios for 2050 and 2100 in Portland, Maine

Scenario	2050: RSL (ft.) / MHHW, ft. relative to NGVD29	2100: RSL (ft.) / MHHW, ft. relative to NGVD29
Intermediate	1.48 / 6.93 – commit to manage	3.84 / 9.29 – commit to manage
Intermediate High	2.16 / 7.61	6.00 / 11.45
High	2.95 / 8.40	8.72 / 14.17 – prepare for
Extreme	3.38 / 8.83 – prepare for	10.79 / 16.24 – be aware of

Note: The first value is the RSL rise in ft., as originally reported by Sweet et al., (2017). The second value is the RSL converted to MHHW relative to NGVD29 following the methodology presented in Sweet et al., (2017).

Figure 4-2: Maps of Predicted Daily Inundation Extent in Portland, Maine in 2050 and 2100

Note: The maps in Figure 4-2 are using a base water level elevation of MHHW in 2050 (top) and 2100 (bottom) for recommended RSL rise scenarios. These figures represent an illustrative "bathtub" GIS analysis. A dynamic storm drain modeling exercise is necessary to provide an actual detailed depiction likely of inundation areas.

not include tidal flooding through the current stormwater conveyance system. The availability of detailed maps for each sea level rise scenario is discussed in **Section 5.2**.

The influence of RSL rise on storm surge is presented in **Section 4.2**. However, even in the absence of storm events, sea level rise can play an important role in the frequency of nuisance flooding. NOAA's National Weather Service (NWS) has defined a series of thresholds for minor, moderate, and major flooding at the Portland, ME Tide Station (8418150); these are 7.5, 8.5, and 9.5 ft. relative to NGVD29 respectively. The minor, moderate, and major flooding thresholds are used by the NWS when issuing coastal flood statements. Coastal flood advisories are issued when minor or nuisance coastal flooding is occurring or imminent. Minor flooding causes little to no risk of property damage, however there is some public threat or inconvenience. Coastal flood watches are issued when moderate to major coastal flooding is possible, potentially posing a serious risk to life and property. Coastal flood warnings are issued when moderate to major coastal flooding is occurring or imminent, posing a serious risk to life and property. Moderate flooding causes some inundation of structures and roads and potential evacuations of people and property to higher elevations. Major flooding causes extensive inundation of structures and roads

and may require significant evacuations of people and property to higher elevations.

Table 4-4 and **Table 4-5** show predicted water levels, relative to NGVD29, for today's minor, moderate, and major flood thresholds, as well as MHHW and the highest predicted annual tide for 2050 and 2100 for the various RSL scenarios in 2050 and 2100. **Table 4-4** shows that by 2050 the minor flood elevation will be exceeded daily under the intermediate-high scenario and the moderate flood level will be exceeded daily under the extreme scenario. Also by 2050, the predicted highest annual tide will exceed the moderate flood elevation for all scenarios and will exceed the major flood threshold for the high and extreme scenarios. **Table 4-5** shows that by 2100 the moderate flood threshold is exceeded daily by the intermediate scenario and the major flood threshold is exceeded daily by the intermediate-high through extreme scenarios.

Table 4-4: Water Levels in 2050 for Various Tidal Datums and NWS Flood Thresholds at the NOAA Portland Station (8418150)

	Scenario (RLS Rise in 2050: converted to 1983-2001 Epoch)			
	Intermediate (1.55 ft.)	Intermediate-High (2.23 ft.)	High (3.02 ft.)	Extreme (3.45 ft.)
Water Level National Tidal Epoch (ft. NGVD29)				
MHHW: 5.38	6.93	7.61	8.40	8.83
Highest Annual Tide (2050): 7.13	8.67	9.36	10.15	10.57

Table 4-5: Water levels in 2100 for various tidal datums and NWS flood thresholds at the NOAA Portland Station (8418150)

	Scenario (RSL Rise in 2100: 1991-2009 Epoch)			
	Intermediate (3.93 ft.)	Intermediate-High (6.07 ft.)	High (8.79 ft.)	Extreme (10.86 ft.)
Water Level National Tidal Epoch (ft. NGVD29)				
MHHW: 5.38	9.29	11.45	14.17	16.24
Highest Annual Tide (2100): 7.26	11.16	13.33	16.05	18.12

As sea levels increase, flood thresholds are likely to be exceeded more frequently. An analysis of historical water levels at the Portland Tide Station (8418150) from 1912 to 2016 illustrates this increasing frequency for Portland. **Figure 4-3** shows the number of flood days per year for the entire period of record (1912-2016) at the Portland Tide Station (8418150). Flood days per year is defined as the number of days where the verified hourly water level exceeds the NWS minor flood threshold of 7.5 ft. NGVD29 for at least one hour. The trendline (red circles) shows that the number of flood days per year has increased over time. As sea level rise rates continue to accelerate through the 21st century, the frequency of flood days is also expected to increase.

Figure 4-3: Flood Days Per Year at the Portland, Maine Tide Station (8418150)

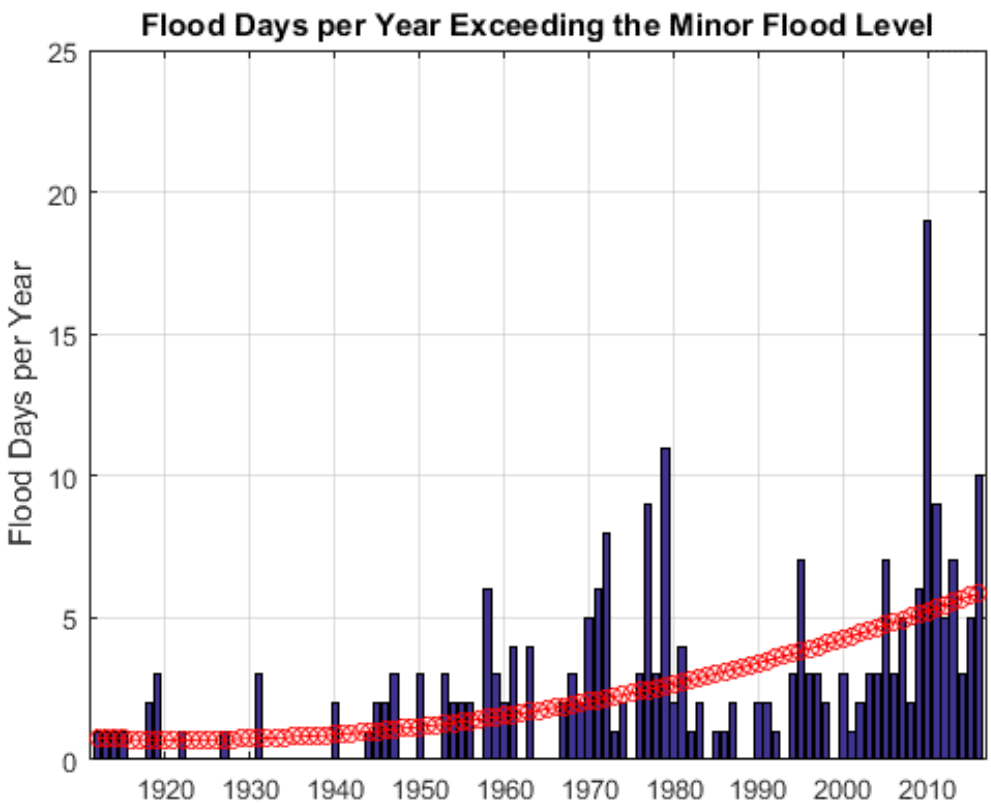


Figure 4-4 shows the same RSL curves as **Figure 4-1** but using MHHW (relative to NGVD29) as the base water level. The figure also shows the NWS flood thresholds, illustrating when each scenario is expected to cause daily flooding in the Portland region. Furthermore, the monthly historic MHHW values from 1980 through 2000 are plotted on the graph to show how these future changes compare to the past. By 2050 the intermediate-high, high, and extreme scenarios all exceed the minor flood threshold and the extreme scenario exceeds the moderate flood threshold. By 2100 all four recommended scenarios exceed the moderate flood threshold and the intermediate-high, high, and extreme scenarios exceed the major threshold. **Table 4-6** summarizes the decade in which each NWS flood threshold (minor, moderate, and major) is expected to be exceeded at least once per day for each of the recommended scenarios.

4.2 Storm Surge

Storm surge elevations for various recurrence intervals have been extracted from the North Atlantic Comprehensive Coast Study (NACCS). The NACCS was a 2015 initiative of the U.S. Army Corps of Engineers (USACE) to provide a risk management framework and improve resilience of coastal communities by supporting management of risk to vulnerable populations, property, ecosystems, and infrastructure. As part of NACCS, the USACE carried out state-of-the-art atmospheric, wave, and storm surge modeling to characterize storm hazards in the North Atlantic region. Coupled numerical

Figure 4-4: Predicted MHHW Elevations from 2000 to 2100 in ft. Relative to NGVD29 in Portland, Maine for all RSL Rise Scenarios

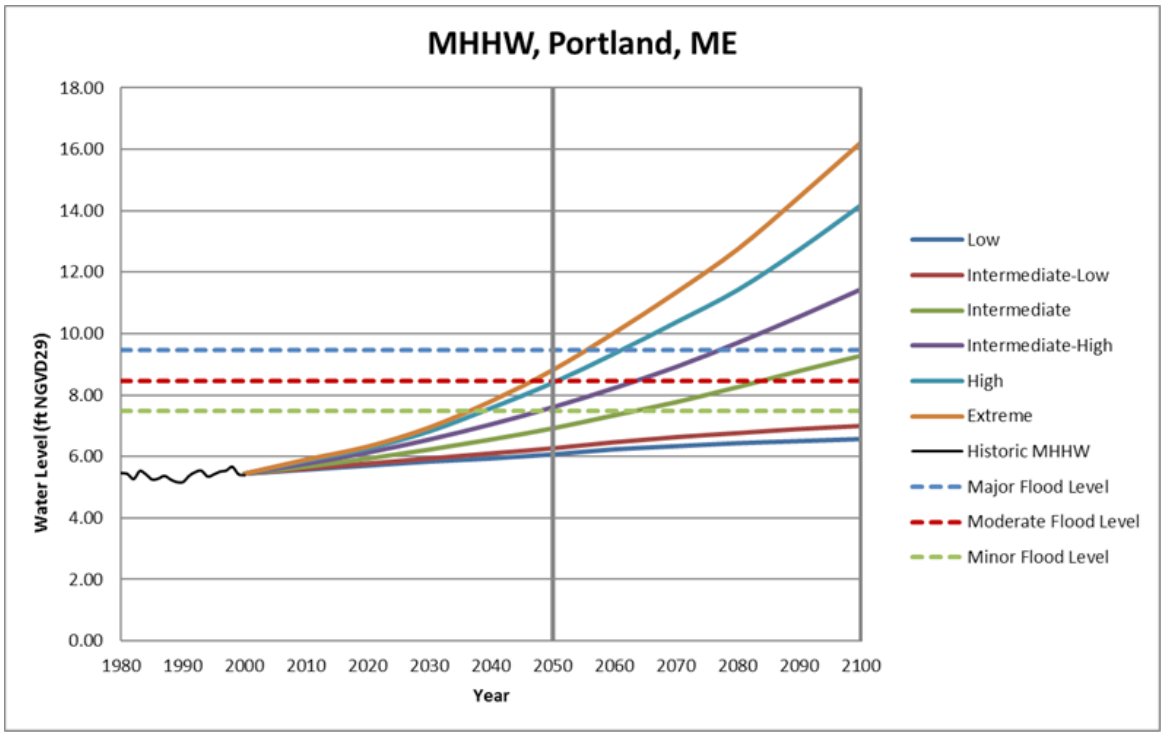


Table 4-6: National Weather Service Flood Warning Thresholds for the Portland, ME NOAA CO-OPS Station (8418150)

		Decade of Daily Exceedance			
NWS Threshold	Water Level	Intermediate (3.93 ft.)	Intermediate -High (6.07 ft.)	High (8.79 ft.)	Extreme (10.86 ft.)
(ft. NGVD29)	Intermediate	Intermediate -High	High	Extreme	16.24
Minor Flooding	7.5	2060	2040	2030	2030
Moderate Flooding	8.5	2080	2060	2050	2040
Major Flooding	9.5	2100	2070	2060	2050

Note: Table 4-6 includes the decade in which those thresholds are expected to be exceeded daily under each of the recommended planning scenarios.

models simulated winds, waves, and water levels along the coast based on 1,050 synthetic tropical storms and 100 historical extratropical storms. The results from each storm simulation were added to 96 random tide phases. These tides are linearly added to the base water level for each storm (Cialone et al., 2015). The result is a large catalog of storm surge, wave heights, and extremal statistics derived from the model runs and stored at high-resolution model output stations along the coast, including several in the Portland, Maine region, as shown in **Figure 4-5**.

While extreme water levels, based on a statistical analysis of historic observations, are also available for the Portland Tide Station (8418150), the NACCS dataset was utilized for this study as it provides the highest resolution and the most recently available modeled data regarding storm-driven water levels. It also provides results at several locations around Portland, including an output point at the entrance to Back Cove, providing insight into the spatial variability of extreme water levels in the region. **Table 4-7** provides a comparison of the 100-year return period water from NACCS station 7221 at the entrance to Back Cove, NACCS station 7047 near the Maine State Pier and the Portland, Maine CO-OPs Tide Station (8418150). The NACCS values represent the mean 100-year water level elevation derived from 1,150 storms modeled and added to each of the 96 randomly selected tide phases for a total of 110,400 water level results (Cialone et al., 2015). The value reported for the Portland Tide Station (8418150) is the mean 100-year storm elevation reported by NOAA for 2016 (NOAA, 2017b).

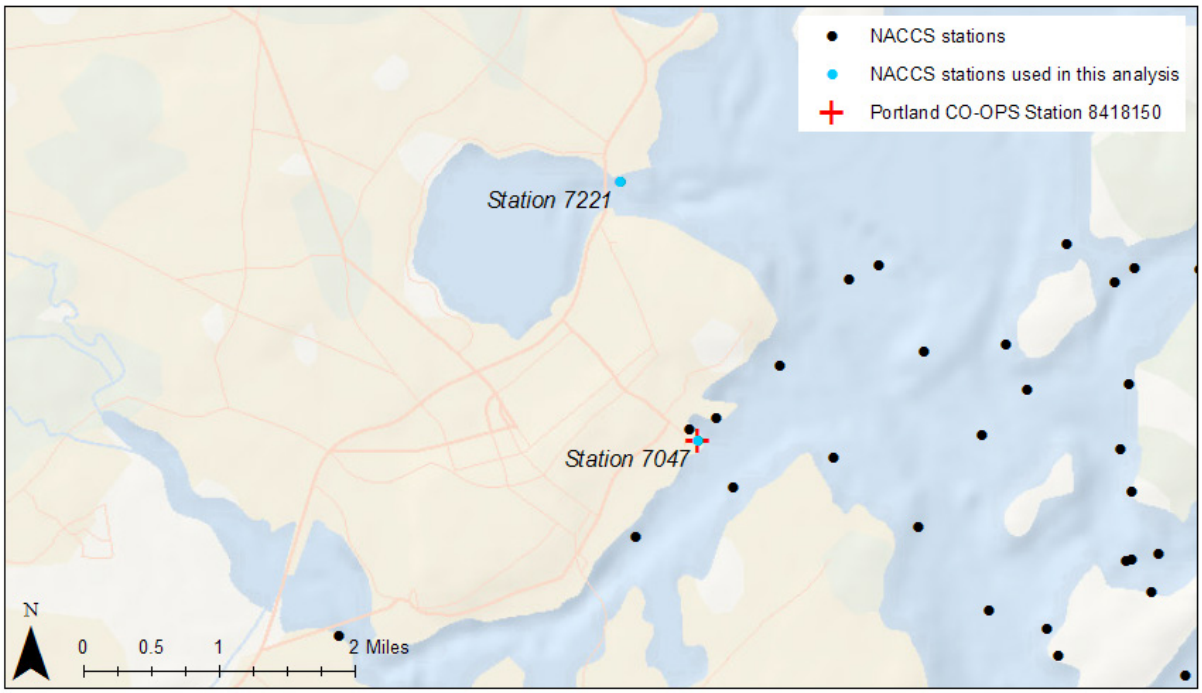
The NACCS output point for the Maine State Pier is very close to the Portland Tide Station and the 100-year water level elevations for both datasets are very similar. However, the NACCS modeling results show that the 100-year storm elevation for the entrance to Back Cove is almost 2 feet higher than that along the Portland waterfront. This difference, would not have been apparent from the tide gage data and is an important consideration when planning for storm surge in the Bayside neighborhood.

Table 4-8 summarizes the 10-year, 20-year, 100-year, and 500-year return period water levels at the two NACCS stations and shows how those are expected to change by 2050 under each of the four predicted MSL scenarios defined in **Section 4.1**. **Table 4-6** shows how the NACCS results for station 7221 and 7047 are expected to change by 2100 under each of the four MSL scenarios defined in **Section 4.1**. **Figure 4-6** provides the same MSL curves as **Figure 4-1** relative to the 100-year stormwater level from 2000 to 2100 at both stations.

Table 4-7: Comparison of the 100-year return period water level for the Back Cove Entrance and Maine State Pier NACCS stations and the Portland Tide Station (8418150)

Location	100-Year Return Period Water Level (ft. NGVD29)
NACCS Back Cove Station (Station 7221)	11.13
NACCS Maine State Pier Station (Station 7047)	9.32
Portland Tide Station (8418150)	9.53

Figure 4-5: NACCS Stations in the Portland, Maine Region



Note: NACCS Station 7221 at the entrance to Back Cove and Station 7047 at the Maine State Pier are highlighted in blue. Each NACCS station provides data on storm surge, wave heights, and extremal statistics. Portland CO-OPS Station 8418150, also located at the Maine State Pier, is depicted by a red cross.

As shown by **Table 4-8** and **Table 4-9**, the storm surge water levels for various return periods are higher at the entrance to Back Cove (Station 7221) when compared to the other side of the Portland peninsula (Maine State Pier - Station 7047). This difference varies based on the return period. For the 10-year water level the difference is 0.2 ft.; for the 500-year water level the difference increases to 1.9 ft.

Table 4-8 and **Table 4-9** also show how the water levels associated with each return period for Back Cove and the Maine State Pier change with each scenario over time. To obtain storm surge values under each of the four MSL scenarios by 2050, under the intermediate scenario at Back Cove, today's 100-year water level (~ 11.1 ft. NGVD29) is nearly a 20-year water level (meaning it is likely to occur five times as frequently) and under the intermediate-high scenario it is nearly a 10-year water level (meaning it is likely to occur ten times as frequently). By 2100 the 100-year water level is expected to occur more frequently than every 10 years under every scenario. For context, the Blizzard of 1978, during which water levels reached 9.6 ft. NGVD29, the highest values ever recorded in Portland by almost 0.9 ft., is representative of the 100-year water level in Portland.

Similarly, by 2050, under the intermediate-high scenario the 500-year water level (~11.8 ft NGVD29) is nearly a 20-year water level and under the high scenario it is nearly a 10-year water level. By 2100 the 500-year water level is also expected to occur more frequently than every 10 years for every scenario.

These conclusions assume that sea level rise and storm surge can simply be added together. The validity of this assumption varies as the actual effect of sea level rise on storm surge is non-linear in some locations, depending on local coastal geomorphology. These non-linear interactions may pose a greater hazard in some locations (Tajalli Bakhsh et al., 2017). Whether there are significant non-linear interactions between sea level rise and storm surge should be further investigated and strategies for filling this data gap are provided in **Section 5.3.2**.

The NACCS results do not provide any insight into storm surge conditions within Back Cove. How the surge might be exacerbated or mitigated by the constriction at the entrance to the cove is another gap that should be further investigated.

Table 4-8: Summary of Extreme Water Levels from the NACCS Study combined with MSL scenarios for 2050.

NACCS Station	Water Level Return Period	Storm Surge Water Level (ft.) [1]	Storm Surge Water Level + 2050 Intermediate MSL of 1.94 (ft. NGVD29)	Storm Surge Water Level + 2050 Intermediate-High MSL of 2.63 (ft. NGVD29)	Storm Surge Water Level + 2050 High MSL of 3.41 (ft. NGVD29)	Storm Surge Water Level + 2050 Extreme MSL of 3.84 (ft. NGVD29)
7221 Back Cove	10-yr	8.04	9.97	10.66	11.45	11.88
	20-yr	8.73	10.66	11.35	12.14	12.57
	100-yr	10.73	12.67	13.35	14.14	14.57
	500-yr	11.45	13.39	14.08	14.86	15.29
7047 Maine State Pier	10-yr	7.81	9.75	10.43	11.22	11.65
	20-yr	8.17	10.11	10.79	11.58	12.01
	100-yr	8.89	10.83	11.52	12.30	12.73
	500-yr	9.95	11.48	12.17	12.96	13.39

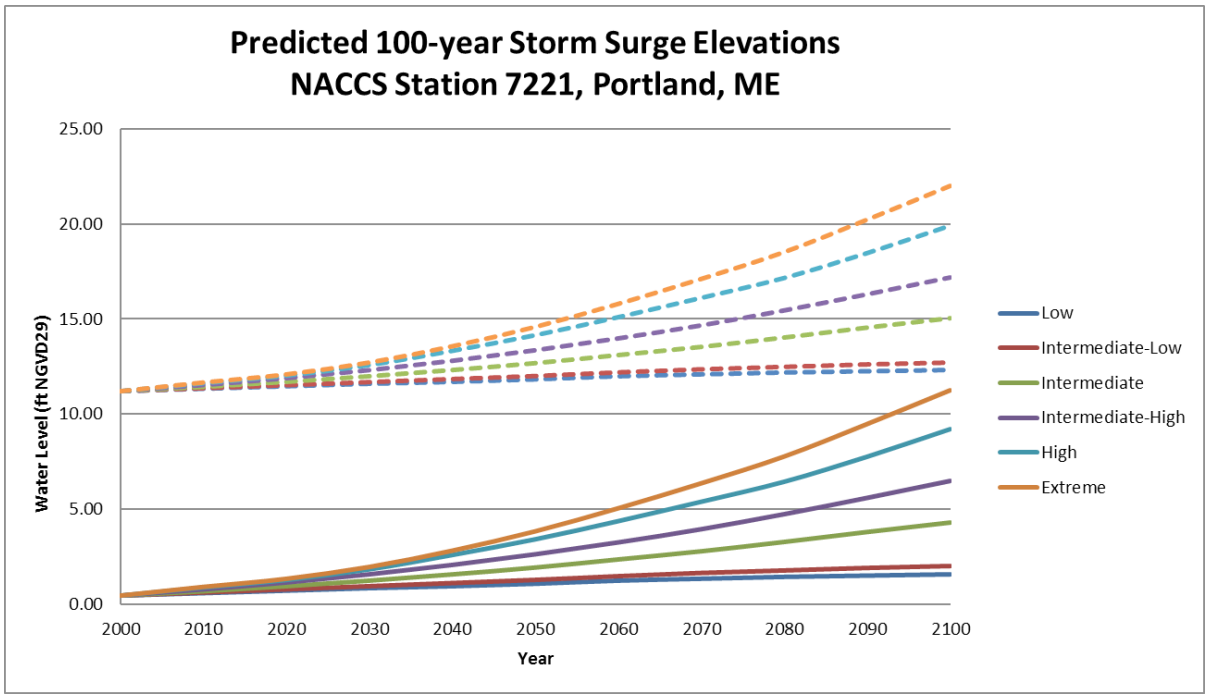
[1] Relative to mean sea level

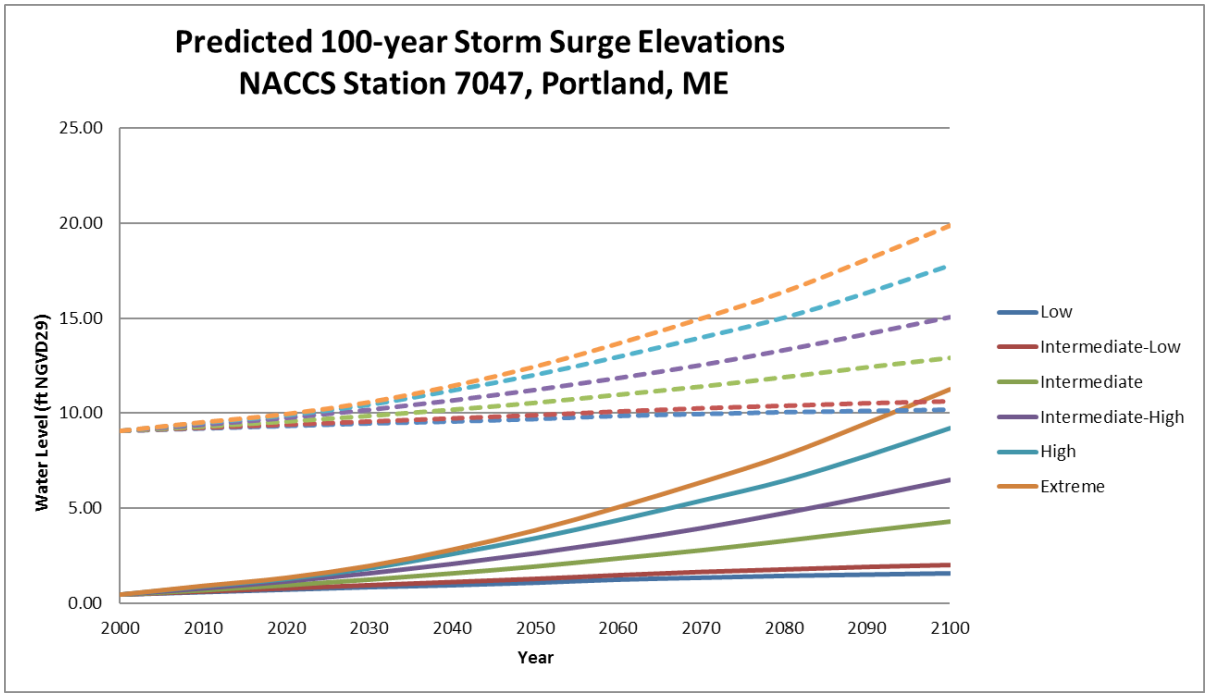
Table 4-9: Summary of Extreme Water Levels from the NACCS Study combined with MSL scenarios for 2100.

NACCS Station	Water Level Return Period	Storm Surge Water Level (ft.)[1]	Storm Surge Water Level + 2100 Intermediate MSL of 4.3 (ft. NGVD29)	Storm Surge Water Level + 2100 Intermediate-High MSL of 6.46 (ft. NGVD29)	Storm Surge Water Level + 2100 High MSL of 9.19 (ft. NGVD29)	Storm Surge Water Level + 2100 Extreme MSL of 11.25 (ft. NGVD29)
7221 Back Cove	10-yr	8.04	12.34	14.50	17.22	19.29
	20-yr	8.73	13.03	15.19	17.91	19.98
	100-yr	10.73	15.03	17.19	19.91	21.98
	500-yr	11.45	15.75	17.91	20.64	22.70
7047 Maine State Pier	10-yr	7.81	12.11	14.27	16.99	19.06
	20-yr	8.17	12.47	14.63	17.35	19.42
	100-yr	8.89	13.19	15.35	18.08	20.14
	500-yr	9.55	13.85	16.01	18.73	20.80

[1] Relative to mean sea level

Figure 4-6: MSL scenarios (solid lines) for the entrance to Back Cove (NACCS Station 7221) (top) and Maine State Pier (NACCS Station 7047) (bottom)





Note: Figure 4-6 shows how the 100-year water level height (dashed lines) changes in magnitude under each scenario.

4.3 Precipitation

As part of this study precipitation characteristics and literature pertaining to present and projected precipitation changes were assessed. The aspects of precipitation important to stormwater management include the characteristics of the design storm, which for the City has been stated to be the 24-hr precipitation event with a 25-yr recurrence interval, and the peak intensity of precipitation on a short-term basis. This analysis has been performed to estimate the present and potential future values of these metrics as well as updated sources for provision of data/approach. First a summary of present precipitation characteristics is presented, then the basis and values to be used in the future are established. An assessment of known flooding events is presented in **Section 5.1**.

4.3.1 Analysis of existing precipitation characteristics

Stormwater management requires an understanding of precipitation characteristics, namely the frequency, duration, intensity and distribution of precipitation. Typically engineers design systems for a given design storm which is a theoretical representation of the precipitation distribution and total for a given statistical significance; in this case the City designs for the 24-hr precipitation that recurs at a 25-yr interval, which can be thought of as the event that has a 4% chance of occurring in any given year. The precipitation distribution throughout the event along with the watershed characteristics dictate the runoff volumes to various components of the stormwater system.

4.3.1.1 Precipitation Event Totals Statistics

A review of data sources (NOAA TP-40, NOAA Atlas 14, NRCS/NRCC) that provide precipitation totals/duration combinations for different recurrence intervals was performed. A sample of the comparison for the 1-hr precipitation and 24-hr precipitation totals at various recurrence intervals is shown in **Figure 4-7** and **Figure 4-8**. Evident in these figures is that there is variability across the sources with the trend in conservatism changing depending on recurrence interval.

Figure 4-7: Summary of Precipitation Totals (in.) for the 1-hr Duration at Various Recurrence Intervals

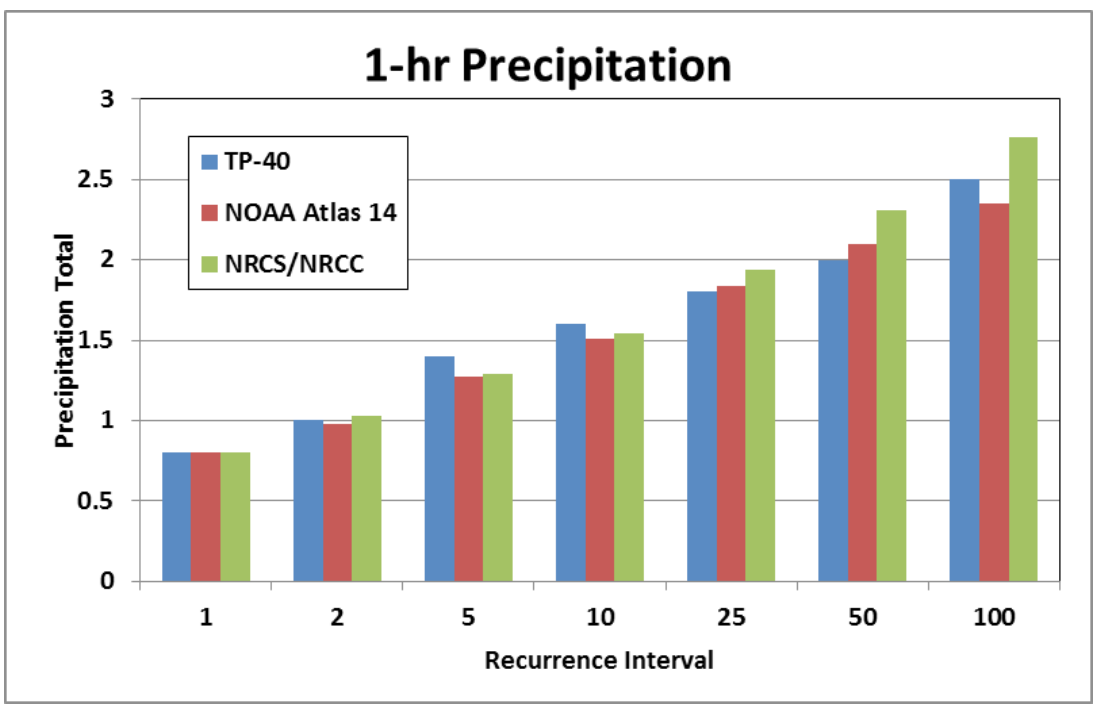
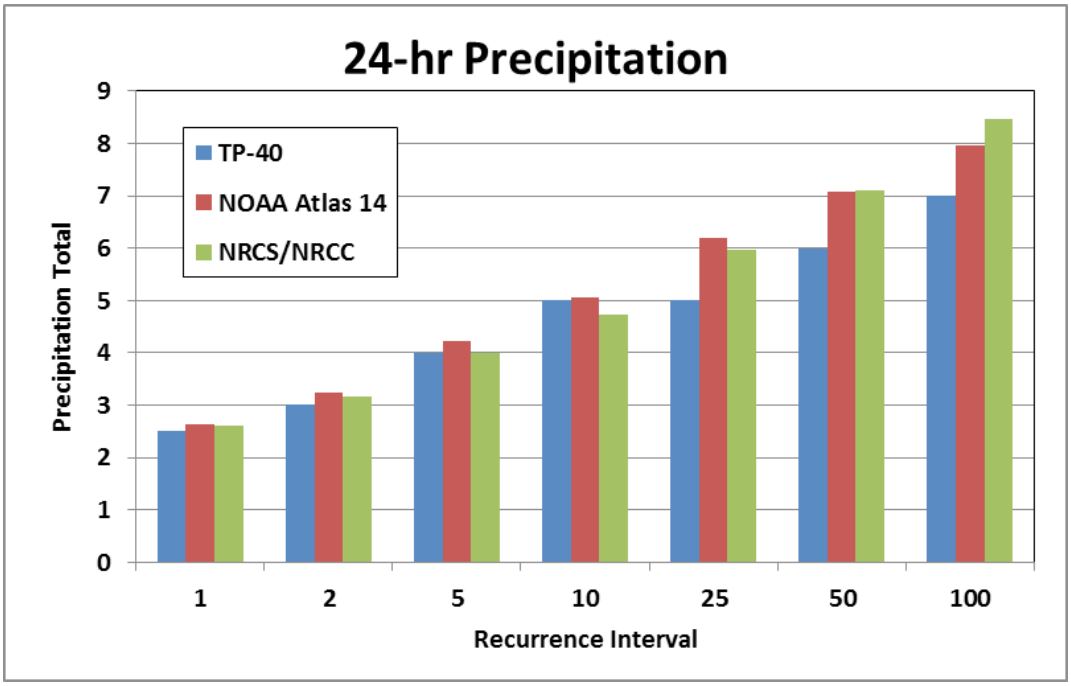


Figure 4-8: Summary of Precipitation Totals (in.) for the 24-hr Duration at Various Recurrence Intervals



The uncertainty of the 24-hour precipitation event totals for various recurrence intervals was also investigated for the NOAA Atlas 14 data **(Figure 4-9)** and the NRCC data **(Figure 4-10)**; TP-40 does not provide uncertainties. This shows that the uncertainty is slightly greater for the NOAA Atlas 14 data and that furthermore the uncertainty can be a relatively high particularly for less frequent events. **Figure 4-9** illustrates that a 24-hr total of 6 inches could be associated with any event ranging from a 10-yr to a 100-yr recurrence interval.

Figure 4-9: Illustration of Uncertainty Associated With the NOAA Atlas-14 24-hr Precipitation Totals at Various Recurrence Intervals

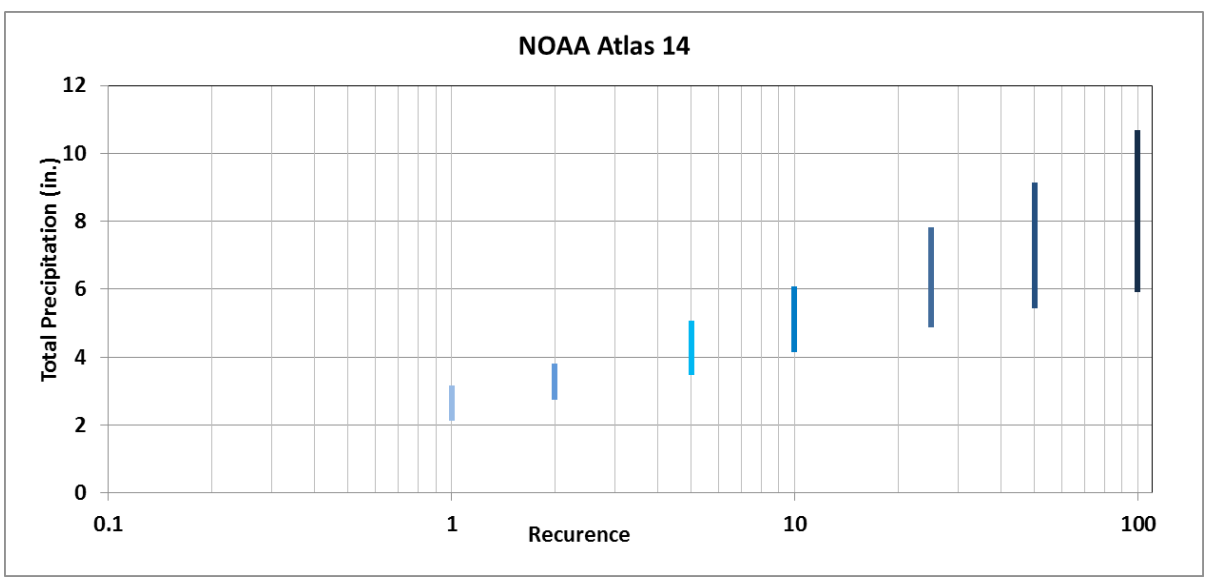
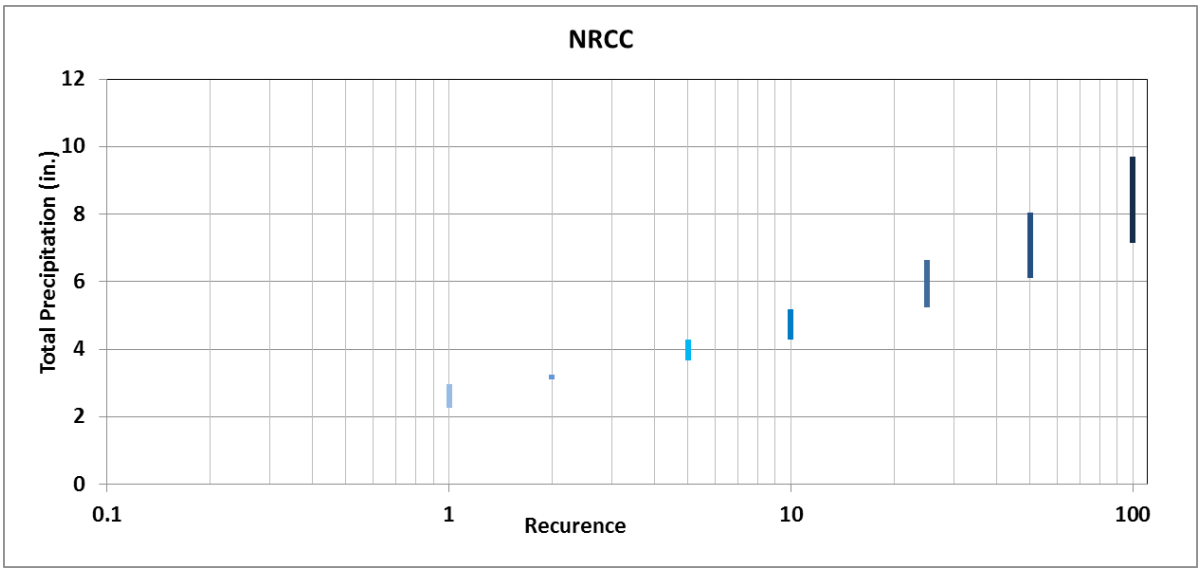


Figure 4-10: Illustration of Uncertainty Associated With NRCC 24-hr Precipitation Totals at Various Recurrence Intervals



4.3.1.2 Precipitation Event Distributions and Intensity

Another important component of precipitation characteristics is the distribution during an event. Historically most planning was done using the NRCS Type III distribution in this region. The NOAA 14 Atlas has updated distributions for some parts of the country, however to date have not yet updated the distributions to be used in Maine though those will be coming. In the interim the Northeast Regional Climate Center has computed distributions for the northeast and have made available a tool that provides site specific distributions. **Figure 4-11** and **Figure 4-12** provide illustrations of the new NRCC and the historic NRCS distributions for the 24-hr precipitation events represented by cumulative and incremental fraction respectively; note that the NRCC data is specific for a 25-yr event and the distribution changes slightly depending on the recurrence interval of the event. These distributions are based on 6-minute time steps so the incremental fraction shows the time history of 6-minute totals throughout the event. The distributions are similar, however the NRCC new distribution has a slightly narrower but peakier pattern. It is suggested that the City move towards assuming the New NRCC distributions for use in studies or planning related to stormwater.

The intensity of precipitation is also a useful metric relative to stormwater management. A summary of the peak intensity during the design storm using various sources of total precipitation (TP-40, NOAA Atlas 14, and NRCS/NRCC) and distributions (Historic Type III and New NRCC) are presented in **Table 4-10**. It can be seen from this table that while the new NRCC distribution produces the greatest 6-minute intensity, the historic NRCS Type III distribution produces the greatest hourly intensity. Further it can be seen that for this design event that the peak hourly intensity varies by almost a half inch depending on the source used to define the event total precipitation. It is recommended that the City use the NOAA Atlas 14 value for planning purposes relative to the 25-yr 24-hr design storm.

Figure 4-11: Comparison of Historic and New Precipitation (in.) Distributions (cumulative)

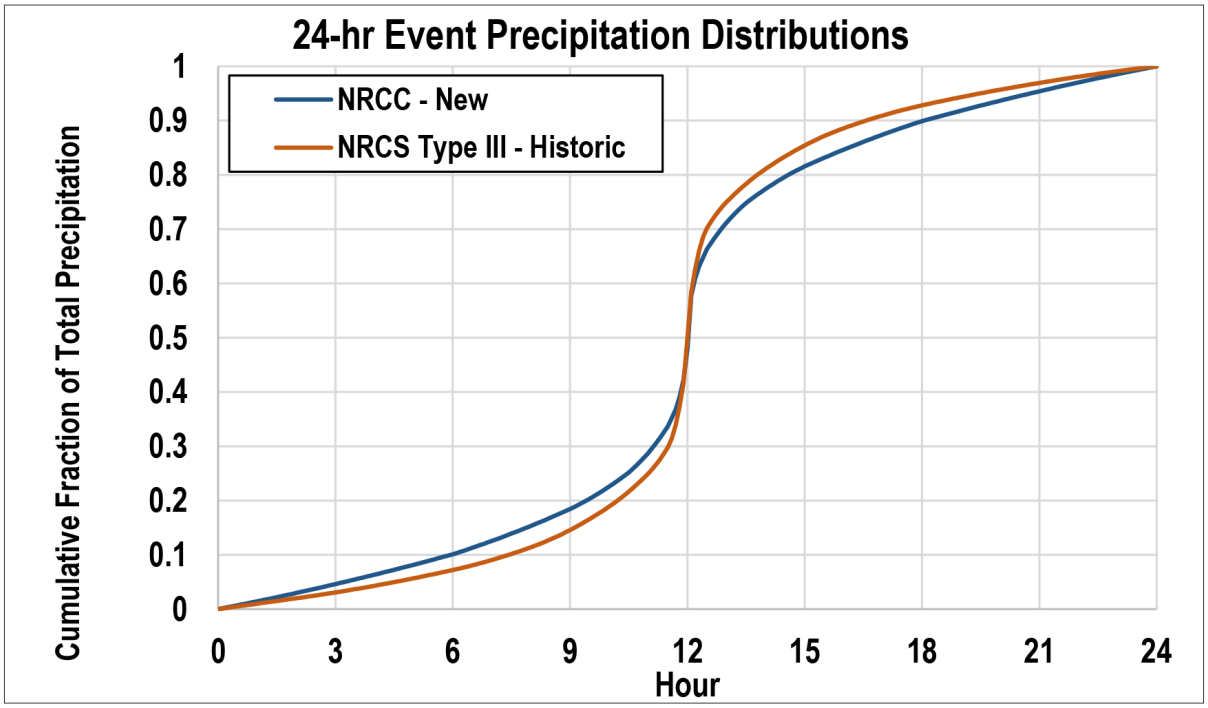


Figure 4-12: Comparison of Historic and New Precipitation (in.) Distributions (incremental)

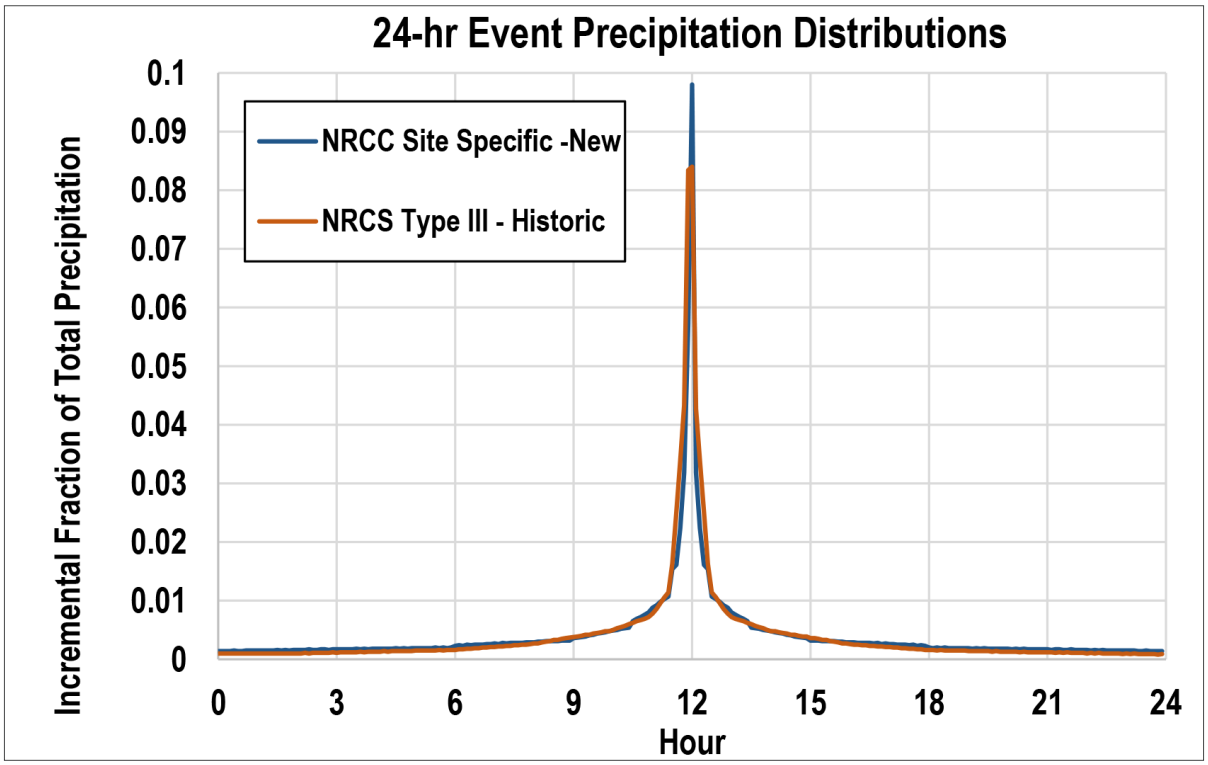


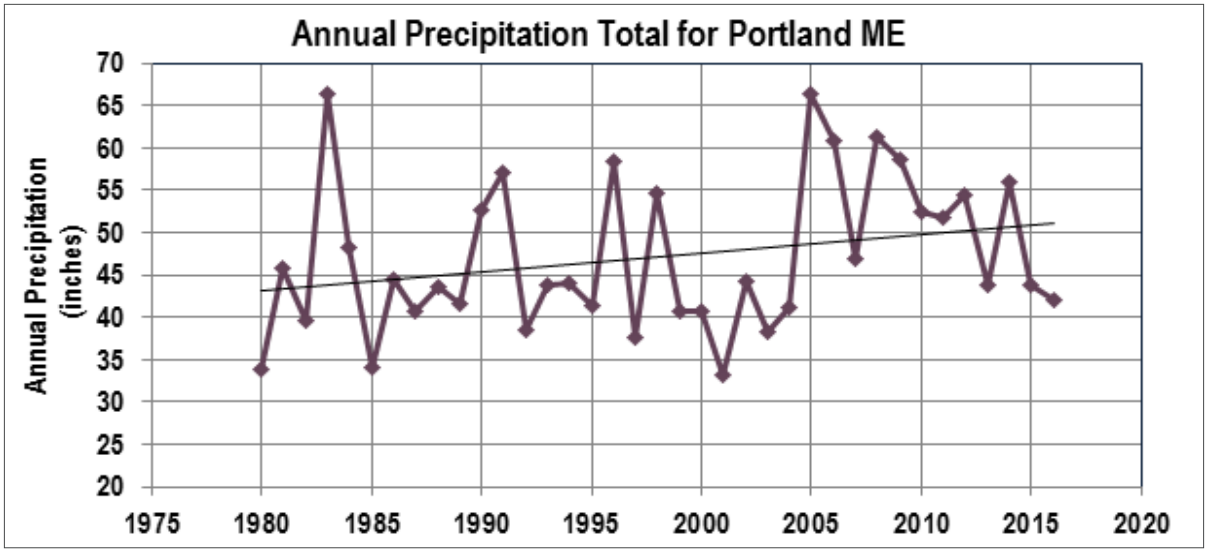
Table 4-10: Summary of Peak 6-minute and Hourly Intensity During the 25-yr 24-hr Precipitation Event

Description	RI	Entire Event Duration	TP40	NOAA ATLAS 14	NRCC
Total Precipitation (in.)	25-yr.	24-hr.	5.00	6.19	5.97
Peak 6-min Using NRCC- New (in./6 min)	25-yr.	24-hr.	0.49	0.61	0.59
Peak 6-min Using NRCS- Historic (in./6 min)	25-yr.	24-hr.	0.42	0.52	0.50
Peak Hourly - Using NRCC New (in./hr.)	25-yr.	24-hr.	1.63	2.02	1.95
Peak Hourly - Using NRCS - Historic (in./hr.)	25-yr.	24-hr.	2.02	2.50	2.41

4.3.1.3 Precipitation Annual Totals

The annual total precipitation has been analyzed for the period of 1980 – 2016; a plot of the annual totals is illustrated in **Figure 4-13**. The average annual precipitation from this period is 47.11 inches with a minimum of 33.12 inches and a maximum of 66.4 inches. A linear trendline fit to the data is also shown in **Figure 4-13**. This trendline is sloped upwards, indicating a trend of increasing annual totals.

Figure 4-13: Annual Precipitation Totals from 1980-2016



Source: (source: http://www.nrcc.cornell.edu/wxstation/nowdata.html)

4.3.2 Establishment of Future Conditions

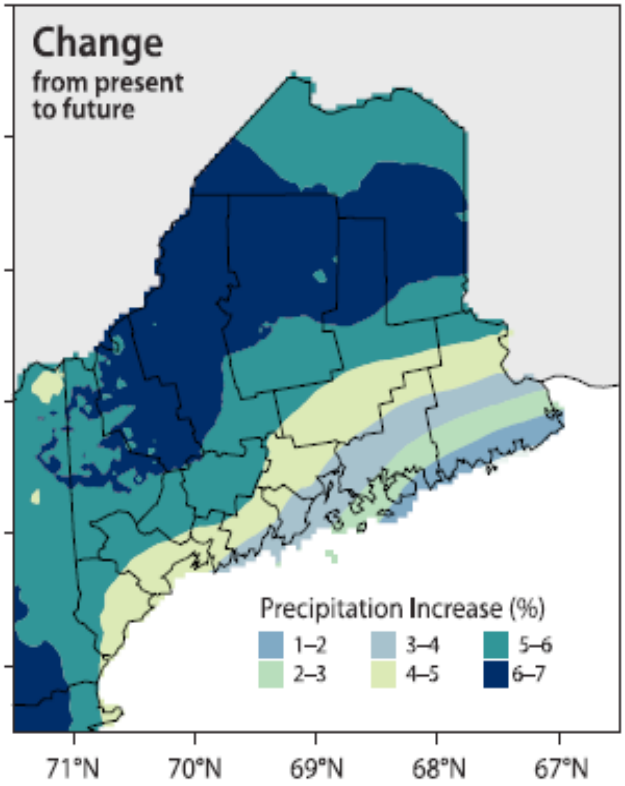
The preceding sections described the sources of precipitation statistics and values associated with the assumed design storm. This section provides insight to projected future conditions and makes recommendations for values to be used in future design scenarios.

Climate change is anticipated to change both the average annual precipitation and the peak intensity on a short-term basis (e.g., 6 minute or hourly). The objective of this analysis is to be able to project the future design storm characteristics and peak intensities in two future timeframes, a mid-term (2050) and long-term (2100). Multiple sources were investigated including the Casco Bay Estuary Program report on Climate Change Trends (CBEP, 2015), the University of Maine Maine's Climate Future (Fernandez, 2015), and the Climate Solutions New England (CSNE) Climate Assessments for New England.

4.3.2.1 Future Design Storm Totals

To develop the future design storm totals, literature that provides projected values or rates was investigated. The CBEP climate change report and website content provide a summary of the past precipitation trends and summarize that based on historic data and showed that the increase from 1895 to 2014 was 0.5 inches (0.0042 in./yr) in Maine while more recent data shows a more rapid increase of 1.92 inches from 1960-2014 (0.0349 in./yr). Further the study suggests that the annual average will continue to increase, and points to the University of Maine (UMaine) report for this topic. The UMaine report provides the same historic hindcast and additionally provides a projection that states the annual average will continue to rise between 5-10% between now and 2050. A reproduction of the map presented in that report is provided in **Figure 4-14** which shows that the Portland region falls within the 4-5 % predicted increase range. This study also discusses how the number of extreme events have been and are expected to continue to increase.

Figure 4-14: Projected Precipitation Increase from 2015 to 2050 (Fernandez et al., 2015)



The CSNE report provided the most comprehensive set of quantitative metrics regarding increase in average annual precipitation, and therefore was chosen as the source for providing future projections for the Bayside project. This study provides projections for the change in annual precipitation for various timeframes and emission scenarios. The study presents the historic annual average as 46.6 in. based on data from 1980-2009, which was consistent with the analysis of the annual data provided in **Section 4.3.1.3**. The study projects the change in the averages for medium term and long term periods for a low and a high emission scenario. Based on these incremental changes, the projected average annual totals were calculated for each timeframe/emission scenario and summarized as shown in **Table 4-11**. The percent change in average annual precipitation was also calculated for each timeframe/emission scenario as summarized in **Table 4-12**; in all cases the percent change is relative to the historic average annual precipitation total of 46.6 inches. Also shown is the average total annual precipitation. Additionally, the average percent change was calculated by averaging the values for the low and high emission scenario for each timeframe. For the purposes of the present study it is proposed to use these averages to scale the precipitation totals to establish the future conditions of each precipitation event. The historic and scaled values for various duration storms is provided in **Table 4-13**. The design event (25-yr 24-hr) is highlighted in this table. The 24-hr event statistics were also plot and shown on two different x-axis extents **(Figure 4-15 and Figure 4-16)** with two different reference lines to illustrate where the historic total crosses the future curves. These figures show how for the 24-hr event the historic 25-yr. event is expected to be equivalent to the 16-yr in 2050 and 13-yr in 2100 and similarly how the historic 100-yr. 24 hr. event is expected to be equivalent to the 52-yr in 2050 and 42-yr in 2100.

Table 4-11: Summary of Projected Average Annual Precipitation for the 2050 and 2100 Representative Scenarios.

Representative Scenario	Range	Low Emission Annual Total (inches)	High Emission Annual Total (inches)
2050	Mid-Term 2040-2069	51.7	52.7
2100	Long-Term 2070-2099	53	56.3

Table 4-12: Summary of Projected Percent Change in Average Annual Precipitation for the 2050 and 2100 Representative Scenarios.

Representative Scenario	Range	Low Emission Annual Total Percent Change (%)	High Emission Annual Total Percent Change (%)	Average Percent Change (%)	Average Total Annual Precipitation (in)
2050	Mid-Term 2040-2069	10.9	13.1	12	52.2
2100	Long-Term 2070-2099	13.7	20.8	17.3	54.7

Table 4-13: Summary of Historic and Suggested Future Precipitation Totals (in.) for Various Durations

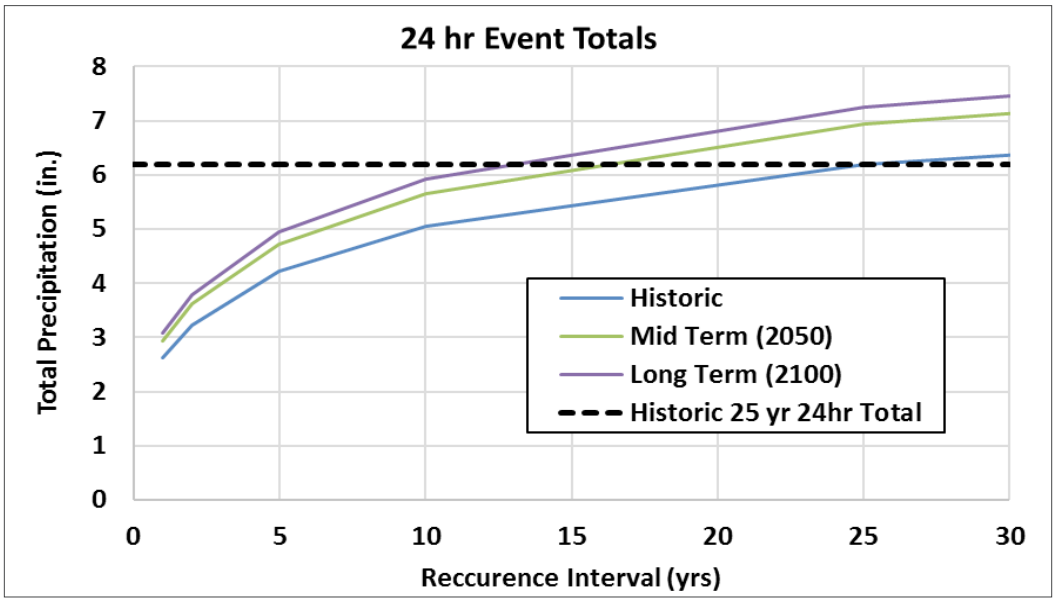
3-hr Precipitation (in.)			
ARI (yrs.)	Historic	Mid Term	Long Term
		2050	2100
1	1.36	1.52	1.59
2	1.67	1.87	1.96
5	2.16	2.42	2.53
10	2.56	2.87	3.00
25	3.13	3.51	3.67
50	3.56	3.99	4.17
100	3.99	4.47	4.68

6-hr Precipitation (in.)			
ARI (yrs.)	Historic	Mid Term	Long Term
		2050	2100
1	1.8	2.02	2.11
2	2.2	2.46	2.58
5	2.84	3.18	3.33
10	3.38	3.79	3.96
25	4.12	4.61	4.83
50	4.68	5.24	5.49
100	5.25	5.88	6.16

12-hr Precipitation (in.)			
ARI (yrs.)	Historic	Mid Term	Long Term
		2050	2100
1	2.26	2.53	2.65
2	2.75	3.08	3.22
5	3.56	3.99	4.17
10	4.23	4.74	4.96
25	5.15	5.77	6.04
50	5.86	6.56	6.87
100	6.58	7.37	7.72

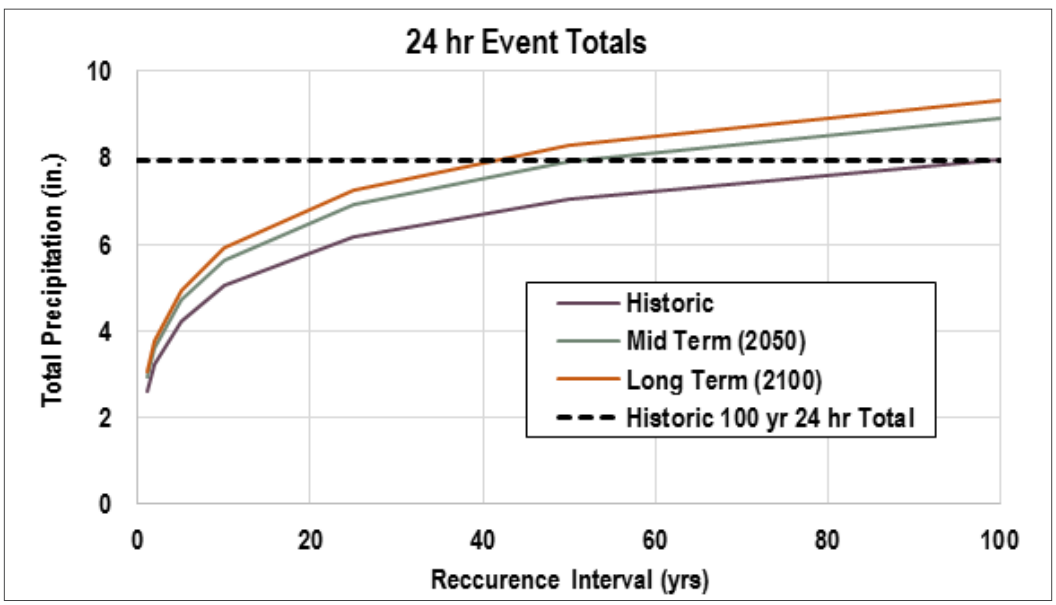
24-hr Precipitation (in.)			
ARI (yrs.)	Historic	Mid Term	Long Term
		2050	2100
1	2.62	2.93	3.07
2	3.23	3.62	3.79
5	4.22	4.73	4.95
10	5.05	5.66	5.92
25	6.19	6.93	7.26
50	7.07	7.92	8.29
100	7.95	8.90	9.32

Figure 4-15: 24-hr Event Recurrence Interval Totals for Historic and Future Timeframes



Note: X-axis zoomed to 30-year timeframe

Figure 4-16: 24-hr Event Recurrence Interval Totals for Historic and Future Timeframes



Note: X-axis extended to 100-year timeframe

4.3.2.2 Future Increases to Precipitation Intensity

The studies reviewed were consistent in suggesting that the precipitation intensity will increase in the future, however few quantitative metrics are available. Most of the literature focuses on the increase in the number of events as opposed to the increase in actual intensity. The projected increase in event totals indicates that intensity will increase throughout the event. The peak 6-minute and hourly precipitation totals were calculated for the future timeframes and are summarized along with historic values in **Table 4-14**. These calculations are based on the NOAA Atlas 14 totals and the NRCC distribution.

Table 4-14: Summary of Peak 6-Minute and Hourly Intensity During the 25-yr 24-hr Precipitation Event for Historic, Mid-Term (2050) and Long Term (2100) Timeframes

Description	RI	Entire Event Duration	Historic	Mid Term (2050)	Long Term (2100)
Total Precipitation (in.)	25-yr.	24-hr.	6.19	6.93	7.26
Peak 6-min Using NRCC-New (in./6 min)	25-yr.	24-hr.	0.61	0.68	0.71
Peak Hourly - Using NRCC New (in./hr.)	25-yr.	24-hr.	2.02	2.26	2.37

4.3.2.3 Precipitation Summary

An analysis of the historic precipitation characteristics, historic analysis approaches to precipitation and future projected precipitation characteristics was performed. The following bullet points provide a summary of major findings.

- The city infrastructure is intended to withstand the 25-yr 24-hr precipitation event.
- Historically total precipitation for design events was obtained from TP-40 and the distribution was based on NRCS Type III curves.
- Newer sources of precipitation statistics and a new approach to precipitation distribution are presently available and recommended for future use since the take in to account more recent precipitation trends.
- It is suggested that the NOAA Atlas-14 recurrence interval statistics are used along with the NRCC precipitation distribution to define design storm characteristics.
- Future design storm totals were estimated by averaging the low emission and high emission scenarios annual total values for both a midterm (2050) and long term (2100) timeframe. The average increase from the present total of 46.6 in. was 12% (52.2 in.) for 2050 and 17.3% (54.7 in.) for long term.
- The design storm total based on NOAA Atlas 114 will increase from historic value of 6.19 in. to 6.93 in. by 2050 and 7.26 in. by 2100.
- The peak 6-minute precipitation will increase from 0.61 in. to 0.68 in. by 2050 and 0.71 in. by 2100.
- The peak hourly precipitation will increase from 2.02 in. to 2.26 in. by 2050 and 2.37 in. by 2100.
- The historic precipitation total for the design storm (24-hr 25-yr.) is equivalent to the precipitation total for a 16-yr event in 2050 and a 13-yr. event in 2100.
- The historic precipitation total for the design storm (24-hr 100-yr.) is equivalent to the precipitation total for a 52-yr. event in 2050 and a 42-yr. event in 2100.
- The uncertainties in precipitation recurrence interval totals is high and can rival the magnitude of the storm.

Section 5
Sea Level Rise and Climate Change Findings

5. IMPACTS TO BAYSIDE & DATA GAPS

5.1 Analysis of Known Flooding Events

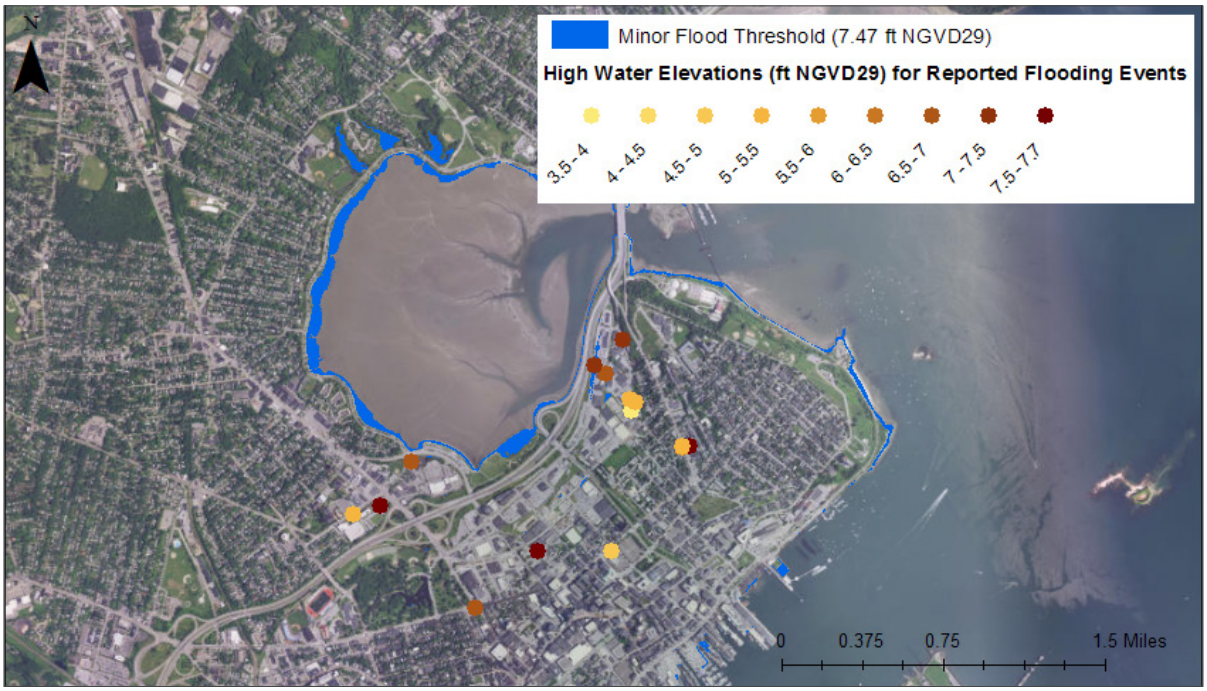
The Bayside neighborhood has stormwater infrastructure that conveys runoff to the coastal waters through a system of catch basins, pipes/culverts, and pumping stations. The system is taxed during extreme events, which can result in drainage issues. These issues may be exacerbated for certain coastal conditions such as unusually high tides or storm surges when the waters rise enough to create a hydraulic connection between the coastal waters and the drainage system; this condition can diminish the capacity of the conveyance system. To understand if Bayside flooding is a function of the coastal water surface elevation or the precipitation or the combination of both, a review of the reported flood events was performed. The total daily precipitation and water surface elevation for each day of report flooding is shown in **Table 5-1**. Reported events are sparse and nothing conclusive regarding precipitation alone as the source of flooding problems can be learned from this data set.

Table 5-1: Summary of Reported Flooding Events and Associated Daily Precipitation Sum and Highest Water Elevation

Event Year	Event Date	Precipitation Total (inches)	Precipitation Notes	Observed Highest Water Elevation (ft. NGVD29)	Predicted Highest Water Elevation (ft. NGVD29)
2013	5/9/2013	0.7		5.8	5.7
2013	6/24/2013	Trace		7.6	7.3
2014	6/13/2014	2.32		6.9	6.5
2014	9/1/2014	1.29	day before	5.3	5.0
2015	4/21/2015	0		7.7	6.8
2015	9/30/2015	5.56		7.6	7.1
2015	10/1/2015	0		6.8	6.9
2015	10/28/2015	0.97		6.8	7.3
2016	3/11/2016	0.13		7.2	6.7
2016	3/31/2016	0		4.0	4.3
2016	4/26/2016	0.4	also 2+ in. snow	5.2	5.0
2016	5/7/2016	Trace		7.3	7.2
2016	5/28/2016	0		5.2	5.2
2016	5/29/2016	0		5.1	5.1
2016	6/15/2016	0		4.9	4.6

Figure 5-1 shows a map of the minor flood threshold (7.5 ft. NGVD29, as described in **Section 4.1.1**) along with the locations of the reported flooding events color coded by the high-water elevation from the date of the reported flood event. Most the reported flood events occurred with high water elevations less than the minor flood threshold. Given that these flood events are occurring at or below the coastal minor flood threshold, further investigation is needed to determine the causation of each of these flood events particularly those occurring when observed coastal water levels are well below the minor flood threshold and no rain has been reported. The lack of information as to the origin of these events should be considered a data gap.

Figure 5-1: Map of Minor Flood Threshold Compared to Reported Flooding Events and the Respective High Water Elevation



5.2 Sea Level Rise

5.2.1 Sea Level Rise Impacts

Sea level rise causes permanent inundation along the coast. In Maine, this will lead to loss of salt marches, beach erosion, and increased flooding due to storm surge (Fernandez, 2015; Whitman et al., 2013). Previous studies of Bayside have shown that a one to three-foot increase in sea level will impact existing infrastructure in the neighborhood including properties and roads along Marginal Way, Somerset Street, Preble Street, and Back Cove Park (Bohlen et al., 2013).

While the scenarios presented in **Section 4.1** and summarized in **Table 5-2** provide water level elevations for planning purposes, it is necessary to map potential areas of inundation to understand impacts.

Table 5-2: Summary of Predicted Daily Inundation Elevations

Scenario	2050: MHHW, ft. relative to NGVD29	2100: MHHW, ft. relative to NGVD29
Intermediate	6.93	9.29
Intermediate High	7.61	11.45
High	8.40	14.17
Extreme	8.83	16.24

Note: Expressed as MHHW relative to ft. NGVD29 for 2050 and 2100

While mapping each of the scenarios is outside the scope of this study, there are several sources of existing inundation maps that provide insight into the impacts of these scenarios, these include:

- Climate Central: Surging Sea's Risk Zone Map
- NOAA Sea Level Rise Viewer
- Maine Geological Survey (MGS) – Sea Level Rise/Storm Surge Viewer
- Sea Level Rise and Casco Bay's Wetlands: A Look at Potential Impacts – Portland Edition
- Maine Geological Survey (MGS) – Adapting to Sea Level Rise in South Portland
- Natural Resource Council of Maine Inundation Maps: Maps of Maine Communities Affected by Sea-level Rise

Table 5-3 includes a detailed summary of these studies including the sea level rise scenarios included and the base water level used for mapping. The maps available from each of these studies have been matched to the scenarios recommended above to show extent and depth of potential inundation where possible and to identify data gaps.

Table 5-3: Summary of Resources that Provide Inundation Mapping for the Portland Region

Existing Data	Year	Sea Level Rise Scenarios	Base Water Level	Source
Climate Central: Surging Sea's	2015	1 ft.; 2 ft.; 3 ft.; 4 ft.; 5 ft.; 6 ft.; 7 ft.; 8 ft.; 9 ft.; 10 ft., 11.2 ft.	Local MHHW	http://sealevel.climatecentral.org/
NOAA Sea Level Rise Viewer	Rolling updates	1 ft.; 2 ft.; 3 ft.; 4 ft.; 5 ft.; 6 ft.;	Local MHHW	https://coast.noaa.gov/digitalcoast/tools/slr
MGS Sea Level Rise/Storm Surge	2015	1 ft.; 2 ft.; 3.3 ft.; 6 ft.	2015 HAT	http://www.maine.gov/dacf/mgs/hazards/slr_ss/index.shtml
Sea Level Rise and Casco Bay's Wetlands: Portland Edition	2011; updated in 2013	1 ft.; 3 ft.	1998 FEMA SWEL	https://www.cascobayestuary.org/wp-content/uploads/2014/06/2013_cbep_slr_report_portland.pdf.pdf
Adapting to Sea Level Rise in South Portland (MGS)	2012	1.97 ft. (0.6 m); 3.28 ft. (1 m); 5.91 ft. (1.8 m)	HAT; FEMA 100-year SWEL	http://www.capeelizabeth.com/planning_board/2013/10-01-2013/SPO%20approved%20final%20report.pdf
Natural Resources Council of Maine	2006	3.3 ft. (1 m); 19.7 ft. (6 m)	Unknown	http://www.nrcm.org/projects/climate/global-warming-air-pollution/sea-level-rise-maine/

Each of the resources listed in Table 5-3 is reviewed for relevance to the recommended scenarios in more detail below. While some are outdated or use low-resolution national elevation datasets, they do provide a screening level indication of potential inundation due to sea level rise.

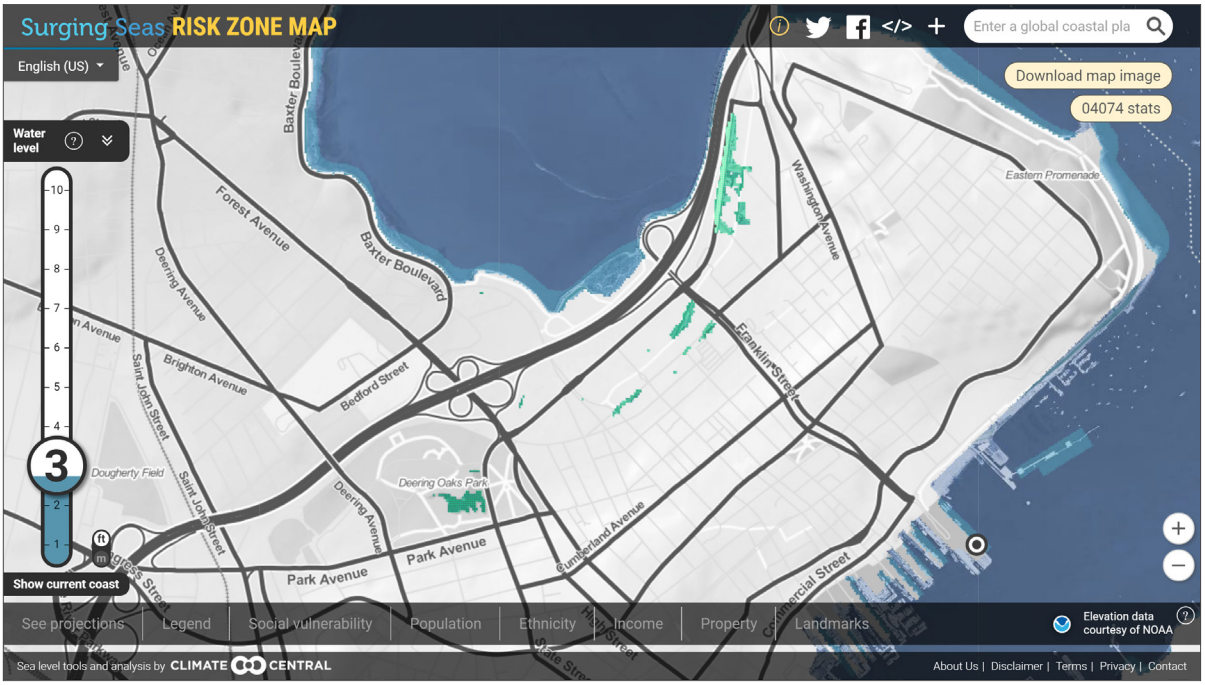
Climate Central – Surging Seas Risk Zone Map Web Viewer

Climate Central's Surging Seas web viewer is a comprehensive national data viewer that allows the public to view the inland extent of sea level rise on top of a base water level of local MHHW. The exact value of MHHW used in each location is not published. Sea level rise scenarios varying from 1 to 10 ft. are provided. The data, although available for download as a static image or KML, is not available for download in GIS format. In Portland, assuming a local MHHW of 5.38 ft. NGVD29, the surging seas scenarios are equivalent to the following:

- **1 ft. above MHHW = 6.4 ft. NGVD29 (5.4 ft. NGVD29 + 1 ft. SLR):** This layer can be used to visualize what the 2050 intermediate (6.93 ft. NGVD29) scenario would inundate. This layer is about 0.5 ft. lower than the 2050 intermediate scenario.
- **2 ft. above MHHW = 7.4 ft. NGVD29 (5.4 ft. NGVD29 + 2 ft. SLR):** This layer can be used to visualize what the 2050 intermediate-high (7.61 ft. NGVD29) scenario would inundate. This layer is about 0.2 ft. lower than the 2050 intermediate-high scenario.
- **3 ft. above MHHW = 8.4 ft. NGVD29 (5.4 ft. NGVD29 + 3 ft. SLR):** This layer can be used to visualize what the 2050 high (8.4 ft. NGVD29) and 2050 extreme (8.83 ft. NGVD29) scenarios would inundate. This layer is equivalent to the 2050 high scenario and 0.43 ft. lower than the 2050 extreme scenario.
- **4 ft. above MHHW = 9.4 ft. NGVD29 (5.4 ft. NGVD29 + 4 ft. SLR):** This layer can be used to visualize what the 2100 intermediate (9.3 ft. NGVD29) scenario would inundate. This layer is 0.1 ft. higher than the 2100 intermediate scenario.
- **5 ft. above MHHW = 10.4 ft. NGVD29 (5.4 ft. NGVD29 + 5 ft. SLR):** N/A – this scenario is not within 0.5 ft. of any of the recommended daily inundation scenarios.
- **6 ft. above MHHW = 11.4 ft. NGVD29 (5.4 ft. NGVD29 + 6 ft. SLR):** This layer can be used to visualize what the 2100 intermediate-high (11.45 ft. NGVD29) scenario would inundate.
- **7 ft. above MHHW = 12.4 ft. NGVD29 (5.4 ft. NGVD29 + 7 ft. SLR):** N/A – this scenario is not within 0.5 ft. of any of the recommended daily inundation scenarios.
- **8 ft. above MHHW = 13.4 ft. NGVD29 (5.4 ft. NGVD29 + 8 ft. SLR):** N/A– this scenario is not within 0.5 ft. of any of the recommended daily inundation scenarios.
- **9 ft. above MHHW = 14.4 ft. NGVD29 (5.4 ft. NGVD29 + 9 ft. SLR):** This layer can be used to visualize what the 2100 high (14.17 ft. NGVD29) scenario would inundate. This layer is 0.23 ft. higher than the 2100 high scenario.
- **10 ft. above MHHW = 15.4 ft. NGVD29 (5.4 ft. NGVD29 + 10 ft. SLR):** N/A– this scenario is not within 0.5 ft. of any of the recommended daily inundation scenarios.
- **11.2 ft. above MHHW = 16.6 ft. NGVD29 (5.4 ft. NGVD20 + 11.2 ft. SLR):** this scenario was developed recently by Climate Central to represent the extreme sea level rise scenario provided in Sweet et al., (2017). It corresponds to the 83rd percentile of the GMSL rise projections provided by Sweet et al., (2017) and is thus slightly higher than the recommendations provided here, which correspond to the mean. This layer can be used to visualize what the 2100 extreme (16.24 ft. NGVD29) scenario would inundate. This layer is 0.36 ft. higher than the 2100 extreme scenario.

An example map of inundation for 3 ft. of sea level rise is shown in **Figure 5-2**; this sea level rise projection corresponds to the 2050 high scenario of 8.4 ft. NGVD29 and is approximately 0.5 ft. lower than the 2050 extreme scenario of 8.83 ft. NGVD29. The map shows permanent inundation along the coastline as well as some areas of inundated land that are isolated from the coast but could be susceptible to flooding via the drainage system.

Figure 5-2: Example of the Surging Sea's Web Viewer



Note: Figure 5-2 is showing 3 ft. of sea level rise on a base water level of MHHW (8.4 ft. NGVD29), which is equivalent to the 2050 high scenario and about 0.5 ft. lower than the 2050 extreme scenario. Blue overlay indicates inundated land. Green overlay indicates inundated land that is isolated from the coast.

NOAA Sea Level Rise Viewer

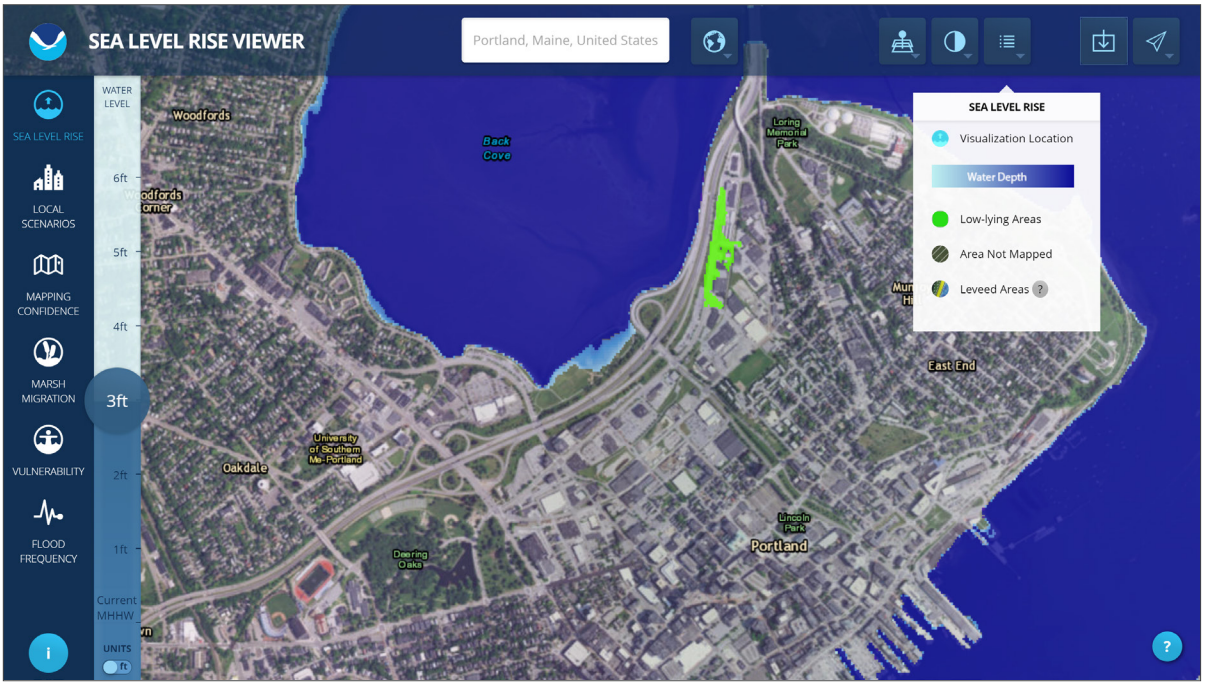
The NOAA Sea Level Rise web viewer is a comprehensive national data viewer that allows the public to view the inland extent of sea level rise on top of the base water level of the local MHHW. Sea level rise scenarios varying from 0 to 6 ft. are provided. These data layers are also available to download in GIS format. In Portland, assuming a local MHHW of 5.38 ft. NGVD29, these values are equivalent to the following:

- **0 ft. above MHHW = 5.4 ft. NGVD29 (5.4 ft. NGVD29 + 0 ft. SLR):** N/A – this scenario is not within 0.5 ft. of any of the recommended daily inundation scenarios.
- **1 ft. above MHHW = 6.4 ft. NGVD29 (5.4 ft. NGVD29 + 1 ft. SLR):** This layer can be used to visualize what the 2050 intermediate scenario (6.93 ft. NGVD29) would inundate. This layer is 0.54 ft. lower than the 2050 intermediate scenario.
- **2 ft. above MHHW = 7.4 ft. NGVD29 (5.4 ft. NGVD29 + 2 ft. SLR):** This layer can be used to visualize what the 2050 intermediate-high (7.61 ft. NGVD29) scenario would inundate. This layer is 0.21 ft. lower than the 2050 intermediate-high scenario.
- **3 ft. above MHHW = 8.4 ft. NGVD29 (5.4 ft. NGVD29 + 3 ft. SLR):** This layer can be used to visualize what the 2050 high (8.4 ft. NGVD29) and 2050 extreme (8.83 ft. NGVD29) scenarios would inundate. This layer is equivalent to the 2050 high scenario and 0.43 ft. lower than the 2050 extreme scenario.
- **4 ft. above MHHW = 9.4 ft. NGVD29 (5.4 ft. NGVD29 + 4 ft. SLR):** This layer can be used to visualize what the 2100 intermediate (9.3 ft. NGVD29) scenario would inundate. This layer is 0.1 ft. higher than the 2100 intermediate scenario.
- **5 ft. above MHHW = 10.4 ft. NGVD29 (5.4 ft. NGVD29 + 5 ft. SLR):** N/A– this scenario is not within 0.5 ft. of any of the recommended daily inundation scenarios.

- **6 ft. above MHHW = 11.4 ft. NGVD29 (5.4 ft. NGVD29 + 6 ft. SLR):** This layer can be used to visualize what the 2100 intermediate-high (11.45 ft. NGVD29) scenario would inundate. This layer is 0.05 ft. lower than the 2100 intermediate-high scenario.

An example map of inundation for 3 ft. of sea level rise is shown in **Figure 5-3**; this sea level rise projection corresponds to the 2050 high scenario of 8.4 ft. NGVD29 and is approximately 0.5 ft. lower than the 2050 extreme scenario of 8.83 ft. NGVD29. The map shows show permanent inundation along the coastline as well as some areas of inundated land that are isolated from the coast but could be susceptible to flooding via the drainage system. The NOAA inundation map shows slightly less inundation than the corresponding Climate Central Surging Seas Map shown in **Figure 5-2**.

Figure 5-3: Example of the NOAA Sea Level Rise Viewer



Note: Figure 5-3 is showing 3 ft. of sea level rise on a base water level of MHHW (8.4 ft. NGVD29), which is equivalent to the 2050 high scenario and about 0.5 ft. lower than the 2050 extreme scenario. Blue overlay indicates inundated land. Green overlay indicates inundated land that is isolated from the coast

Maine Geological Survey – Sea Level Rise/Storm Surge Web Viewer

The MGS Sea Level Rise/Storm Surge Viewer allows the public to view the inland extent of sea level rise on top of the base water level of the 2015 Highest Annual Tide, which varies along the coast of Maine and was determined using tide tables for each of the NOAA CO-OPS stations. At the Portland Maine CO-OPS Tide Station (8418150) the highest annual tide occurred on October 28th and reached an elevation of 7.3 ft NGVD 29. Sea level rise scenarios varying from 0 to 6 ft. are provided. These data layers are also available to download in GIS format. In Portland, assuming a local MHHW of 7.3 ft. NGVD29, these values are equivalent to the following:

- **0 ft. above HAT = 7.3 ft. NGVD29 (7.3 ft. NGVD29 + 0 ft. SLR):** This layer can be used to visualize what the 2050 intermediate-high (7.6 ft. NGVD29) scenario would inundate. This layer is 0.3 ft. lower than the 2050 intermediate-high scenario.

- **1 ft. above HAT = 8.3 ft. NGVD29 (7.3 ft. NGVD29 + 1 ft. SLR):** This layer can be used to visualize what the 2050 high (8.4 ft. NGVD29) and extreme (8.83 ft. NGVD29) scenarios would inundate. This layer is 0.1 and 0.5 ft. lower than the 2050 high and extreme scenarios, respectively.

- **3.3 ft. above HAT = 10.6 ft. NGVD29 (7.3 ft. NGVD29 + 3.3 ft. SLR):** N/A– this scenario is not within 0.5 ft. of any of the recommended daily inundation scenarios.
- **6 ft. above HAT = 13.3 ft. NGVD29 (7.3 ft. NGVD29 + 6 ft. SLR):** N/A– this scenario is not within 0.5 ft. of any of the recommended daily inundation scenarios.

An example map of inundation for 1 ft. of sea level rise is shown in **Figure 5-4**; this sea level rise projection corresponds to the 2050 high scenario of 8.4 ft. NGVD29 and is approximately 0.5 ft. lower than the 2050 extreme scenario of 8.83 ft. NGVD29. The map shows permanent inundation along the coastline as well as some areas of inundated land that are isolated from the coast but could be susceptible to flooding via the drainage system. The MGS inundation map shows slightly more inundation than the corresponding NOAA Sea Level Rise Viewer Map shown in **Figure 5-3** and approximately equivalent inundation to the corresponding Climate Central Surging Seas Map shown in **Figure 5-2**.

Figure 5-4: Example of the Maine Geological Survey Sea Level Rise/Storm Surge Scenarios Viewer

Note: Figure 5-4 is showing 1 ft. of sea level rise on a base water level of the 2015 highest annual tide (8.3 ft. NGVD29), which is equivalent to the 2050 high scenario and about 0.5 ft. lower than the 2050 extreme scenario. Blue overlay indicates inundated land.

Sea Level Rise and Casco Bay's Wetlands: A Look at Potential Impacts – Portland Edition

The maps in the 2013 Portland edition of Sea Level Rise and Casco Bay's Wetlands: A Look at Potential Impacts provides inland extents of 1 ft. and 3 ft. of SLR using a starting base water level elevation of 9.63 ft. NGVD29, which is the 100-year stillwater elevation (SWEL) from the 1998 FEMA Flood Insurance Study. This value is approximately the same as the current 100-year water level reported in Section 4.2 above. The scenarios presented in this study are equivalent to the following:

- **1 ft. above 1998 FEMA SWEL = 10.63 ft. NGVD29 (9.63 ft. NGVD29 + 1 ft. SLR):** N/A– this scenario is not within 0.5 ft. of any of the recommended daily inundation scenarios.
- **3 ft. above the 1998 FEMA SWEL = 12.63 ft. NGVD29 (9.63 ft. NGVD29 + 3 ft. SLR):** N/A– this scenario is not within 0.5 ft. of any of the recommended daily inundation scenarios.

Additional Studies

Two additional studies were evaluated but are ultimately not recommended for evaluating the impact of sea level rise scenarios in Bayside. The "Adapting to Sea Level Rise in South Portland" report estimated impacts to infrastructure based for various sea level rise scenarios using base water levels of the 2012 HAT and the FEMA 100-year SWEL (1978 storm elevation). The maps provided are for the greater Portland region and are difficult to interpret at a Bayside-specific level.

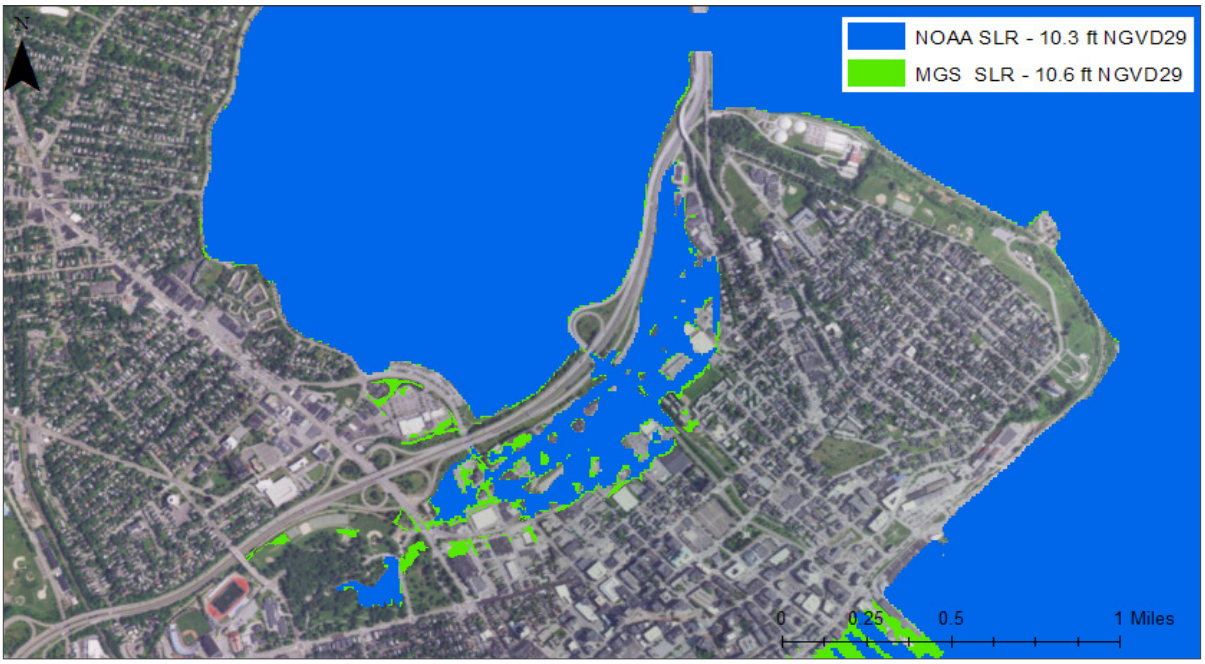
The Natural Resource Council of Maine also provides inundation maps for Portland for sea level rise scenarios of 3.3 ft. and 19.7 ft. These maps are more than 10 years old and the base flood elevation is unknown so they cannot be used to estimate sea level rise impacts in the Bayside neighborhood.

5.2.2 Sea Level Rise Data Gaps

The resources described in **Section 5.2.1** provide insight into potential inundation due to sea level rise for the scenarios recommended in **Section 4.1**. Climate Central's Surging Seas Viewer has inundation maps for water level scenarios within 0.5 ft. of each of sea level rise scenarios recommended by this study. Inundated areas were identified through a GIS analysis of elevation data at 5-meter resolution. The data is available for download as KML, however the KML lacks the necessary geographic reference information for converting to shapefile and use in further spatial analysis. NOAA's Sea Level Rise viewer provides inundation maps for all scenarios recommended by this study except for the 2100 high and extreme scenarios. These maps appear to indicate slightly smaller inundation areas than Climate Central for most scenarios, particularly for areas of inundation isolated from the coast. As with the Climate Central viewer, inundated areas were identified through a GIS analysis of elevation data at 5-meter resolution. The data is available for download and as web-based map services. The MGS Sea Level Rise and Storm Surge Scenario Viewer provides inundation maps representative of the 2050 intermediate-high, high, and extreme scenarios and the 2100 high scenario. As with the Climate Central and NOAA viewers, inundated areas were identified through a GIS analysis of LiDAR data, though the resolution is not reported. Of the three studies the NOAA viewer is the only one that provides an indication of depth.

Figure 5-5 shows a comparison of similar water levels from the NOAA Sea Level Rise Viewer and the MGS Sea Level Rise/Storm Surge Viewer. Corresponding data was not available from Surging Sea's Risk Zone Map Viewer at the time of this study. The MGS results, which represent a slightly higher water level than the NOAA results, indicate more inland flooding for this scenario. Isolated low-lying areas have not been removed since it is already well known that some of these locations may become hydraulically connected to the coast under certain tidal conditions.

Figure 5-5: Comparison of Inundation Extent Layers from NOAA SLR Viewer and the MGS SLR/Storm Surge Viewer



While all three studies are useful in predicting the extent of potential inundation, they are all simple GIS analyses of elevation data and none account for the local drainage features around the Bayside neighborhood. As it is well known that 'sunny-day' inland flooding (isolated from the coast) is already occurring in Bayside, it is important to account for underground pathways that contribute to inland flooding. As discussed in **Section 2.2** of this Report, there are seven drainage/combined sewer conduits in the Bayside area. All seven are at least partially unprotected by tide gates. As sea level rise continues to exacerbate tidal flooding it is critical to determine the elevation of each discharge pipe and understand how water can backflow through the system and flood inland areas.

5.3 Storm Surge

5.3.1 Storm Surge Impacts

The storm surge scenarios in **Section 4.2** provide water level elevations for various return period storms, extracted from the NACCS database, under various sea level rise scenarios at two points in the Portland region. A summary of the ranges of potential storm surge water levels for various return periods at the entrance to Back Cove (NACCS Station 7221) for 2050 and 2100 is provided in **Table 5-4**. The ranges represent how storm surge would change under the intermediate through extreme sea level rise scenarios in 2050 and 2100.

Table 5-4: Range of Potential Extreme Water Levels at the Entrance to Back Cove for 2050 and 2100

NACCS Station	Water Level Return Period	NACCS Storm Surge Water Level (ft. NGVD29)	Potential Storm Surge Water Levels 2050 (ft. NGVD29)	Potential Storm Surge Water Levels 2100 (ft. NGVD29)
7221 Back Cove	10-yr	8.44	9.97 - 11.88	12.34 - 19.29
	20-yr	9.13	10.66 - 12.57	13.03 - 19.98
	100-yr	11.13	12.67 - 14.57	15.03 - 21.98
	500-yr	11.85	14.08 - 15.29	15.75 - 22.70

Mapping storm surge inundation is more complex than mapping sea level rise inundation because storm surge elevations for a single event vary along the coast due to local dynamics and geomorphology. Typical GIS analyses of elevation data use static water level elevations and do not account for this spatial variation. While **Table 5-5** provides a summary of the existing mapping resources that correspond to the NACCS Station 7221 storm surge water level predictions, these maps should be used with caution as they do not account for the spatial variability of storm surge. Using them to predict potential inundation also assumes that sea level rise can simply added to storm surge elevations, which may not be the case in the Portland region, as discussed in **Section 4.2**.

To illustrate the impact of the spatial variability of storm surge elevations around Portland, **Figure 5-6** and **Figure 5-7** were generated for this study using a custom python script developed by RPS to interpolate water level elevations between the NACCS output points, providing a continuous and spatially varying water level surface. The continuous water level surface was then used with the 2015 LiDAR data to show areas of potential inundation. These figures show the predicted extent of inundation for the 100-year event in 2050 for the intermediate and extreme sea level rise scenarios and 2100 for the intermediate and high sea level rise scenarios. While this approach to mapping storm surge helps to account for spatial variability, it still assumes that sea level rise can be added linearly to storm surge elevations. Even under the most extreme of these scenarios, it still appears that most of the inundation in Bayside is coming from Back Cove indicating that mitigation of this inundation can be carried out on a fairly local scale.

Figure 5-6: Inundation from the NACCS Mean 100-year Storm Surge Water Level for the 2050 Intermediate (top) and Extreme (bottom) Scenarios

Figure 5-7: Inundation from the NACCS Mean 100-year Storm Surge Water Level for the 2100 Intermediate (top) and High (bottom) Scenarios

Table 5-5: Summary of Storm Surge Water Levels for Various Return Periods and Sea Level Rise Scenarios and the Existing Map Resources that Correspond Most Closely

Existing Data Sources				
Storm Surge Scenario	Time-Frame	SLR Scenario	Water Level (ft. NGVD29)	Refer to Corresponding Map
10-year	2050	Intermediate	9.97	Climate Central - 4 ft. NOAA SLR Viewer - 4 ft.
10-year	2050	Intermediate-High	10.66	Climate Central - 5 ft. NOAA SLR Viewer - 5 ft. MGS – 3.3 ft.
10-year	2050	High	11.45	Climate Central - 6 ft. NOAA SLR Viewer - 6 ft.
10-year	2050	Extreme	11.88	Climate Central - 6 ft. NOAA SLR Viewer - 6 ft.
10-year	2100	Intermediate	12.34	Climate Central - 7 ft.
10-year	2100	Intermediate-High	14.50	Climate Central - 9 ft.
10-year	2100	High	17.22	N/A
10-year	2100	Extreme	19.29	N/A
20-year	2050	Intermediate	10.66	Climate Central - 5 ft. NOAA SLR Viewer - 5 ft. MGS – 3.3 ft.
20-year	2050	Intermediate-High	11.35	Climate Central - 6 ft. NOAA SLR Viewer - 6 ft.
20-year	2050	High	12.14	Climate Central - 7 ft.
20-year	2050	Extreme	12.57	Climate Central - 7 ft.
20-year	2100	Intermediate	13.03	Climate Central - 8 ft. MGS - 6 ft.
20-year	2100	Intermediate-High	15.19	Climate Central - 10 ft.
20-year	2100	High	17.91	N/A
20-year	2100	Extreme	19.98	N/A
100-year	2050	Intermediate	12.67	Climate Central - 7 ft.
100-year	2050	Intermediate-High	13.35	Climate Central - 8 ft. MGS - 6 ft.
100-year	2050	High	14.14	Climate Central - 9 ft.
100-year	2050	Extreme	14.57	Climate Central - 9 ft.
100-year	2100	Intermediate	15.03	Climate Central - 10 ft.
100-year	2100	Intermediate-High	17.19	N/A
100-year	2100	High	19.91	N/A
100-year	2100	Extreme	21.98	N/A
500-year	2050	Intermediate	13.39	Climate Central - 8 ft. MGS - 6 ft.
500-year	2050	Intermediate-High	14.08	Climate Central - 9 ft.
500-year	2050	High	14.86	Climate Central - 9 ft.
500-year	2050	Extreme	15.29	Climate Central - 10 ft.
500-year	2100	Intermediate	15.75	Climate Central - 10 ft.
500-year	2100	Intermediate-High	17.91	N/A
500-year	2100	High	20.64	N/A
500-year	2100	Extreme	22.70	N/A

5.3.2 Storm Surge Data Gaps

Historic high water marks from the Blizzard of 1978 (representative of a 100-year storm) show that there was little spatial variability in storm surge water elevations throughout the City of Portland. However, the water levels extracted from the NACCS database, see **Section 4.2**, show spatial variation of nearly 2 ft. between Back Cove and the opposite side of the Portland Peninsula. This uncertainty of spatial variability in Portland is an important data gap that should be investigated.

As discussed in **Section 4.2**, the storm surge predictions for 2050 and 2100 are simple linear additions of the predicted mean sea level scenarios for those periods and the NACCS storm surge elevations. For the Portland region, the validity of this assumption should be further investigated. Two potential sources of information include the NACCS study results and published SLOSH model results for the Penobscot Bay Basin, which covers the Portland Region.

The NACCS study included a set of scenarios that modeled a static water level adjustment of 1.0 m to simulate a potential future GMSL rise scenario. While this adjustment for sea level rise doesn't cover the range of scenarios recommended in **Section 4.1**, a review of these NACCS results would indicate whether the storm surge water levels increase linearly when using a higher base water level elevation. For example, if the NACCS storm surge values at the entrance to Back Cove are approximately 1.0 m higher for the sea level rise scenarios than the base scenarios the assumption that sea level rise can be added to storm surge elevations to predict future extreme water levels for Bayside is correct. If not, further analysis is needed to determine how sea level rise will impact future storm surge elevations in the region. This analysis would require numerical modeling of storm surge in the region using base water level elevations that include sea level rise. Unfortunately, the set of NACCS results that includes sea level rise is not currently available for public use and thus represent a data gap. NOAA SLOSH model results with varying base water level are available for the Portland region. The NOAA SLOSH MOMs (Maximum of Maximum Envelope of Water) are provided for two base water level elevations, mean tide and high tide, and four hurricane categories, 1 through 4. The high tide simulations simply add five feet to the mean tide elevation and can be used as a simple proxy for sea level rise. The SLOSH results at the entrance to Back Cove, summarized in **Table 5-6**, indicate variations of between 2.6 and 5.2 ft. for the mean vs high scenarios. These results indicate that for the lower surge elevations, the assumption that that sea level rise can be added to storm surge is reasonable, but for higher surge elevation, non-linear effects appear to decrease the impact of a higher base water level. It should be noted that SLOSH is run on a much coarser resolution grid (approximately 1.5 nautical miles in the Portland region) than the NACCS model. Also, the data examined only accounts for storm surge resulting from hypothetical hurricanes, where as the top 10 water levels recorded at the Portland Tide Gage (8418150) occur during the months of November through April (NOAA, 2017c) and are likely the result of extra-tropical events.

Table 5-6: SLOSH Model Results for the Penobscot Bay v2 Basin, cell 96, 6 (entrance to Back Cove)

SLOSH Scenario	Surge at Mean Tide (ft. NGVD29)	Surge at High Tide (+ 5 ft.) (ft. NGVD29)	Difference (ft.)
Category 1	7.0	12.2	5.2
Category 2	12.8	17.9	5.1
Category 3	19.0	22.9	3.9
Category 4	24.3	26.9	2.6

Note: Table 5-6 shows the difference between base water levels representing mean and high tide.

Though the SLOSH model results indicate that linear addition of sea level rise to storm surge may not be a valid assumption, because SLOSH does not account for typical (extra-tropical) storm surges in the region, and because the model is low resolution we recommend verifying the validity of this assumption with the NACCS study sea level rise scenarios when they become publicly available. Alternatives to waiting for additional NACCS results to become available include obtaining the detailed storm surge modeling results from the 2016 Casco Bay Region Climate Change Resiliency Assessment, which modeled storm surge under three different sea level rise scenarios. There is also an ongoing study of regional resiliency in the Northeast, spearheaded by the Northeast Regional Association Coastal Ocean Observing System and in collaboration with researchers from the University of Maine, that includes numerical modeling of storm surge for Maine. The results of this study are not publicly available yet.

5.4 Precipitation

5.4.1 Precipitation Impacts

The impacts due to precipitation will vary due to the characteristics of the precipitation event. The main impact of precipitation is the potential for flooding. The flooding could occur anywhere though would be most predominant in the lower lying regions, particularly those adjacent to stormwater collection basins. Depending on the precipitation event, another possible impact is Combined Sewer Overflows. These impacts are present today and are predicted to occur more frequently and with a greater magnitude (e.g., larger area with flood depths >0.5 ft. or more CSOs triggered).

While precipitation alone can cause problems, it is likely that combined events of storm surge will be accompanied by relatively large precipitation totals. Similarly, as sea level rises the coincidence of precipitation events with high waters will increase. When these events occur, the drainage system is compromised and increased upland flooding can be expected. A recent study performed by Argonne National Laboratory (Yan et al., 2016) evaluated combined events with a 2D hydrodynamic model in the Back-Cove Area in Portland. The study was focused on identifying differences in the spatially and temporally varied precipitation distributions between radar based sources and rain gauge sources and to evaluate their impact on urban flooding. The study simulated two historic events, April 16, 2007 and September 30, 2015 with Flo-2D. The model application included a depiction of topography, ground cover (roughness), buildings, streets, the stormwater system (piping, inlets, outlets, storage, pumps), hydraulic structures, streamflow and precipitation, for which as mentioned two versions of precipitation were simulated for each event (radar and gauge), and variable coastal water surface elevation based on observations at the NOAA Buoy. **Table 5-7** summarizes the precipitation total and high water as stated in the Argonne report; note that the high water was not referenced to a vertical datum. The model outputs included total precipitation volume in the study area as measured by acre-ft, delineation of inundated areas and the depth of flood flow as well as flooding velocity. The flow depth and velocity were also used to determine the hazard level as either low, medium or high. **Figure 5-8** through **Figure 5-11** present maps of flow depth and flow hazard for the two events (using results from driven by radar based precipitation) respectively. What can be seen when comparing the two predictions is that the footprint of inundation is larger for the September 30th event, which is likely due to the precipitation in the presence of a compromised drainage system. As a point of reference, the September 30th event is close to the present design storm (25-yr 24-hr present P total =6.19 in.) precipitation total, though not quite as large and the April 16th event is more like a precipitation total of a 2-yr recurrence interval (2-yr 24-hr present P total =3.23 in.). The recurrence interval of the associated surge was not provided in the study, and the omission of the vertical datum provides uncertainty. For both simulations, a larger inundation area and greater inundation depth would be expected if the precipitation was increased or possibly if the surge was increased; alternatively, a smaller inundation footprint and depth would be expected if the precipitation decreased or the surge decreased; additional model simulations would be needed to quantify such trends.

Table 5-7: Precipitation Total and High Water from Argonne Simulations.

	Precipitation in.	High Water* ft.
April 16, 2007	3.36	13.3
September 30, 2015	5.56	8.3

**source report did not reference vertical datum*

Figure 5-8: Map of Flood Flow Depth from Radar Precipitation Driven Flo-2D Simulation of April 16, 2007 Event (Figure 5.7 from Yan et al. 2016)

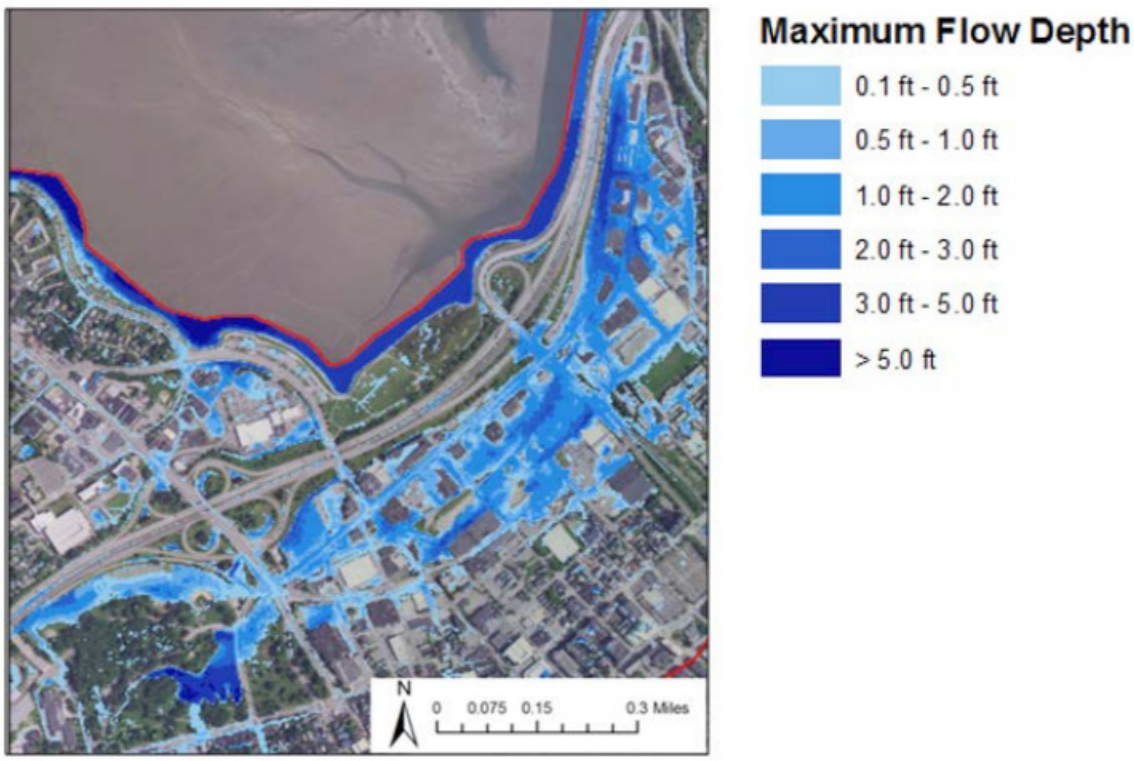


Figure 5-9: Map of Flood Flow Depth from Radar Precipitation Driven Flo-2D Simulation of September 30, 2015 Event (Figure 5.8 from Yan et al. 2016)

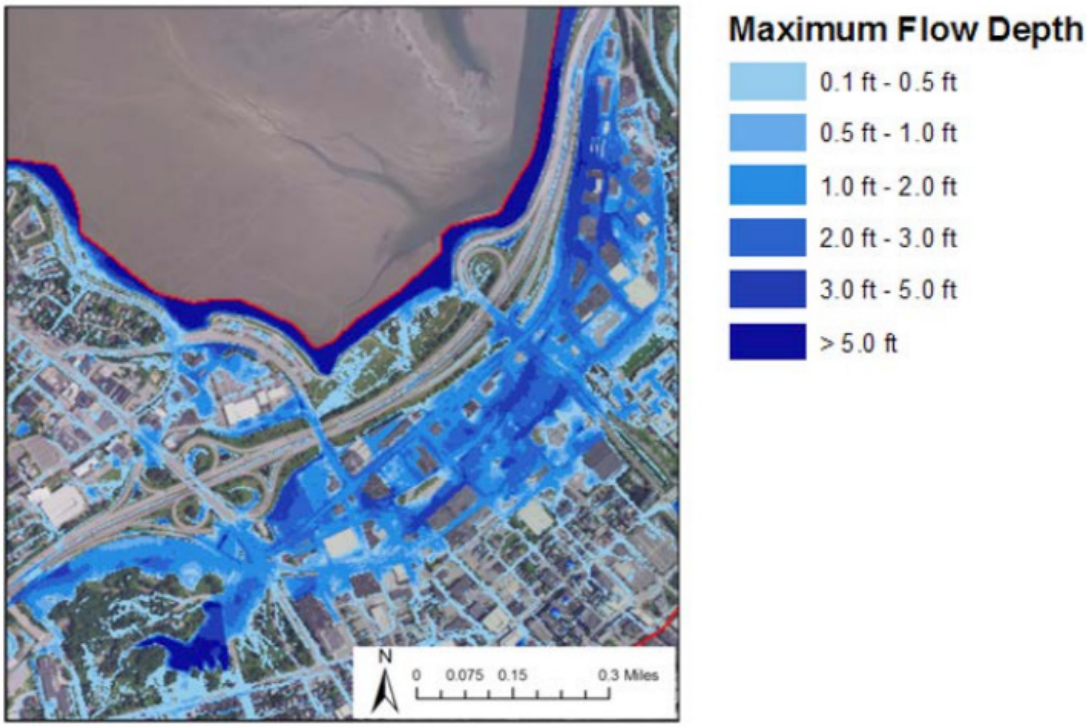


Figure 5-10: Map of Flood Hazard from Radar Precipitation Driven Flo-2D Simulation of April 16, 2007 Event (Figure 5.7 from Yan et al. 2016)

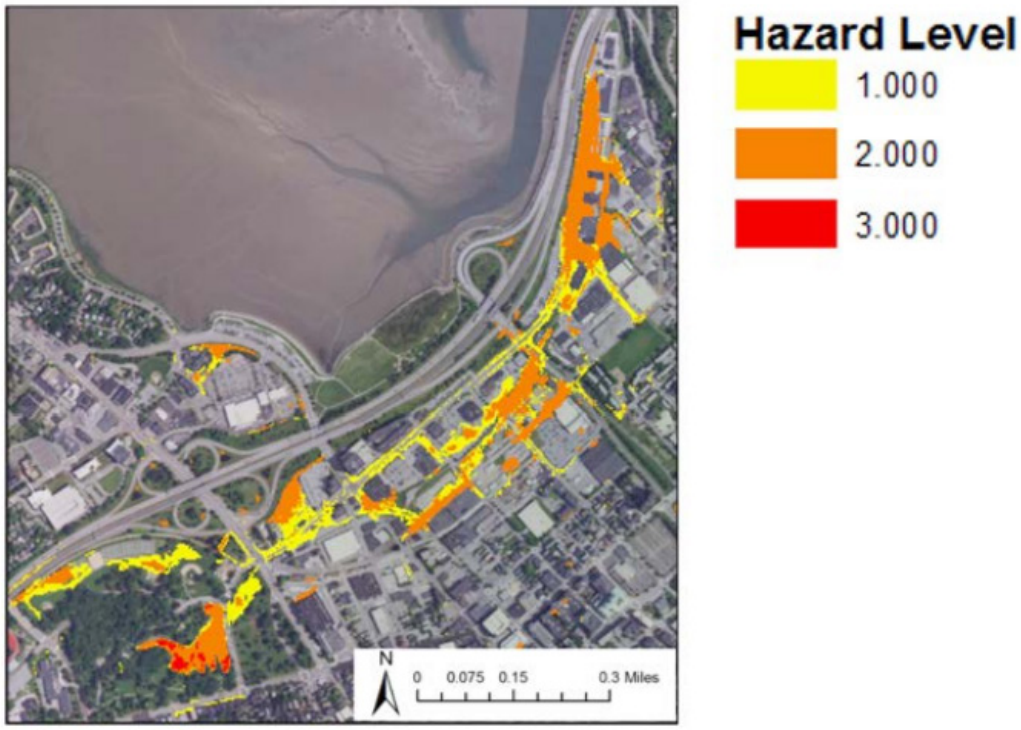
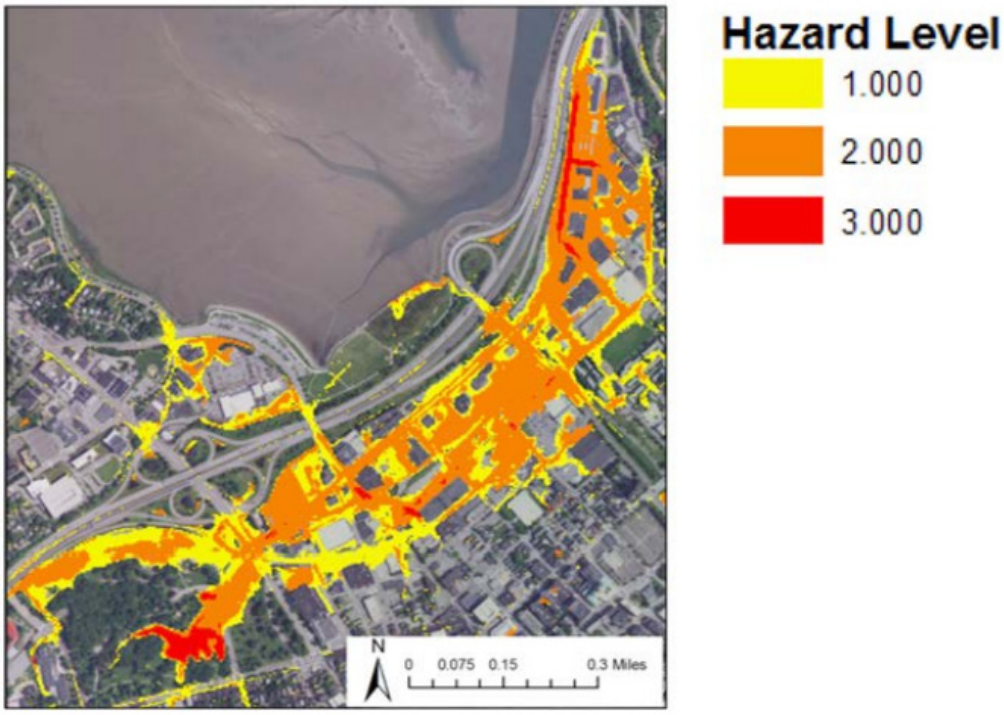


Figure 5-11: Map of Flood Hazard from Radar Precipitation Driven Flo-2D Simulation of September 30, 2015 event (Figure 5.7 from Yan et al. 2016)



5.4.2 Precipitation Data Gaps

The City is interested in understanding any data gaps relative to precipitation. Based on the literature there are means to estimate the future recurrence intervals and distributions to produce future design storm conditions. In that sense, such data is not a data gap, however it is recommended that the literature and numbers be updated continuously.

It is not understood if precipitation events alone are presently causing flooding problems, meaning precipitation events that do not coincide with high tides/submerged outfalls that may diminish the conveyance capacity. Therefore, the precipitation based flooding triggers are considered a data gap. Ideally a model or analysis of different design storms that mapped associated flood depths and identified components of the conveyance system that were at capacity would provide the type of information needed for planning.

Lastly it is understood that flooding can occur when there are storm surges or high tides. It is known that this flooding is exacerbated when it coincides with precipitation. The factors that will influence the degree of this problem are related to understanding the behavior of coastal waters relative to the stormwater system, specifically it is suggested that the invert elevation of all outfalls that have the potential to be submerged be obtained and that an inventory of internal tide gates be performed. Also, it would be useful to have a model or analysis of different design storms with variations of high tide and storm surge to produce maps of associated flood depths and to evaluate potential mitigation measures.

Section 6
Recommendations

1 Compile and Extract Existing Data for Integration into City GIS

The City's multi-year, multi-million dollar investments into maintaining their sewer systems and abating CSOs has generated a significant amount of high accuracy data, which will be used to populate their GIS and help inform future modeling and adaptation planning exercises in Bayside. This recommendation will integrate existing data into the City's GIS database as the sole repository for infrastructure needed for Bayside Adaptation planning.

Specific tasks include:

- Confirmation of key infrastructure attributes that must be obtained for future use in Bayside modeling and adaptation planning and confirmation that the City's ESRI Local Government Information Model will accommodate selected model data input. It is recommended that this task include working meetings between technical engineering and modeling consultants, City GIS and Public Works staff, Maine DOT and Portland Water District (Project Team). The Project Team shall develop an approach for data source control and documentation (metadata) for all new data collection. Near-term utility construction or reconstruction projects should be considered during working meetings and those locations avoided for data collection migration.
- Obtain existing utility surveys from City, MaineDOT and PWD (as necessary). Extract data and migrate into GIS.
- Obtain existing survey data (10k LF), extract and migrate into GIS
- Obtain existing structural condition reports, review for adequacy and ensure association of condition defect ratings (both structural and operational) with current GIS assets.
- Extract manhole and catch basin rim elevation from LiDAR and incorporate into GIS.
- Summarize new data availability in GIS and present to Bayside Project Team.

Budget Cost: $50,000

Key Assumptions: City to ensure engagement with Maine DOT and PWD.

Data Gaps Resolved

Infrastructure Data Gaps

- X City's GIS Database Gaps
- X City Infrastructure Data Gaps: Surveys
- X City Infrastructure Data Gaps: Condition Assessments
- ○ City Infrastructure Data Gaps: Condition, Form & Function of Special Structures
- X Maine DOT Infrastructure Gaps

Model Gaps

- ○ Model Components
- ○ Data Sources
- X Data Accuracy
- ○ Model Calibration and Validation
- ○ Model Capabilities

2 Targeted Field Data Collection Program

This recommendation will identify, obtain, and integrate additional infrastructure data necessary for Bayside Adaptation planning and model development. This recommendation also includes an assessment of tide control devices to further inform the City's ongoing efforts to maintain and replace tide control infrastructure.

Specific tasks include:

- Identify additional, targeted data collection needs for the SWMM model updates that have not been resolved during Recommendation 1. This task requires engagement of the modeling consultant to inform final selection of specific stormwater drainage infrastructure to be utilized in the SWMM model.
- Initiate survey and/or condition assessment on segments of stormwater drainage infrastructure that will be utilized in the future SWMM Model and primary drainage conduits under I-295. All pipe and structures should be cleaned prior to initiation of assessment. All infrastructure must be assessed during low tide cycle only.
- Conduct cleaning maintenance on areas to be surveyed/inspected including Special Structures with Tide Gates.
- Survey (3,000 LF) and Clean and TV Inspect (10k - 35k LF)
- Initiate condition assessment on three Special Structures with Tide Gates. This assessment will include structural condition and operational/mechanical functionality assessment with City DPW staff. This task should include visual leak testing during high tide cycle and development of updated schematics of each of the Special Structures.
- Review video logs (from condition assessment) and conduct spot inspection for assessment of unprotected separate stormwater infrastructure for tide control retrofit opportunities. Develop recommendations.
- Incorporate new survey and condition assessment data into GIS.
- Present findings of survey, condition assessment and tide control retrofit opportunities to Bayside Team.

Budget Cost: $135,000

Key Assumptions: City will provide police detail and traffic control for survey and condition assessments, as determined necessary.

Data Gaps Resolved

Infrastructure Data Gaps

- X City's GIS Database Gaps
- X City Infrastructure Data Gaps: Surveys
- X City Infrastructure Data Gaps: Condition Assessments
- X City Infrastructure Data Gaps: Condition, Form & Function of Special Structures
- X Maine DOT Infrastructure Gaps

Model Gaps

- Model Components
- X Data Sources
- Data Accuracy
- Model Calibration and Validation
- Model Capabilities

3 Explore Additional Model Capabilities / Options for Adaptation Planning

Hydrologic/hydraulic models in conjunction with GIS models, are used for the following flood abatement related activities:

- Flood predictions: The model can calculate the depth and area of flooding, including the combined effects of high tides, tidal surges, rainfall and snowmelt. With a fully developed and calibrated model, flood predictions can be made based on a series of likely and worst case scenarios.
- Detailed design. The model can be used to test a variety of design options and predict the level of abatement a design option will potentially result in.
- Operational optimization: A fully developed and calibrated model, along with live flow monitoring data, can be used in "real-time" to provide short term predictions of impending flooding. Also, in areas where flood abatement involves the use of active controls (flood gates, pump stations, etc.), the models can be used to help optimize the implementation of these controls.

This recommendation will consider and identify the appropriate modeling software necessary for Bayside Adaptation planning. The SWMM model is a solid foundation for future flood planning and there are several module additions to SWMM (InfoSWMM, InfoSWMM2D) that will simulate surface flooding. Alternatively, there are other software products being utilized for flood modeling that may also be considered.

Specific tasks include:

- ▶ Project Team to engage Bayside Working Group to identify guiding principles and adaptation strategies of most interest to inform modeling needs.
- ▶ Develop Request for Information from various modeling software providers to provide presentation and overview of how their product could be utilized for future Bayside Adaptation planning and potential costs for procurement and development of the model.
- ▶ Select and procure model software and services of a modeler.

Budget Cost: TBD at later date, upon completion of recommendations #1 and #2

Key Assumptions: Adaptation planning and principles are developed with sufficient definition to inform model selection decisions

Data Gaps Resolved

Infrastructure Data Gaps

- City's GIS Database Gaps
- City Infrastructure Data Gaps: Surveys
- City Infrastructure Data Gaps: Condition Assessments
- City Infrastructure Data Gaps: Condition, Form & Function of Special Structures
- Maine DOT Infrastructure Gaps

Model Gaps

- Model Components
- Data Sources
- Data Accuracy
- Model Calibration and Validation
- X Model Capabilities

4 Update / Calibrate / Validate Model(s)

This recommendation will migrate data into the selected model, identify calibration and validation needs and provide model software training to City staff and Project Team.

Specific tasks include:

- Provide software training to City and consultant team. Update/build model inputs based on data acquired during previous recommendations. Additional hydrologic data inputs such as drainage areas for separate storm sewer additions and the latest land use information will be included in the model.
- Identify areas necessary for calibration and validation. This task should consider calibration efforts previously undertaken by the City during CSO abatement planning. The range of flows assessed during the period of calibration may be useful for flood planning as they may have accommodated design storms and tides of interest.
- Conduct calibration and validation.
- Refine model based on calibration results.

Budget Cost: TBD at later date, upon completion of recommendation #3

Key Assumptions: The City establishes a multi-year relationship with a consultant or hires staff to ensure that there is consistency in building and updating the model throughout the first years of adaptation planning.

Data Gaps Resolved

Infrastructure Data Gaps

- City's GIS Database Gaps
- City Infrastructure Data Gaps: Surveys
- City Infrastructure Data Gaps: Condition Assessments
- City Infrastructure Data Gaps: Condition, Form & Function of Special Structures
- Maine DOT Infrastructure Gaps

Model Gaps

- X Model Components
- X Data Sources
- X Data Accuracy
- X Model Calibration and Validation
- Model Capabilities

Section 7
References & Glossary

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GLOSSARY

C

Combined Sewer: Pipes carrying both sewage and stormwater.

CSO (Combined Sewer Overflow): During large precipitation events, pipes carrying both sewage and stormwater can exceed the capacity of the combined pipe, pump station, or wastewater treatment plant and "overflow" into surface water. During heavy rain events, combined sewer pipes in the Bayside neighborhood overflow into Back Cove.

CSO Abatement: Systematic reduction of combined sewer overflows through separation of drainage from sanitary wastewater, storage of combined sewage, reduction of runoff from drainage collection areas, or increases in combined sewer pipe capacity. The City has a multi-year, multi-million dollar CSO Abatement program that is in the process of reducing combined sewer overflows throughout the City.

I

I&I Maps (Infiltration-Inflow Analysis Maps): The City and Portland Water District have a library of scanned maps developed in the 1970s and 1980s that show the known extent of the sanitary and combined sewer system; these maps were developed to assist with an infiltration and inflow abatement program and are commonly referred to as I&I Maps. These maps were utilized as the base data for the City's sewer GIS data layers.

L

LGIM (Local Government Information Model): The City currently utilizes ESRI's Local Government Information Model for attribute data schema in GIS.

M

MHHW (Mean Higher High Water): The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. There are two high tides in each tidal day; one of them is higher than the other. Higher high water height refers to the height of highest of the two daily high tides.

N

NACCS (North Atlantic Comprehensive Coast Study): A 2015 initiative that evaluated storm surge elevations at numerous study points for various storm event conditions conducted by the U.S. Army Corps of Engineers. For this report, storm surge elevations for various recurrence intervals have been extracted from the NACCS.

National Tidal Datum Epoch: The specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g. mean higher high water, etc.) for tidal datums.

NGVD29 (National Geodetic Vertical Datum of 1929): NGVD29 is the vertical datum of record for the City of Portland, utilized as the base datum for surveys, GIS, and I&I Maps.

S

Separate Stormwater: Unlike Combined Sewer pipe systems that carry both sewage and stormwater, Separate Stormwater pipe systems convey only stormwater.

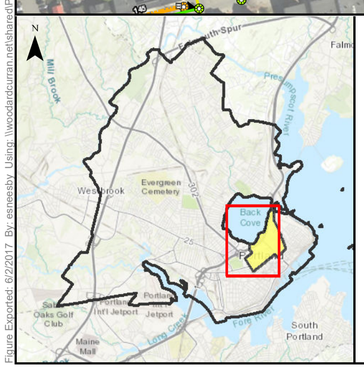
Special Structure: "Special Structure" is the term used in this Report to describe combined sewer infrastructure that contains various flow control devices such as weirs, orifices, tide gates, etc.

Storm Surge: Rise in sea level that occurs due to a storm.

Storm Water Management Model (SWMM): The Environmental Protection Agency's (EPA) stormwater management model, SWMM is a dynamic hydrology-hydraulic water quantity and quality simulation model. It is used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The City of Portland and the Portland Water District use a SWMM model for evaluating compliance with the City's combined sewer overflow abatement program.

SWEL (Stillwater Elevation): The flood elevation not including the effects of waves (wave amplitude and wave setup).

Appendix A
Existing GIS Data



LEGEND

Stormwater System

Discharges to or below Special Structure (Sewer Network Structure or Sewer Diversion Chamber)

- Storm Gravity Main
- Storm Under Drain
- Storm Discharge Points
- Storm Inlets
- Storm Manholes

Sewer System

- Sewage
- Combined Waste Water
- Sewer Pressurized Mains
- Sewer Manholes
- Sewer Network Structure (Other)
- Sewer Diversion Chamber
- Sewer Pump Station
- Sewer Tide Chamber

Stormwater System

- Storm Gravity Mains
- Under Drain
- Storm Virtual Drainlines
- Storm Open Drains
- Storm Inlets
- Storm Discharge Points
- Storm Manholes

Available Sewer & Stormwater Infrastructure GIS Data

City of Portland, ME

FIGURE A-1

Woodard & Curran shall assume no liability for any of the following; 1. Any errors, omissions, or inaccuracies in the information provided regardless of how caused or; 2. Any decision or action taken or not taken by the reader in reliance upon any information or data furnished hereunder. Data Sources:

WOODARD & CURRAN
41 Hutchins Drive
Portland, Maine 04102
800.426.4262 | www.woodardcurran.com
COMMITMENT & INTEGRITY DRIVE RESULTS

SCALE: 1 " = 225 '	PROJECT #: 0230429.00
DATE: JUNE 2017	DRAWN BY: ES

Figure Exported: 6/2/2017 By: esnessby Using: \\woodardcurran.net\shared\Projects\0230429.00 Portland Bayside Adapts Planning Svcs\wip\GIS\Projects\BaysideAdapt Available GIS Data.mxd

Null Analysis of Existing City GIS Attribute Data

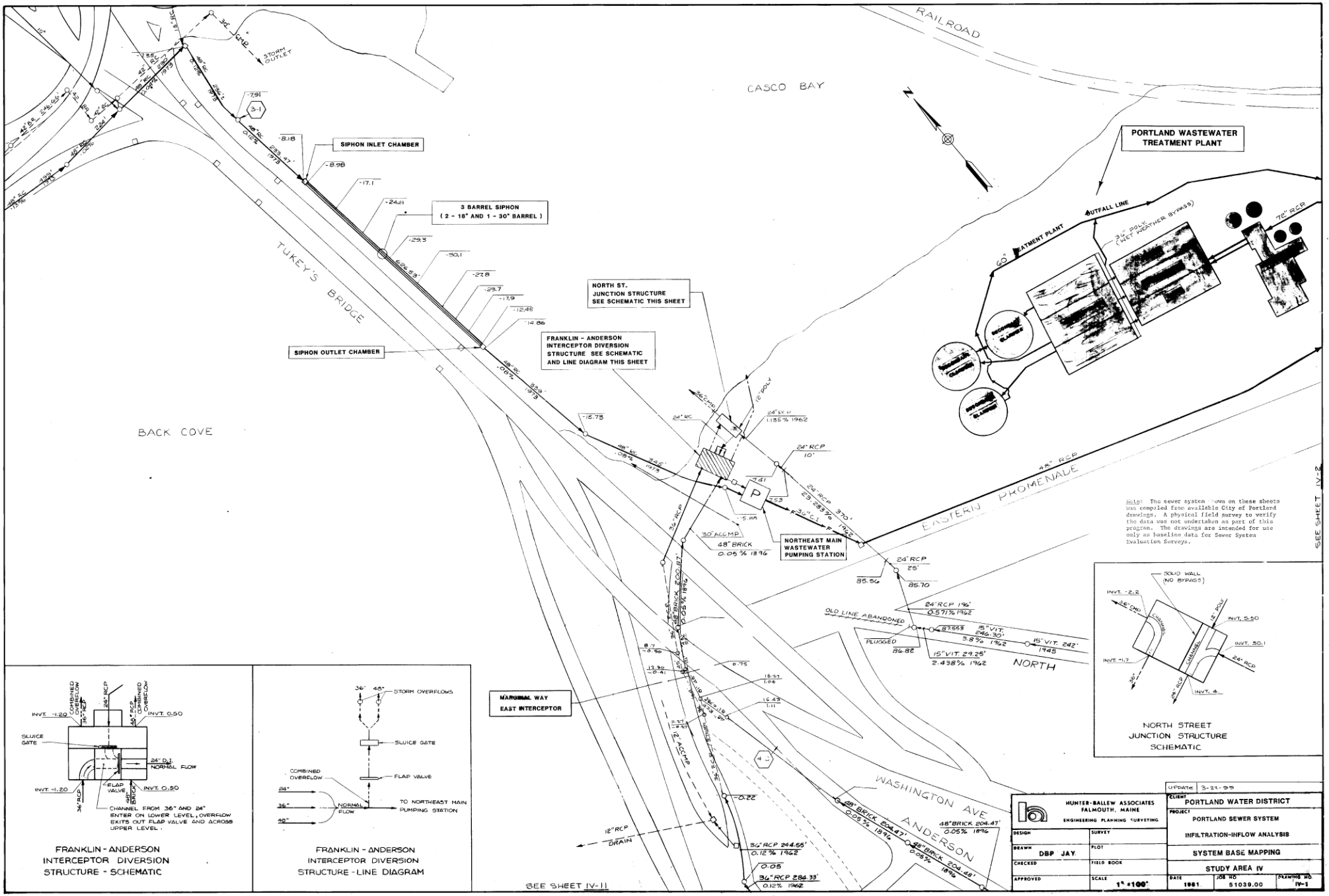
(City's Sewer and Stormwater Infrastructure GIS Database)

Dataset	Selected Features	DIAMETER (Value is Assigned)	% Assigned	MATERIAL (Value is Assigned)	% Assigned	DOWNSTREAM ELEV. (Value is Assigned)	% Assigned	UPSTREAM ELEV. (Value is Assigned)	% Assigned
swGravityMain	550	400	73	321	58	87	16	106	19
swGravityMain (Previous)	*487*	*342*	*70*	*258*	*53*	*Not Analyzed*		*Not Analyzed*	
ssGravityMain (subtype = Sewer)	39	33	85	31	79	0	0	0	0
ssGravityMain (subtype = Sewer)(Previous)	*39*	*33*	*85*	*26*	*67*	*Not Analyzed*		*Not Analyzed*	
ssGravityMain (subtype = Combined)	396	382	96	364	92	18	5	13	3
sGravityMain (subtype = Combined)(Previous)	*380*	*365*	*97*	*326*	*86*	*Not Analyzed*		*Not Analyzed*	
ssGravityMain (subtype = NULL)	12	10	83	10	83	0	0	0	0
ssGravityMain (subtype = NULL)(Previous)	*12*	*7*	*58*	*7*	*58*	*Not Analyzed*		*Not Analyzed*	

Dataset	Selected Features	INVERT ELEVATION (Value is Assigned)	% Assigned	RIM ELEVATION (Value is Assigned)	% Assigned
swManhole	113	0	0	17	15
swManhole (Previous)	*98*	*0*	*0*	*6*	*6*
swInlet	497	260	52	64	13
swInlet (Previous)	*491*	*267*	*54*	*14*	*3*
ssManhole	365	0	0	45	12
ssManhole (Previous)	*346*	*0*	*0*	*45*	*3*

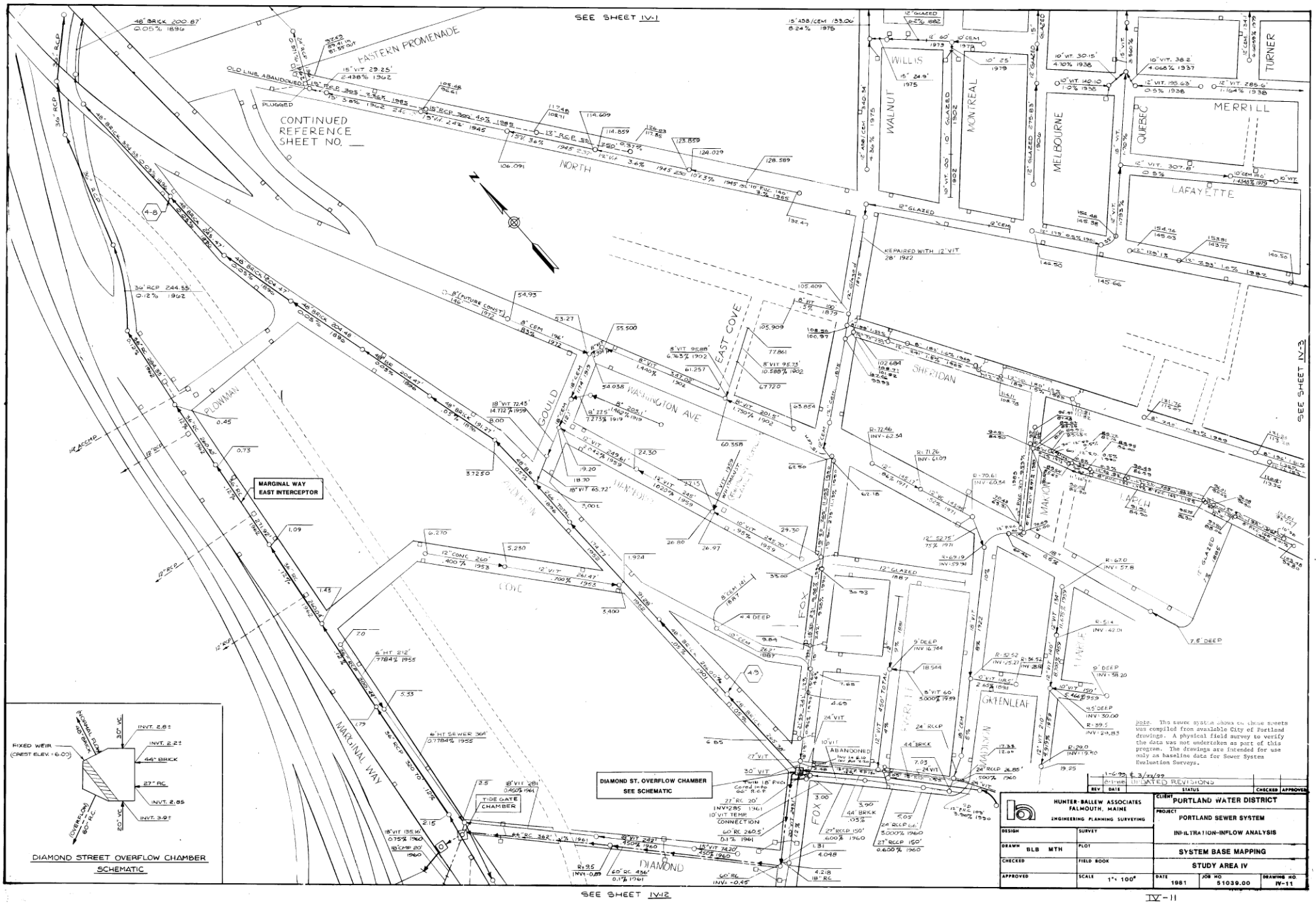
Appendix B

Existing I&I Map and Special Structures Data

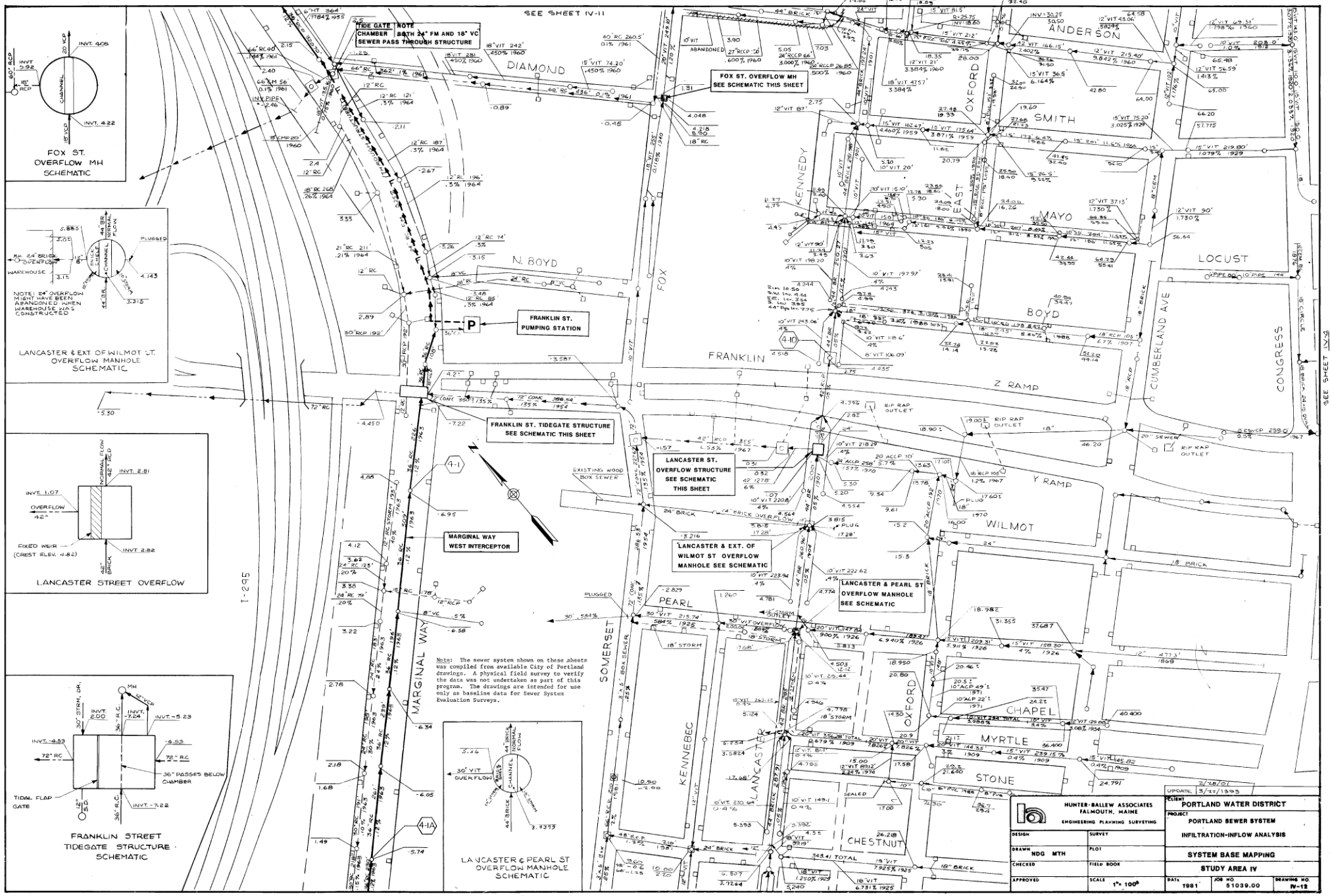


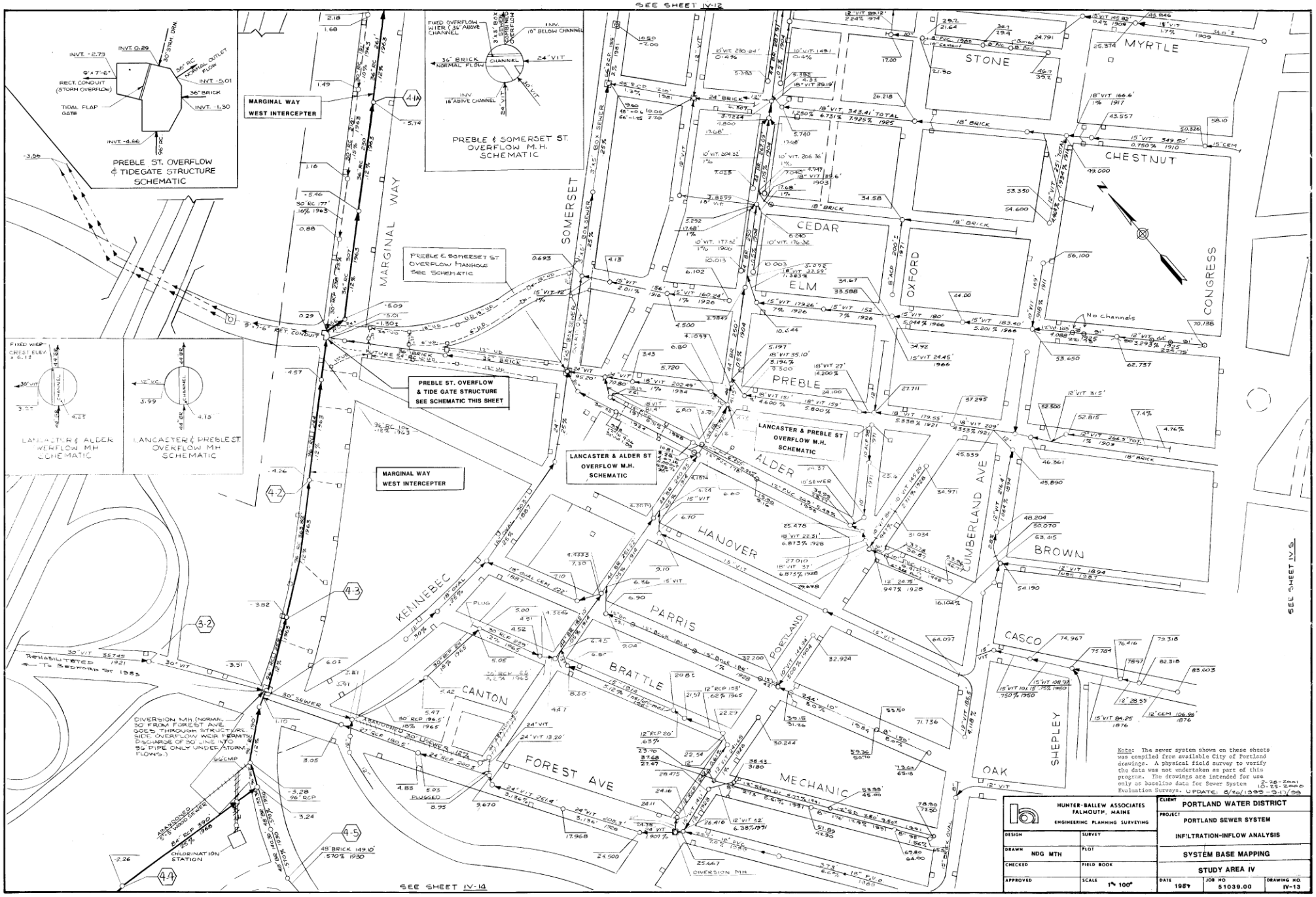
Note: The sewer system shown on these sheets was compiled from available City of Portland drawings. A physical field survey to verify the data was not undertaken as part of this program. The drawings are intended for use only as baseline data for Sewer System Evaluation Surveys.

HUNTER-BALLEW ASSOCIATES FALMOUTH, MAINE ENGINEERING PLANNING SURVEYING		UPDATE 3-21-99	
DESIGN	SURVEY	CLIENT PORTLAND WATER DISTRICT	
DRAWN DBP JAY	PLOT	PROJECT PORTLAND SEWER SYSTEM	
CHECKED	FIELD BOOK	INFILTRATION-INFLOW ANALYSIS	
APPROVED	SCALE 1" = 100'	SYSTEM BASE MAPPING	
		STUDY AREA IV	
		DATE 1981	JOB NO 51039.00	DRAWING NO IV-1


SEE SHEET IV-1
SEE SHEET IV-3
SEE SHEET IV-12
EASTERN PROMENADE
CONTINUED REFERENCE SHEET NO. ___
NORTH
WALNUT
WILLIS
MONTREAL
MELBOURNE
QUEBEC
MERRILL
LAFAYETTE
TURNER
EAST COVE
WASHINGTON AVE
SHERIDAN
PLOWMAN
GOULD
ANDREW
HERMON
COVE
FOX
MARION
MARCH
GREENLEAF
MADISON
MARGINAL WAY
DIAMOND
MARGINAL WAY EAST INTERCEPTOR
DIAMOND ST. OVERFLOW CHAMBER SEE SCHEMATIC
T-DE GATE CHAMBER
FIXED WEIR (CREST ELEV. = 6.0')
DIAMOND STREET OVERFLOW CHAMBER SCHEMATIC
Note. The sewer system shown on these sheets was compiled from available City of Portland drawings. A physical field survey to verify the data was not undertaken as part of this program. The drawings are intended for use only as baseline data for Sewer System Evaluation Surveys.
HUNTER-BALLEW ASSOCIATES
FALMOUTH, MAINE
ENGINEERING PLANNING SURVEYING
CLIENT PORTLAND WATER DISTRICT
PROJECT PORTLAND SEWER SYSTEM
INFILTRATION-INFLOW ANALYSIS
SYSTEM BASE MAPPING
STUDY AREA IV
DRAWN BLB MTH
SCALE 1" = 100'
DATE 1981
JOB NO 51039.00
DRAWING NO IV-11
UPDATED REVISIONS
IV-11

905
1


SEE SHEET IV-11
TIDE GATE CHAMBER NOTE
BOTH 24" FM AND 18" VC SEWER PASS THROUGH STRUCTURE
FOX ST. OVERFLOW MH SEE SCHEMATIC THIS SHEET
FRANKLIN ST. PUMPING STATION
FRANKLIN ST. TIDEGATE STRUCTURE SEE SCHEMATIC THIS SHEET
LANCASTER ST. OVERFLOW STRUCTURE SEE SCHEMATIC THIS SHEET
LANCASTER & EXT. OF WILMOT ST OVERFLOW MANHOLE SEE SCHEMATIC
LANCASTER & PEARL ST OVERFLOW MANHOLE SEE SCHEMATIC
MARGINAL WAY WEST INTERCEPTOR
FOX ST. OVERFLOW MH SCHEMATIC
LANCASTER & EXT. OF WILMOT ST. OVERFLOW MANHOLE SCHEMATIC
NOTE: 24" OVERFLOW MIGHT HAVE BEEN ABANDONED WHEN WAREHOUSE WAS CONSTRUCTED
LANCASTER STREET OVERFLOW
FRANKLIN STREET TIDEGATE STRUCTURE SCHEMATIC
LANCASTER & PEARL ST OVERFLOW MANHOLE SCHEMATIC
Note: The sewer system shown on these sheets was compiled from available City of Portland drawings. A physical field survey to verify the data was not undertaken as part of this program. The drawings are intended for use only as baseline data for Sewer System Evaluation Surveys.
DIAMOND
N. BOYD
FOX
KENNEDY
FRANKLIN
ANDERSON
OXFORD
SMITH
EAST
MAYO
BOYD
LOCUST
CUMBERLAND AVE
CONGRESS
Z RAMP
Y RAMP
WILMOT
PEARL
SOMERSET
KENNEBEC
LANCASTER
CHAPEL
MYRTLE
STONE
CHESTNUT
MARGINAL WAY
I-295
SEE SHEET IV-13
SEE SHEET IV-9
HUNTER-BALLEW ASSOCIATES
FALMOUTH, MAINE
ENGINEERING PLANNING SURVEYING
CLIENT PORTLAND WATER DISTRICT
PROJECT PORTLAND SEWER SYSTEM
INFILTRATION-INFLOW ANALYSIS
SYSTEM BASE MAPPING
STUDY AREA IV
DRAWN NDG MTH
CHECKED
APPROVED
SCALE 1" = 100'
DATE 1981
JOB NO. 51039.00
DRAWING NO. IV-12
UPDATE 3/22/1993



Note: The sewer system shown on these sheets was compiled from available City of Portland drawings. A physical field survey to verify the data was not undertaken as part of this program. The drawings are intended for use only as baseline data for Sewer System Evaluation Surveys. UPDATE: 8/20/1999 - 9/13/99 7-28-2001 10-25-2001

HUNTER-BALLEW ASSOCIATES FALMOUTH, MAINE ENGINEERING PLANNING SURVEYING		CLIENT PORTLAND WATER DISTRICT	
DESIGN	SURVEY	PROJECT PORTLAND SEWER SYSTEM INFILTRATION-INFLOW ANALYSIS	
DRAWN NDG MTH	PLOT	SYSTEM BASE MAPPING	
CHECKED	FIELD BOOK	STUDY AREA IV	
APPROVED	SCALE 1" = 100'	DATE 1987	JOB NO 51039.00	DRAWING NO IV-13

905
1

Summary of Available Data on Special Structure in the Bayside

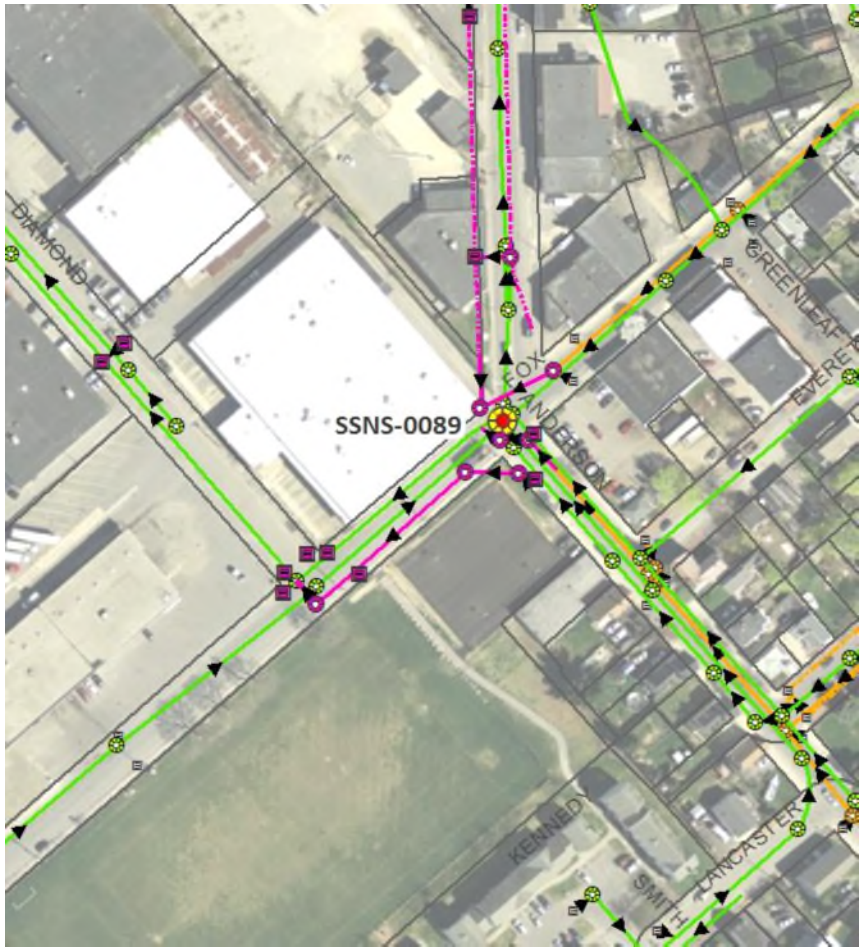
(From City's GIS Database and I&I Maps)

SSNS-0089 Diamond Street

Anderson Street & Fox Street

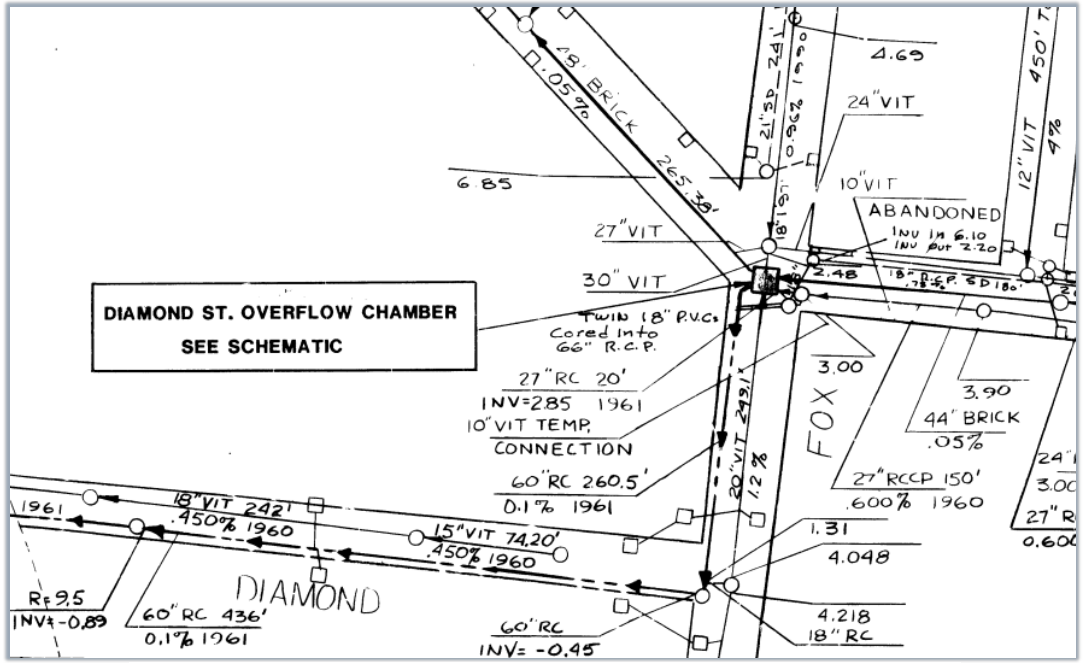
GIS Info	
ID No:	SSNS-0089
Feature Class:	ssNetworkStructure
Structure Type:	Flow Control
Comment:	Diversion Structure; see vault plan 485_023__001
Reference Document	00926_011__002
Install Date	1/1/1961

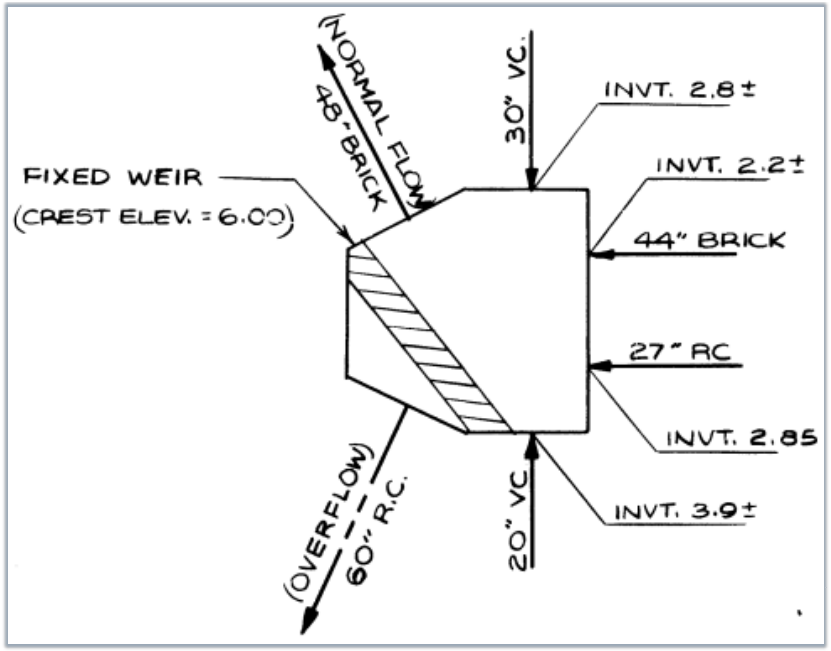
Estimated Rim Elevation: 10.41' NGVD29
(based on LiDAR data)

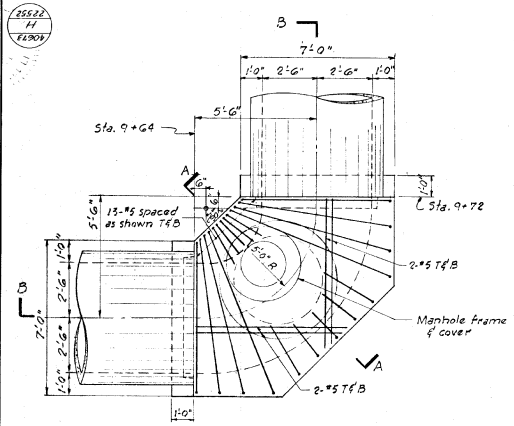


***More info available from Anderson Street project**

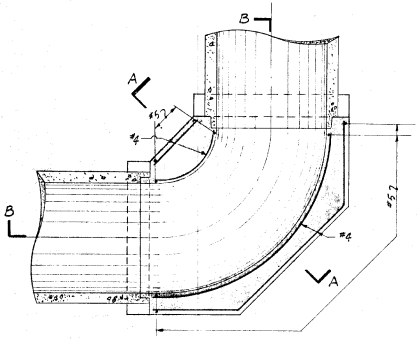
I&I Map Info	
Map No:	IV-11
Structure Type	Overflow Chamber



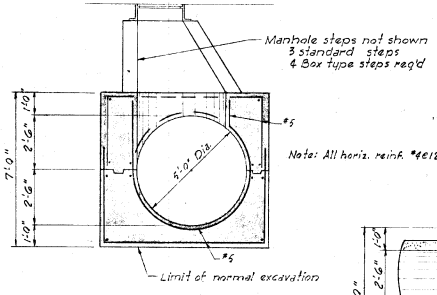




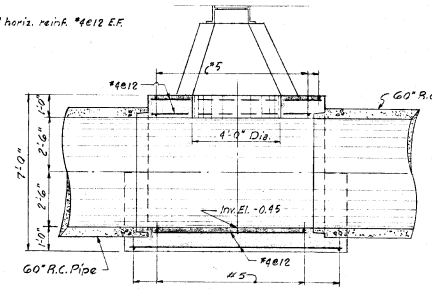
TOP PLAN
M.H AT STA. 9+67



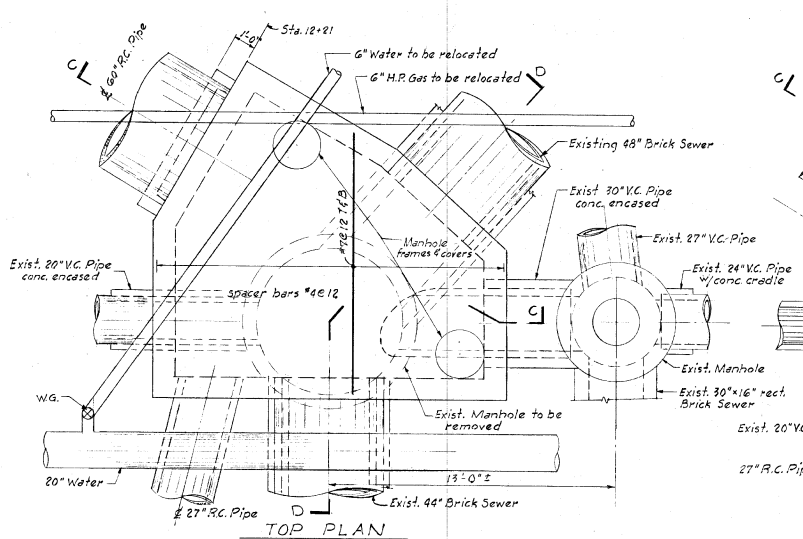
PLAN SECTION
M.H. AT STA. 9+67



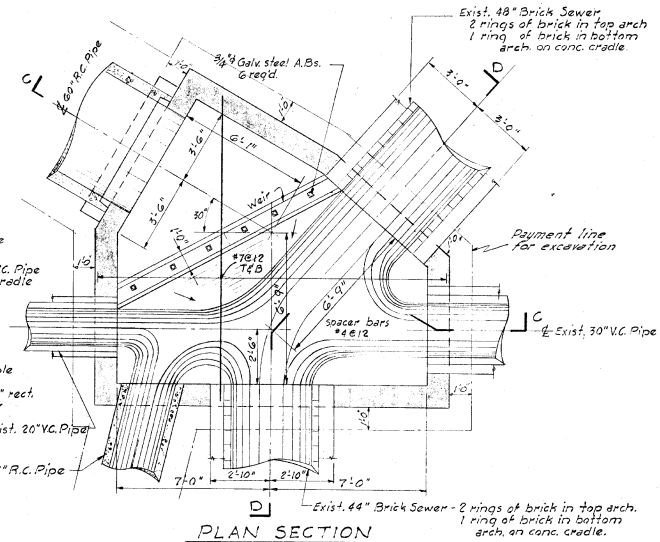
SECTION A-A



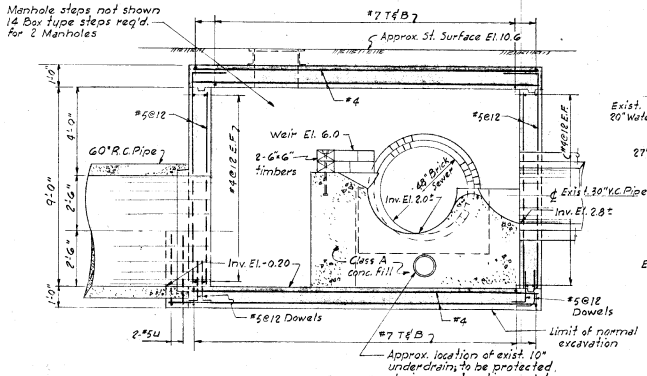
B B



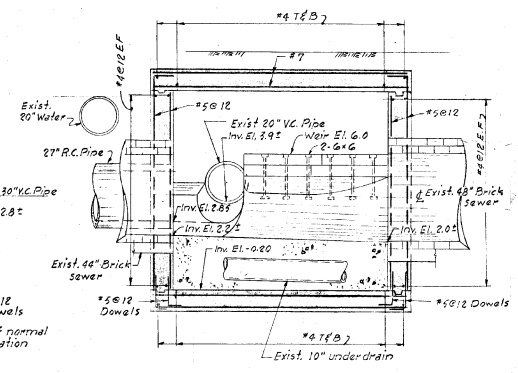
TOP PLAN
OVERFLOW CHAMBER



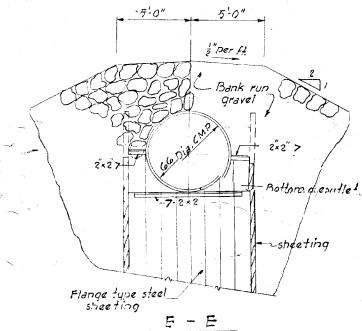
PLAN SECTION
OVERFLOW CHAMBER



C - C

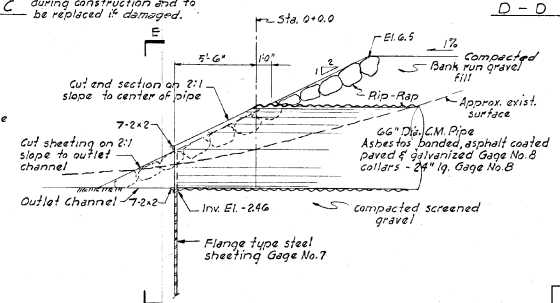


D - D



E - E
Scale: 1/4" = 1'-0"

Note: The contractor shall provide suitable means to connect the 66" pipe to the steel sheeting and the steel sheeting to the timber sheeting.



SECTION AT OUTLET OF 66" C.M. PIPE
Scale: 1/4" = 1'-0"

DRAWN BY A.F. DiV
TRACED BY A.F. DiV
CHECKED BY L.M., J.P.D.

STATE OF MAINE JOHN W. RAYMOND JR. 935 REGISTERED PROFESSIONAL ENGINEER

APPROVED	
FOR METCALF & EDDY, ENGINEERS	
John W. Raymond Jr.	5-31-61
REG. PROF. ENGR. (MAINE NO. 935)	DATE

PORTLAND MAINE
SEWERAGE

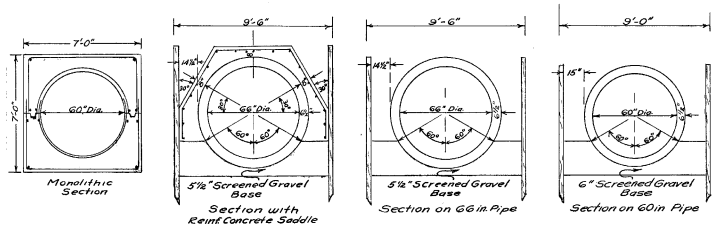
DIAMOND ST. OVERFLOW SEWER

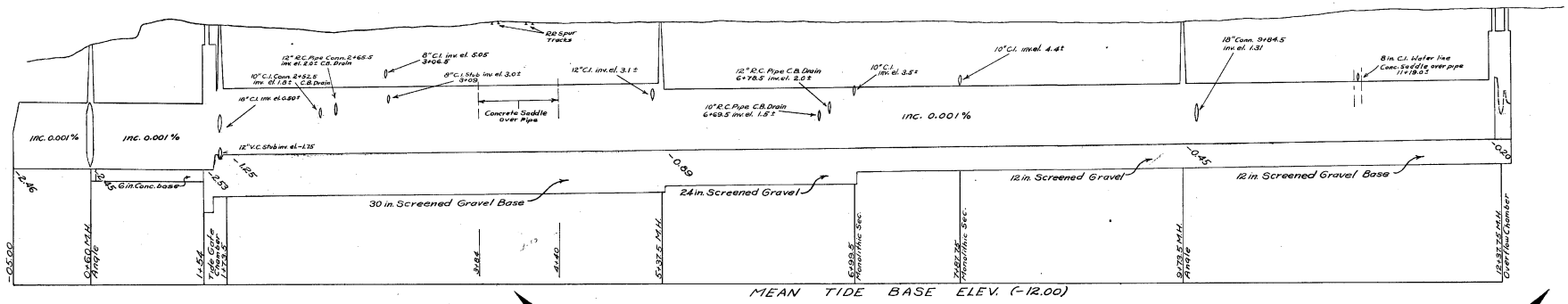
STRUCTURAL DETAILS III
OVERFLOW CHAMBER

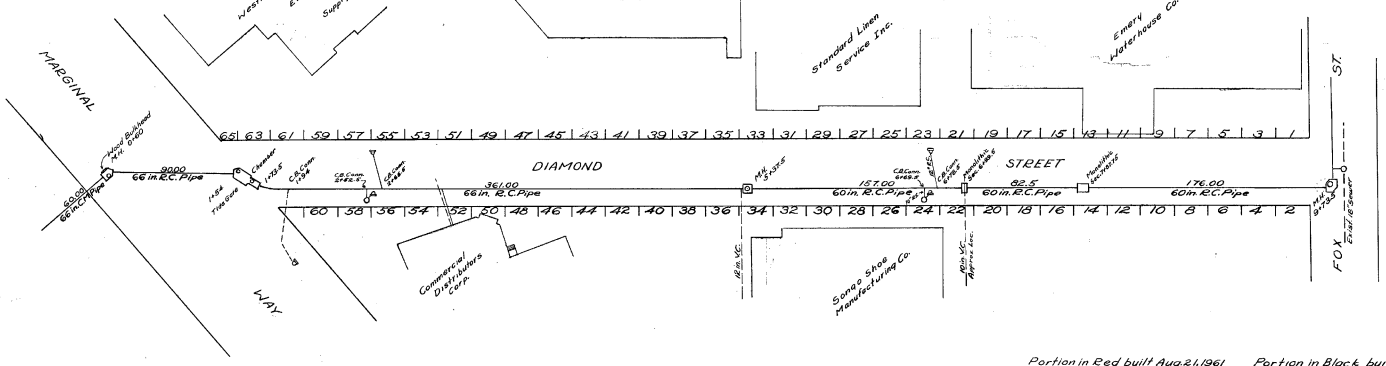
SCALE: 3/8" = 1'-0"
EXCEPT AS SHOWN

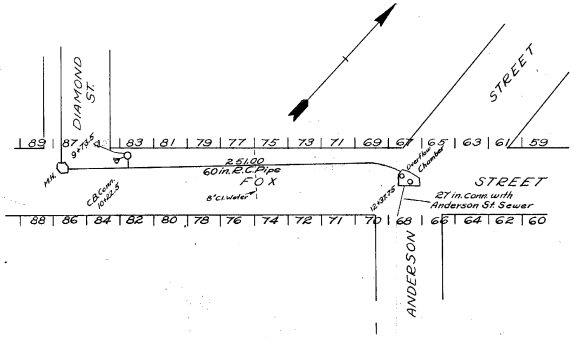
MAY 1961

METCALF & EDDY
ENGINEERS
BOSTON, MASS.









Portion in Red built Aug. 24, 1961 to Jan. 4, 1962
Contractor - E.J. Asselyn
Total Cost - $167,243.30

Portion in Black built Oct. 12, 1959 to Oct. 24, 1959
Contractor - E.J. Asselyn
Total Cost - $11,315.57

Bench Mark:-
Mon. (bolt) 3 ft. offset N'ly. side Fox St. at 1st angle W'ly. of Anderson St.
Elev. 10.955

CITY OF PORTLAND, MAINE
DEPARTMENT OF PUBLIC WORKS

DIAMOND STREET
OVERFLOW SEWER

DRAWN 1962/7/62	REFERENCES	SCALE
TRACED	PP 587/19	HOR. - 1 IN = 50 FT.
CHECKED NW 3-14-62		VER. - 1 IN = 5 FT.
DIRECTED JEER		
APPROVED, 4-13-62	Frederick E. Gatto, Deputy CITY ENGINEER	485 / 23

SSNS-0135 AND SSNS-0098

Marginal Way & Diamond St

GIS Info	
ID No:	SSNS-0135
Feature Class:	ssNetworkStructure
Structure Type:	Diversion Chamber
Comment:	see vault plan 485_023__001, also a tide gate
Reference Document	00473_018__007
Install Date	1/1/1961

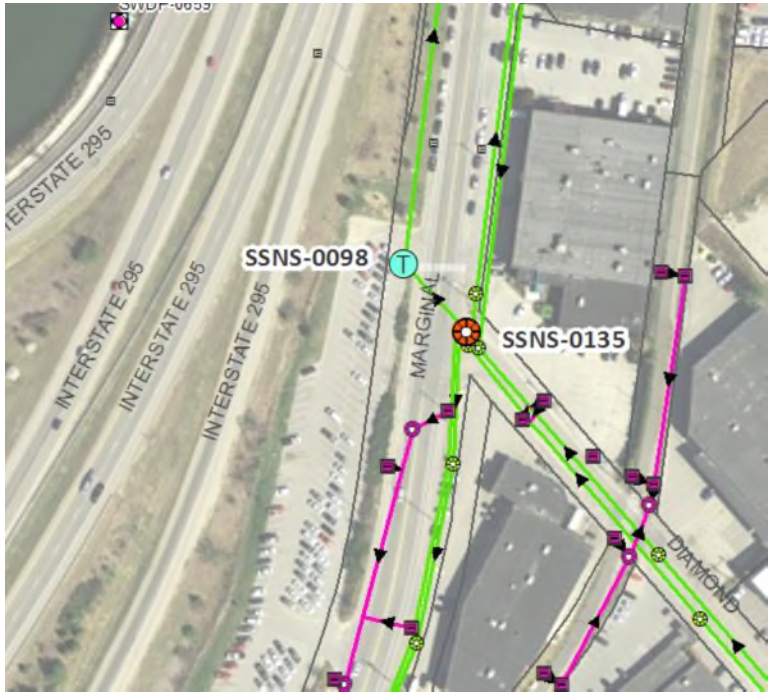
Estimated Rim Elevation: 8.29' NGVD29

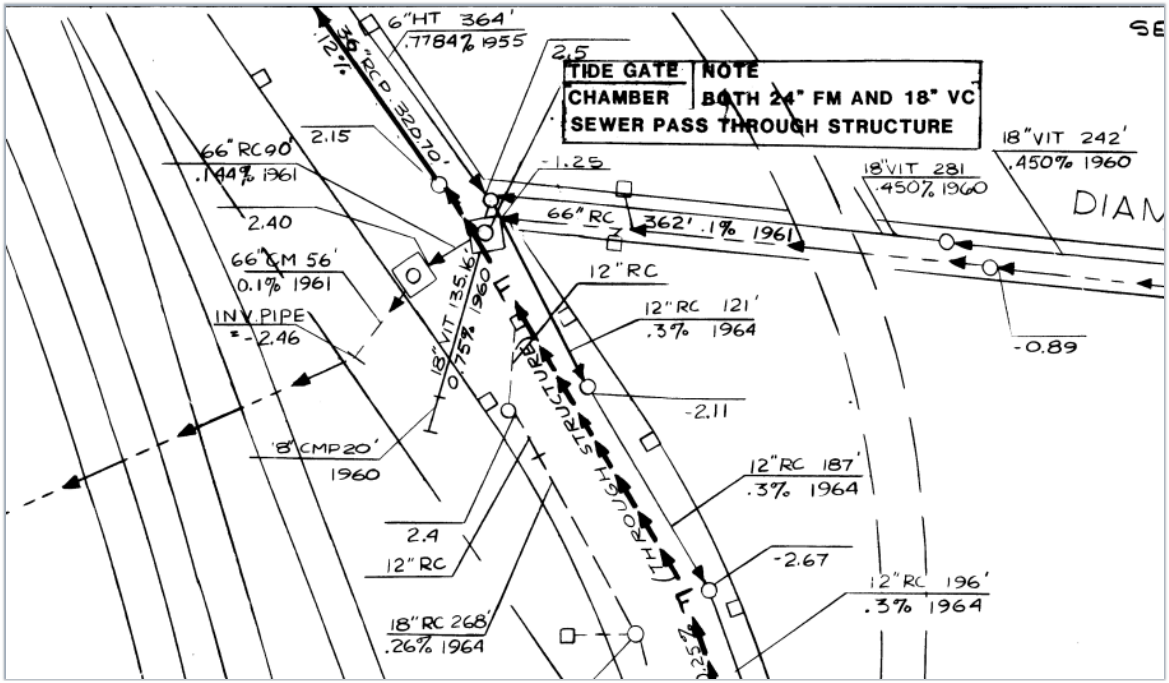
I&I Map Info	
Map No:	IV-12
Structure Type	Tidegate Chamber
Schematic available?	No

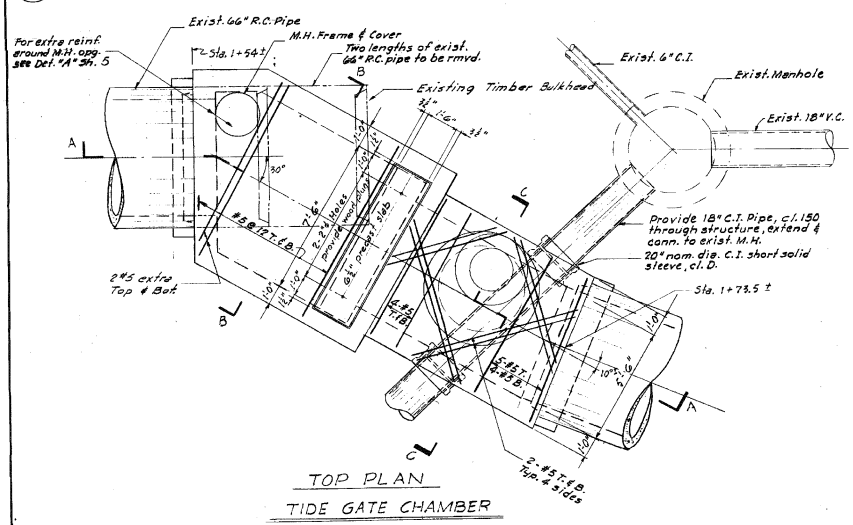
GIS Info	
ID No:	SSNS-0098
Feature Class:	ssNetworkStructure
Structure Type:	Tide Chamber
Comment:	see vault plan 485_023__001
Reference Document	00473_018__002
Install Date	1/1/1961

Estimated Rim Elevation: 8.17' NGVD29
(based on LiDAR data)

I&I Map Info	
Map No:	IV-12
Structure Type	Standard Manhole

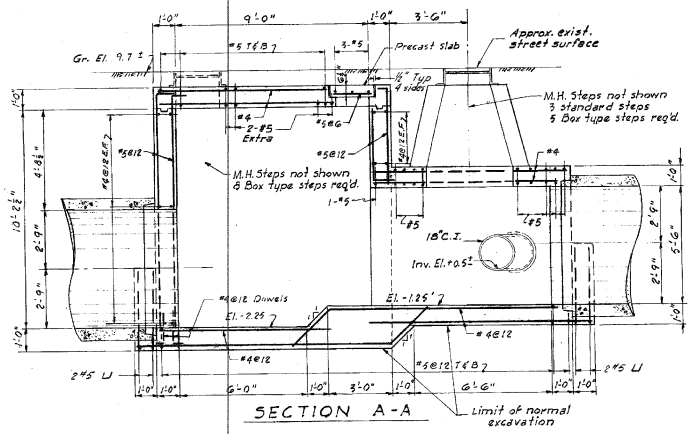




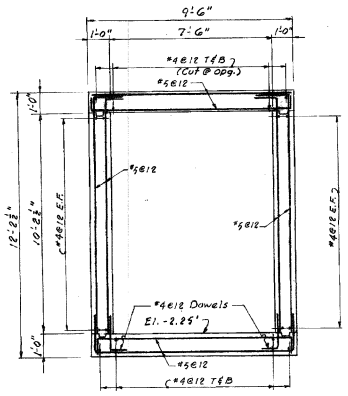


TOP PLAN

TIDE GATE CHAMBER



SECTION A-A



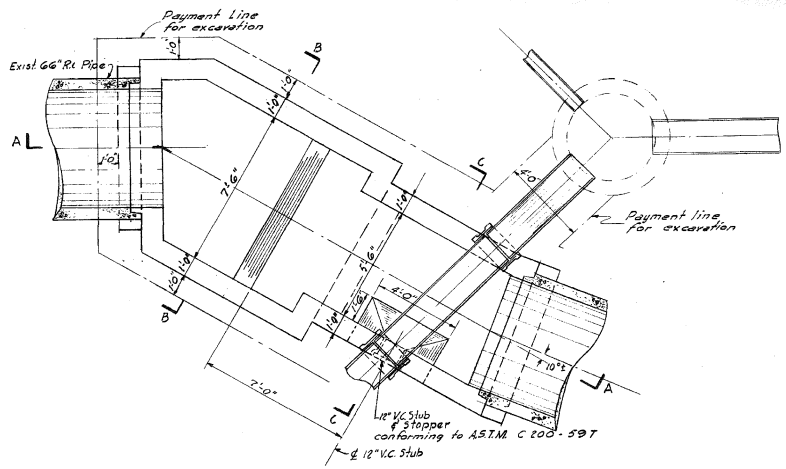
B - B

GENERAL NOTES

1. Concrete shall be Class A.
2. Continuous reinforcing shall be lapped 24 bar diameters at splices with splices of adjacent bars staggered.
3. Tie steel shall be as noted or #4@16.
4. At least two hours shall elapse after depositing concrete in walls, before depositing in slabs supported thereon.
5. Main reinforcing steel shall be placed and maintained at the minimum clear distances from surface of concrete as follows:

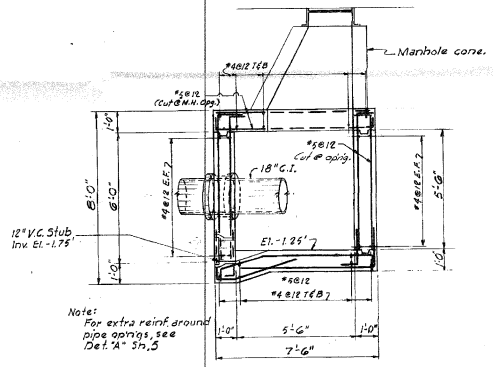
Walls	2" clear
Top Slab	2" clear
Bottom Slab	2" clear Top 2" clear Bottom

6. Apply 2 coats of bituminous waterproofing to top slabs of Tide Gate Chamber and Overflow Chamber.

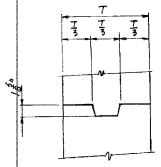


PLAN SECTION

TIDE GATE CHAMBER



C - C



TYPICAL KEY

No Scale

DRAWN BY A.F. DIK
TRACED BY A.F. DIK
CHECKED BY L.M. & JFD

STATE OF MAINE — JOHN W. RAYMOND JR. 935 — REGISTERED PROFESSIONAL ENGINEER

APPROVED

FOR METCALF & EDDY, ENGINEERS

John W. Raymond Jr. 5-31-61

REG. PROF. ENGR. MAINE NO. 935 — DATE

AS BUILT PLAN

PORTLAND, MAINE
SEWERAGE

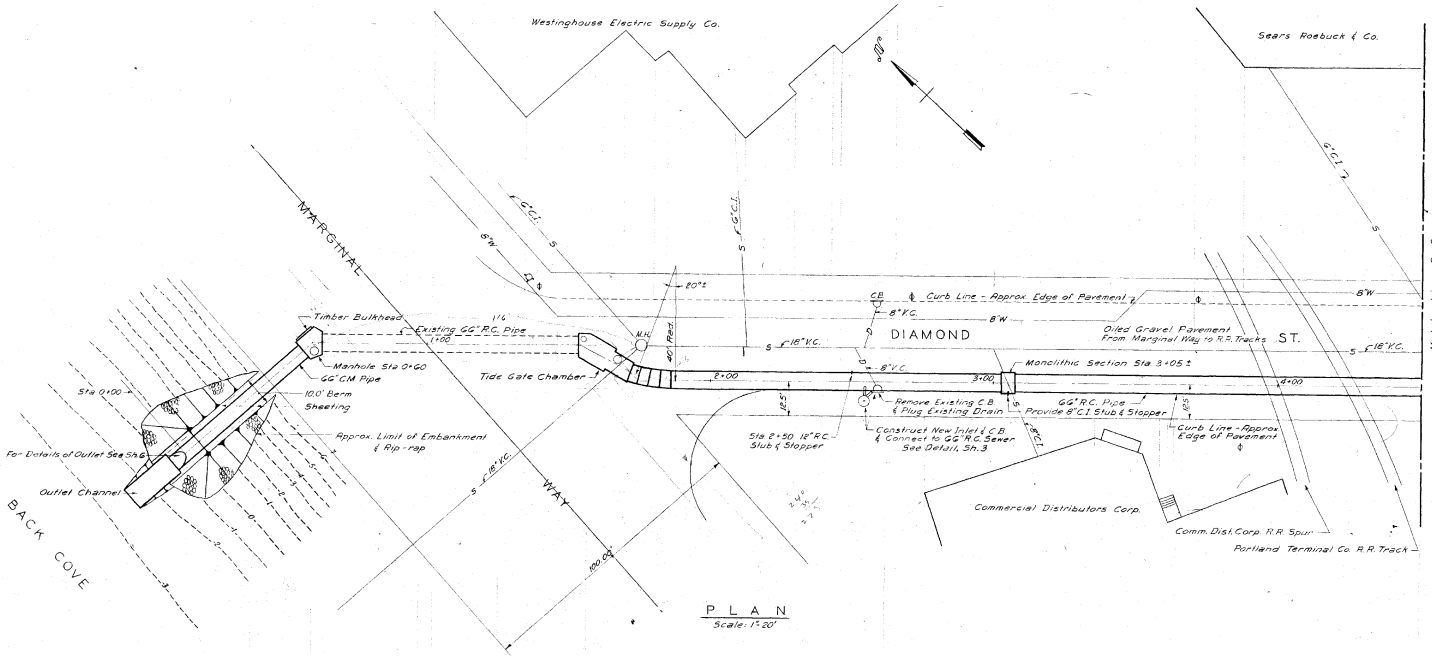
DIAMOND ST. OVERFLOW SEWER

STRUCTURAL DETAILS I
TIDE GATE CHAMBER

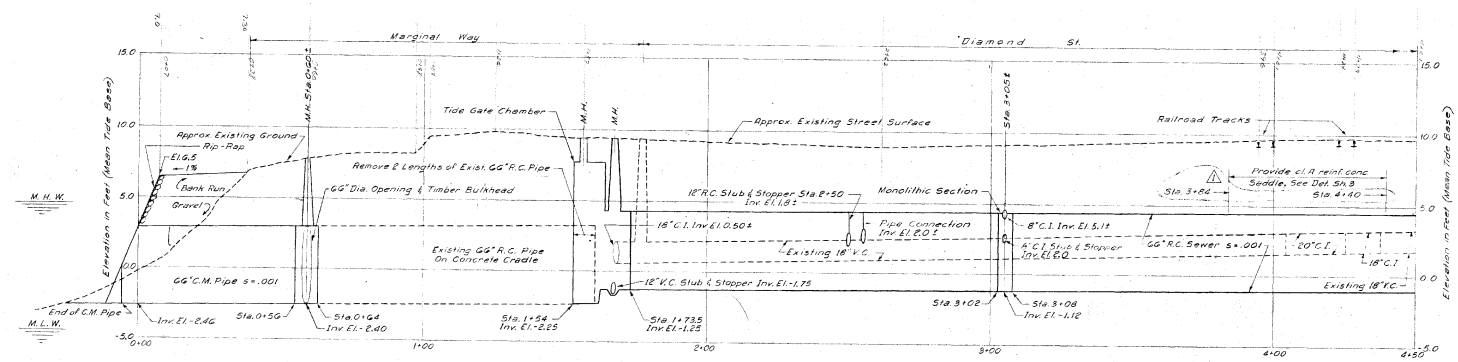
SCALE $\frac{3}{8}$" = 1'-0" — MAY 1961

METCALF & EDDY ENGINEERS BOSTON, MASS. — 488 / 4 — 40671 H 22550

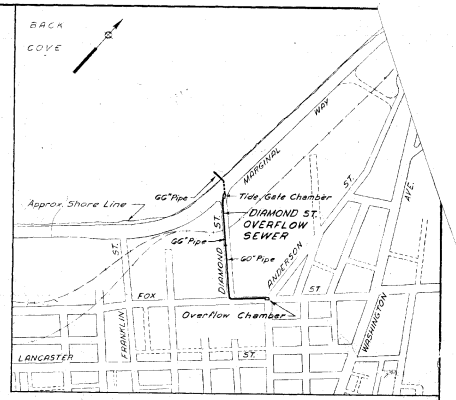
SHEET 4 OF 6



PLAN
Scale: 1" = 20'



PROFILE
Scales: Hor 1" = 20'
Vert 1" = 4'



LOCATION PLAN

LEGEND

- Existing Sewer
- Existing Drain
- Existing Water Main
- Existing Gas Main
- Existing Drain Inlet (D.I.) or Catch Basin (C.B.)
- Hydrant
- Electric Pole

GENERAL NOTE

1 - Service connections for water,

2 - Existing utility pipes crossing the sewer trench sh provided with permanent support by compacted screened gravel fill of suitable top width extending for the screened gravel cradle to the horizontal center of the utility pipe and to the sides of the trench.

3 - The depth of excavation below normal grade, if requi shall be determined in the field by the engineer.

4 - Manhole frames & covers, catch basin frames, grates and traps, standard manhole steps and catch basin stones furnished by City.

5 - No sheeting shall be left in place above El. 6.0, except for the 18" connection at Fox St, where sheeting shall be removed above the top of the pipe.
Sheeting shall be measured for payment as follows:
a - For pipe trenches; below top of the pipe.
b - For the Tidegate and Overflow Chambers; below El. 0.
c - For other structures; below the top of the roof slab.

Construction Plan

PORTLAND, MAINE
SEWERAGE

DIAMOND ST. OVERFLOW SEWER

PLAN AND PROFILE
STA. 0+00 (BACK COVE) TO STA. 4

SCALE, AS SHOWN — MAY 1961

METCALF & EDDY
ENGINEERS
BOSTON, MASS.

STATE OF MAINE — JOHN W. RAYMOND JR. 935 — REGISTERED PROFESSIONAL ENGINEER

APPROVED
FOR METCALF & EDDY, ENGINEERS
John W. Raymond Jr. 5-31-61
REG. PROF. ENGR. MAINE NO. 935 — DATE

No.	DATE	MADE BY	CHD BY	DESCRIPTION
1	6-22-61	V.R.S.	I.F.D.	Revised length of reinf. conc. saddle

DRAWN BY V.R.S.
TRACED BY V.R.S.
CHKD BY V.F.D.

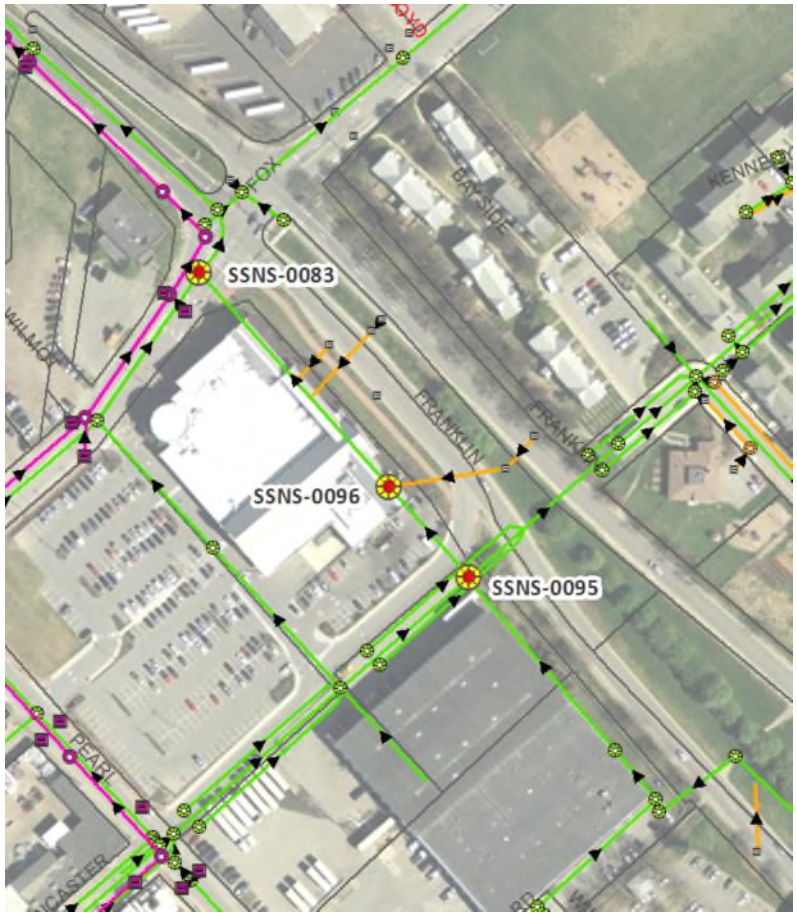
40GGR H 22547

SSNS-0095 Lancaster Street

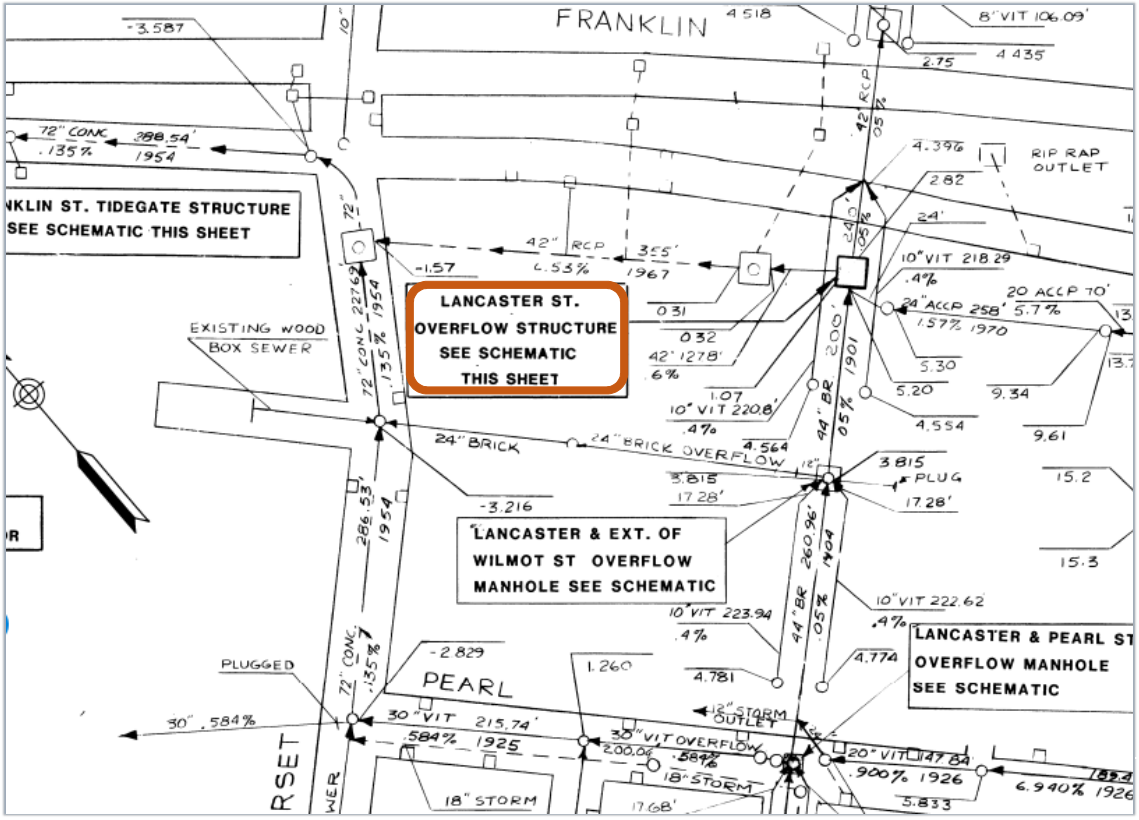
Lancaster St (& Franklin St)

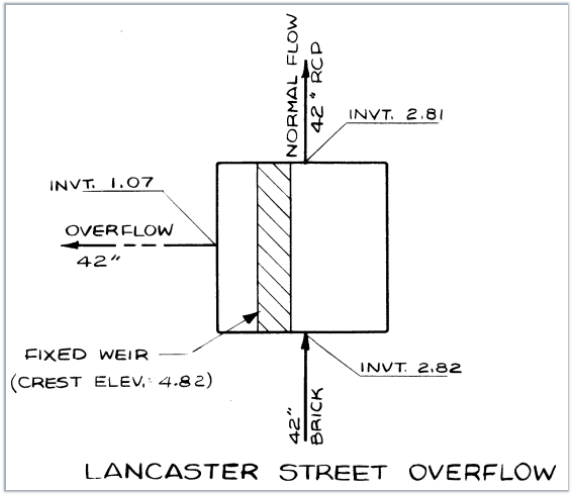
GIS Info	
ID No:	SSNS-0095
Feature Class:	ssNetworkStructure
Structure Type:	Flow Control
Comment:	Lancaster St overflow structure
Reference Document	00488_020__003
Install Date	<Null>

Estimated Rim Elevation: 9.45' NGVD29
(based on LiDAR data)



I&I Map Info	
Map No:	IV-12
Structure Type	Overflow Structure





SSNS-0096 AND SSNS-0083

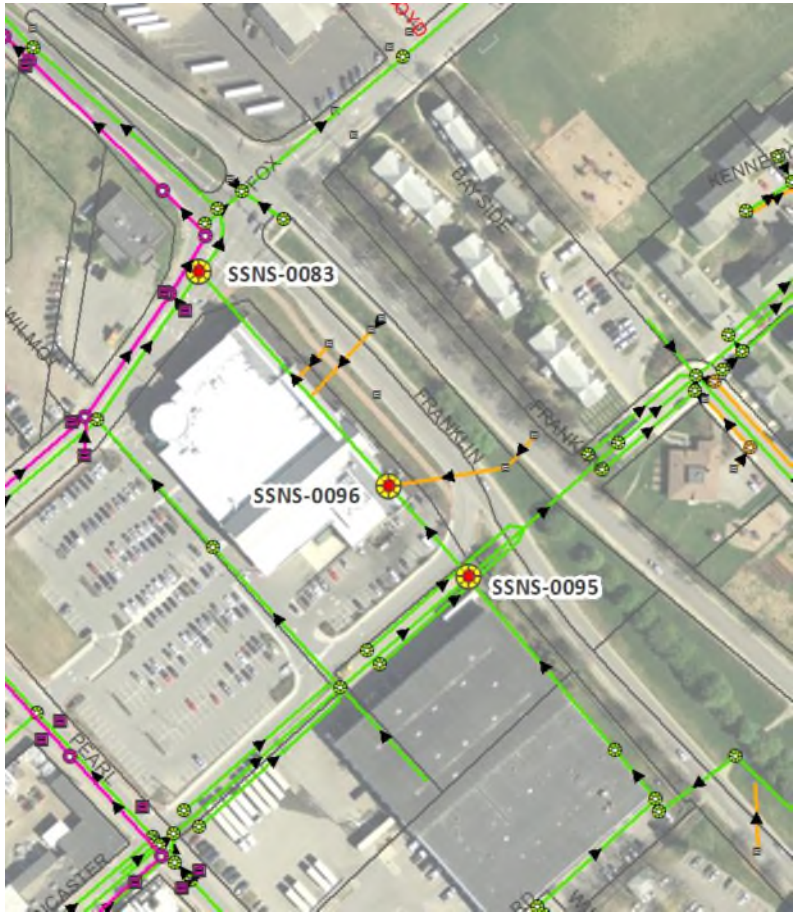
Franklin St. Somerset St.

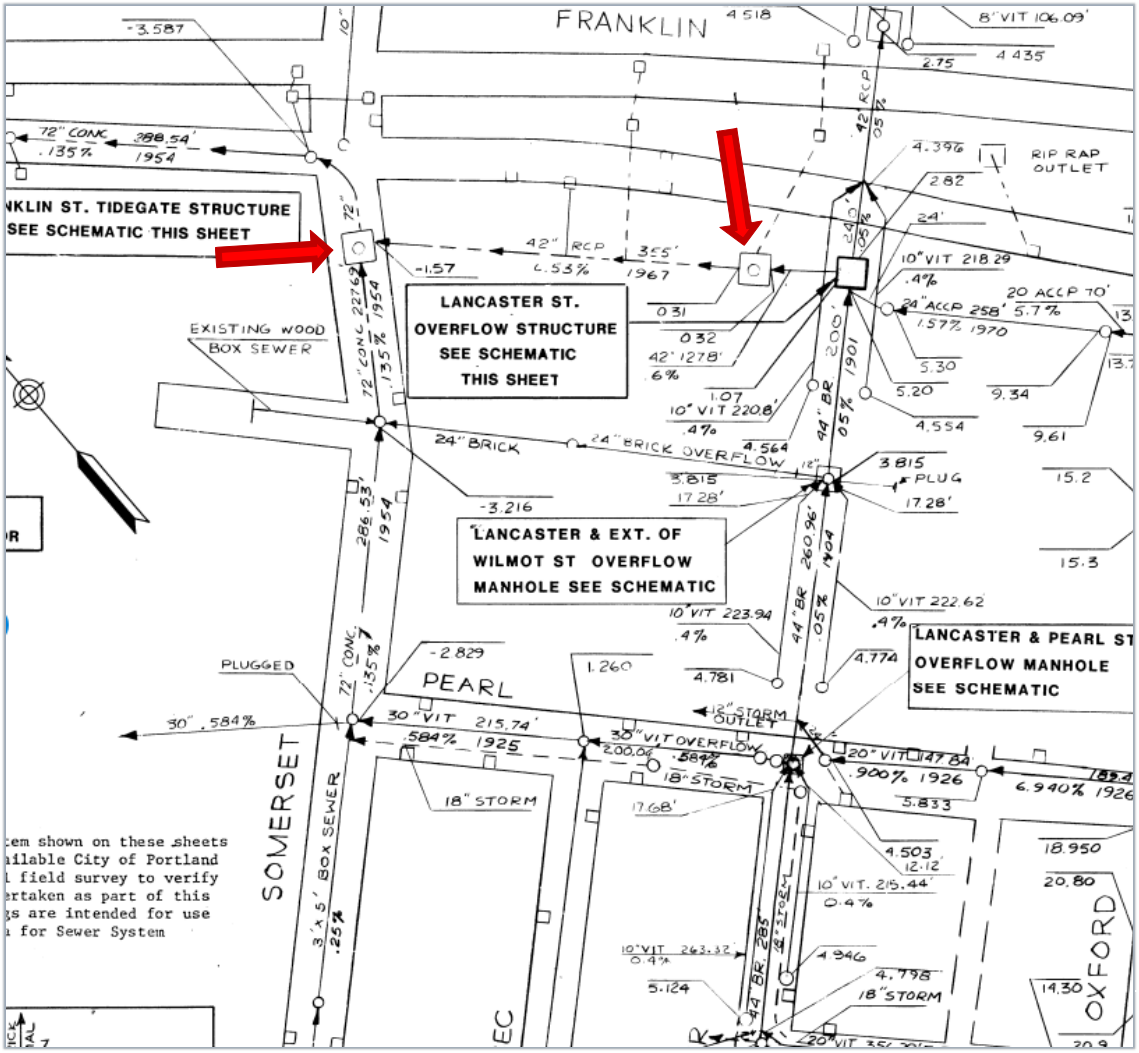
GIS Info	
ID No:	SSNS-0096
Feature Class:	ssNetworkStructure
Structure Type:	<Null>
Comment:	<Null>
Reference Document	<Null>
Install Date	<Null>

I&I Map Info	
Map No:	IV-12
Structure Type	Standard Manhole

GIS Info	
ID No:	SSNS-0083
Feature Class:	ssNetworkStructure
Structure Type:	Flow Control
Comment:	Lancaster St Overflow
Reference Document	<Null>
Install Date	<Null>

I&I Map Info	
Map No:	IV-12
Structure Type	Standard Manhole

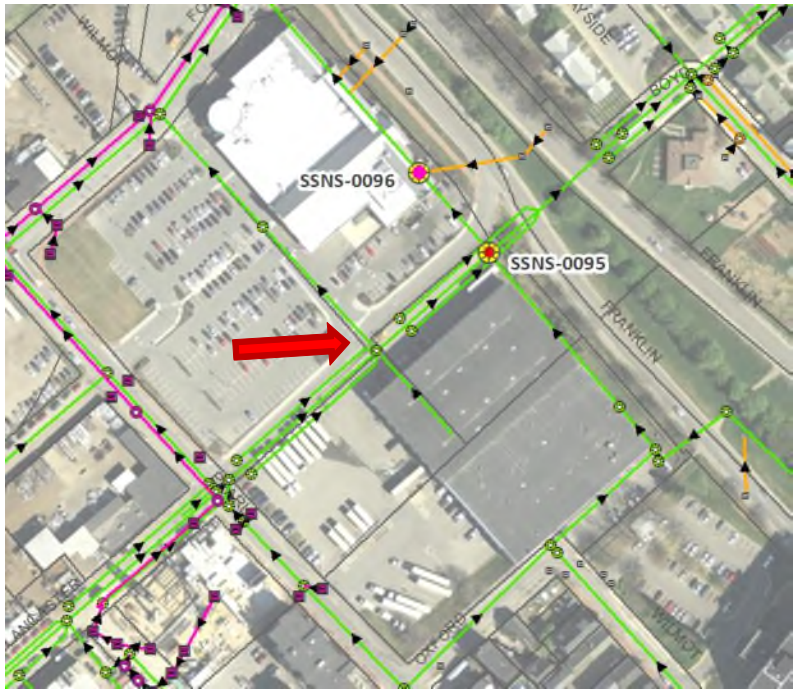




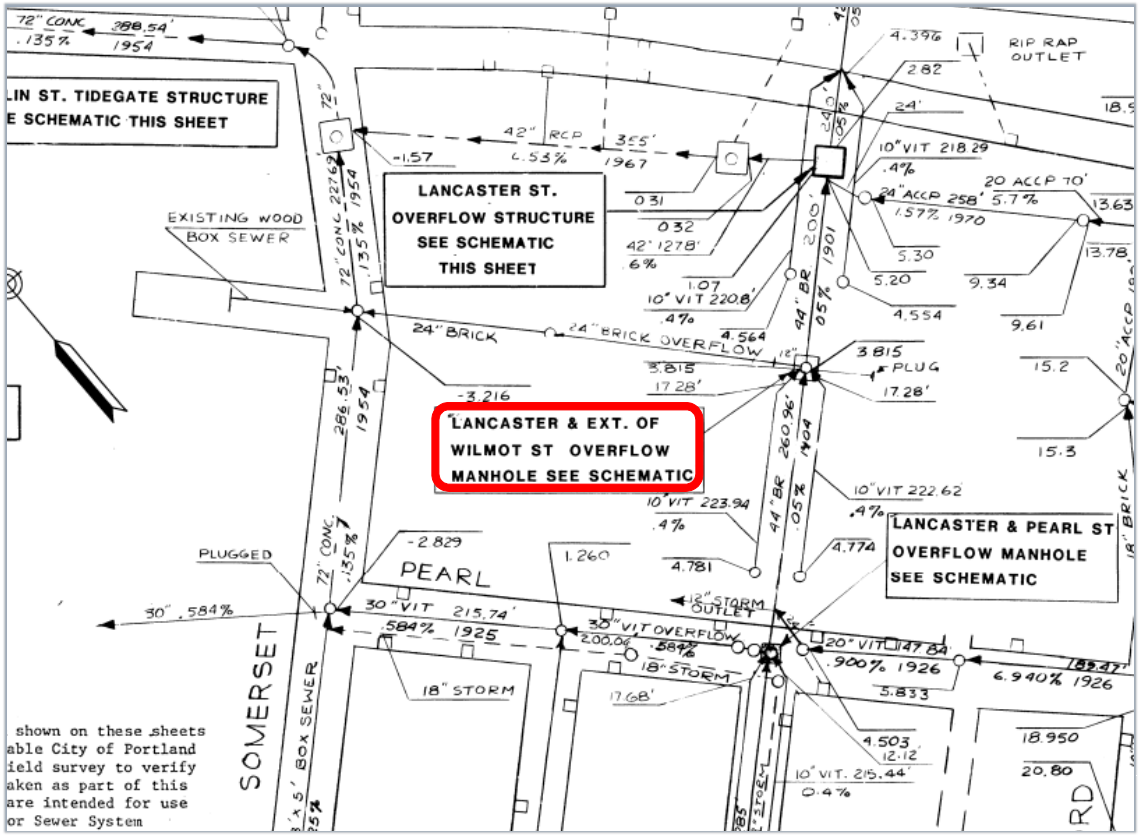
SSMH-3770 Potential Lancaster St Structures

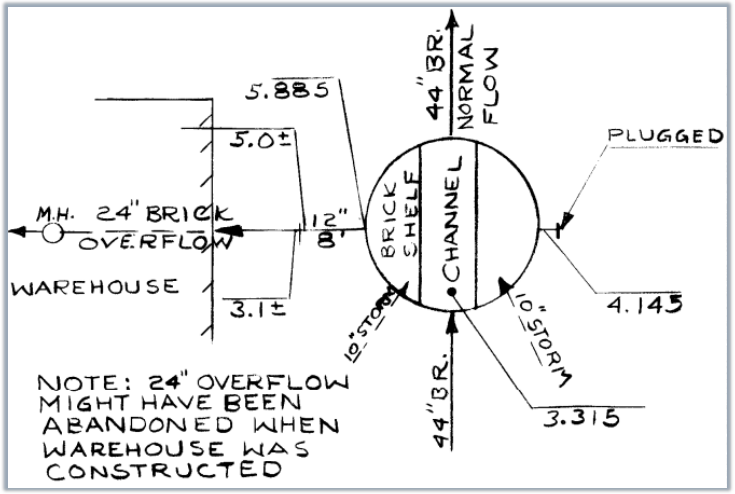
Lancaster Street & Extension of Wilmot Street

GIS Info	
ID No:	SSMH-3770
Feature Class:	ssManhole
Structure Type:	Sewer
Comment:	North Side Intercepting Sewer
Reference Document	00123_003__001
Install Date	1/1/1902



I&I Map Info	
Map No:	IV-12
Structure Type	Overflow Manhole

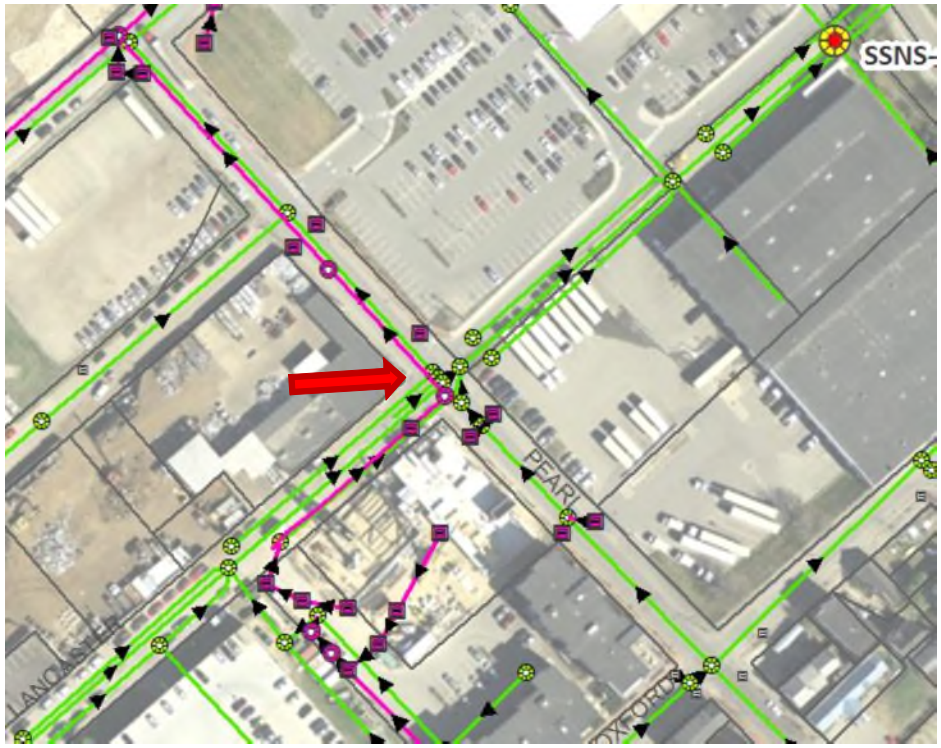




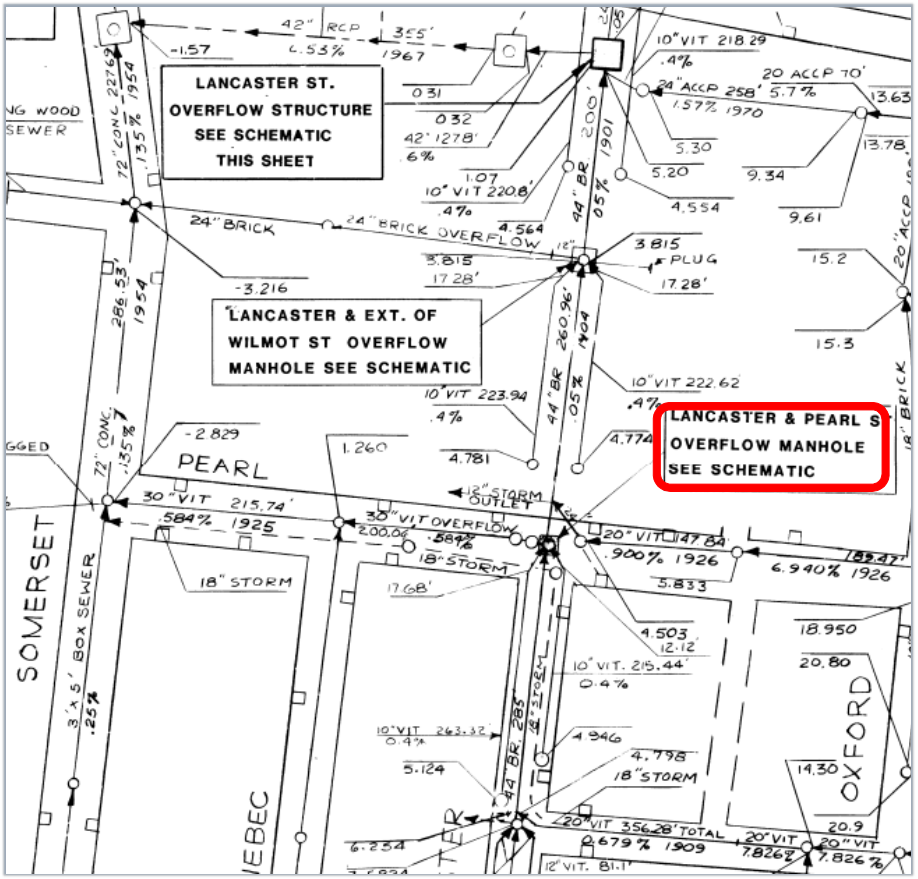
Potential Lancaster St Structures

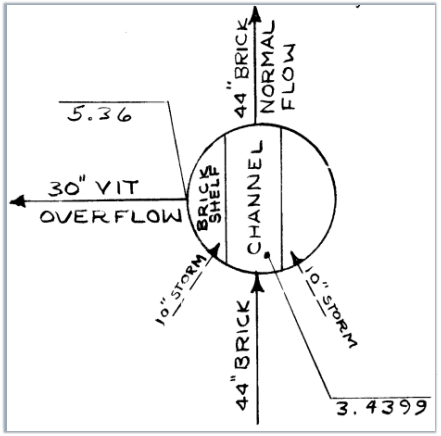
Lancaster Street & Pearl Street

GIS Info	
ID No:	?
Feature Class:	ssManhole
Structure Type:	
Comment:	
Reference Document	
Install Date	



I&I Map Info	
Map No:	IV-12
Structure Type	Overflow Manhole



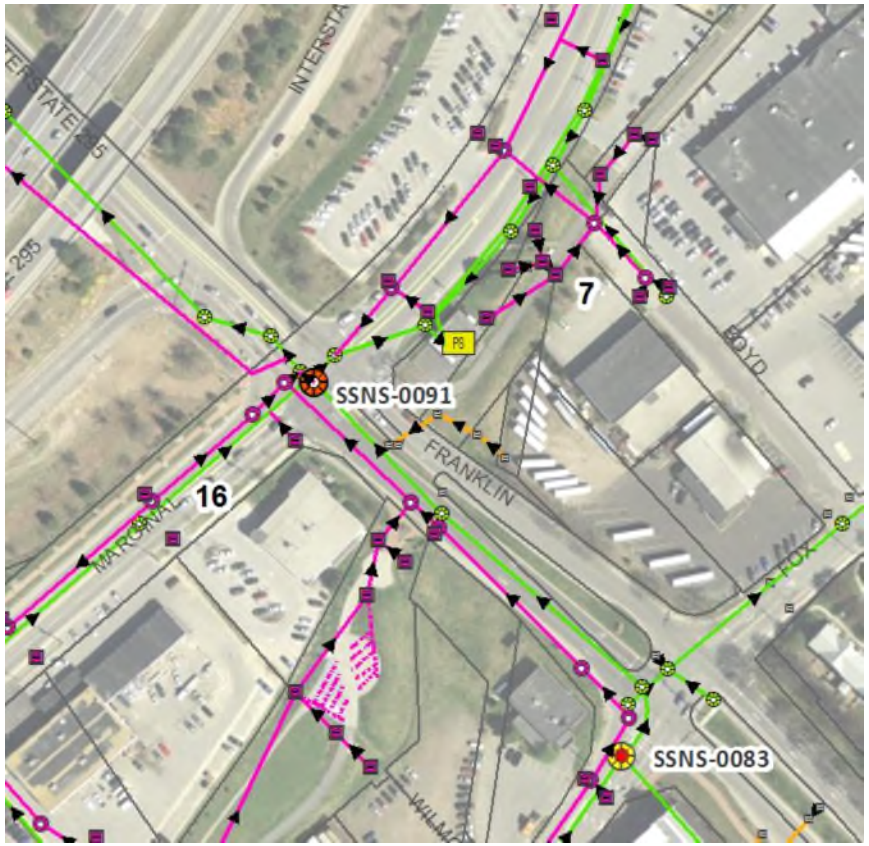


SSNS-0091 Franklin Street

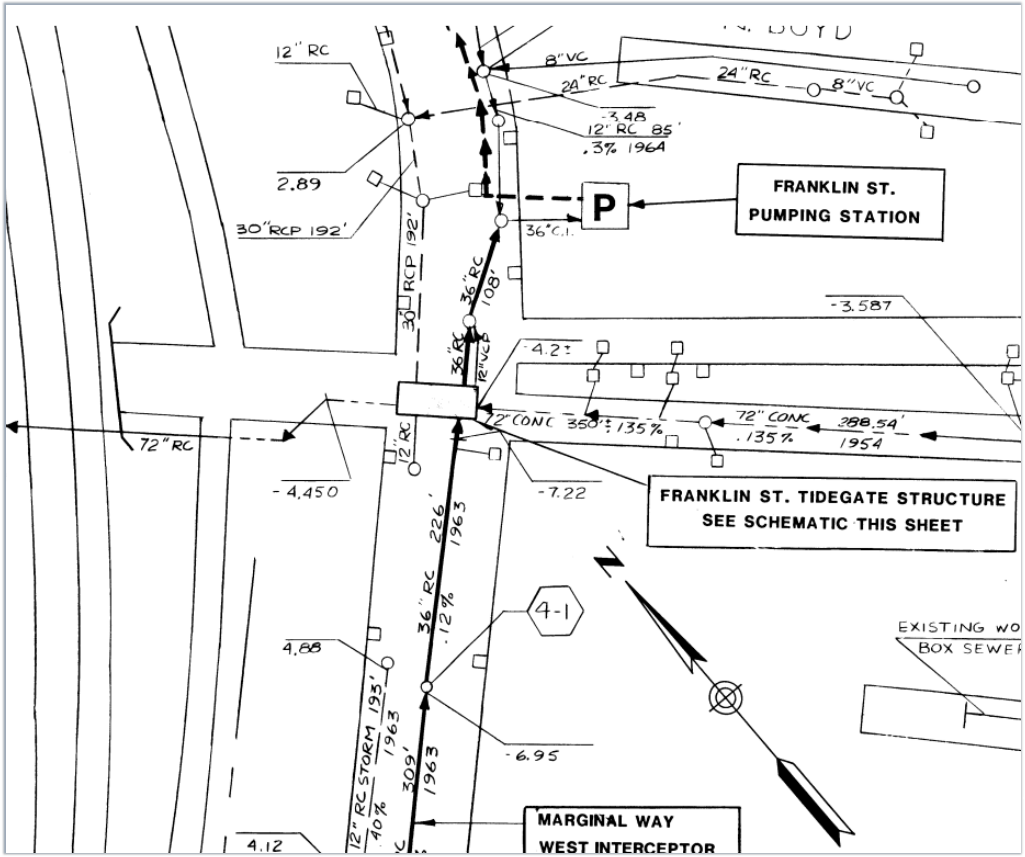
Franklin St & Marginal Way

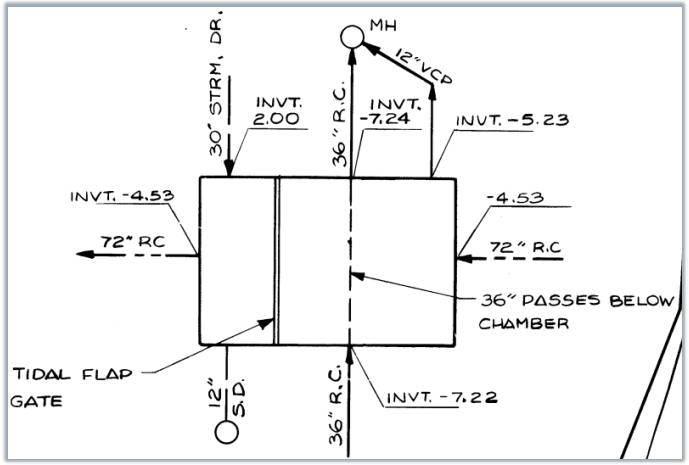
GIS Info	
ID No:	SSNS-0091
Feature Class:	ssNetworkStructure
Structure Type:	Diversion Chamber
Comment:	see vault plan plan 473_018__005, also a tide gate
Reference Document	01006_014A_005
Install Date	<Null>

Estimated Rim Elevation: 10.06' NGVD29
(based on LiDAR data)



I&I Map Info	
Map No:	IV-12
Structure Type	Tidegate Structure



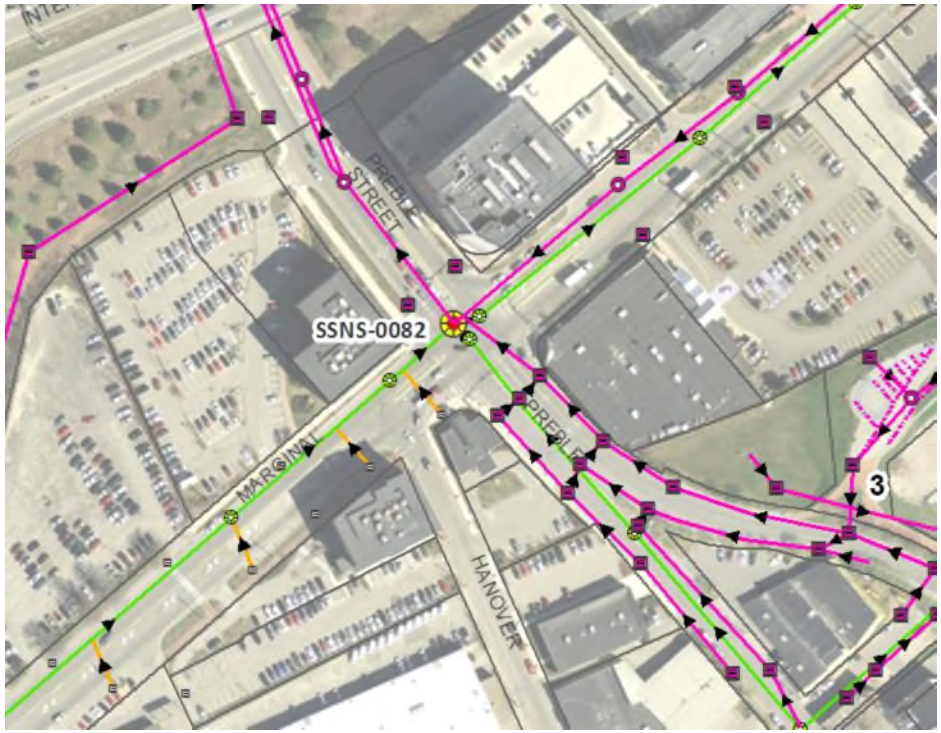


SSNS-0082 Preble Street Overflow & Tidegate

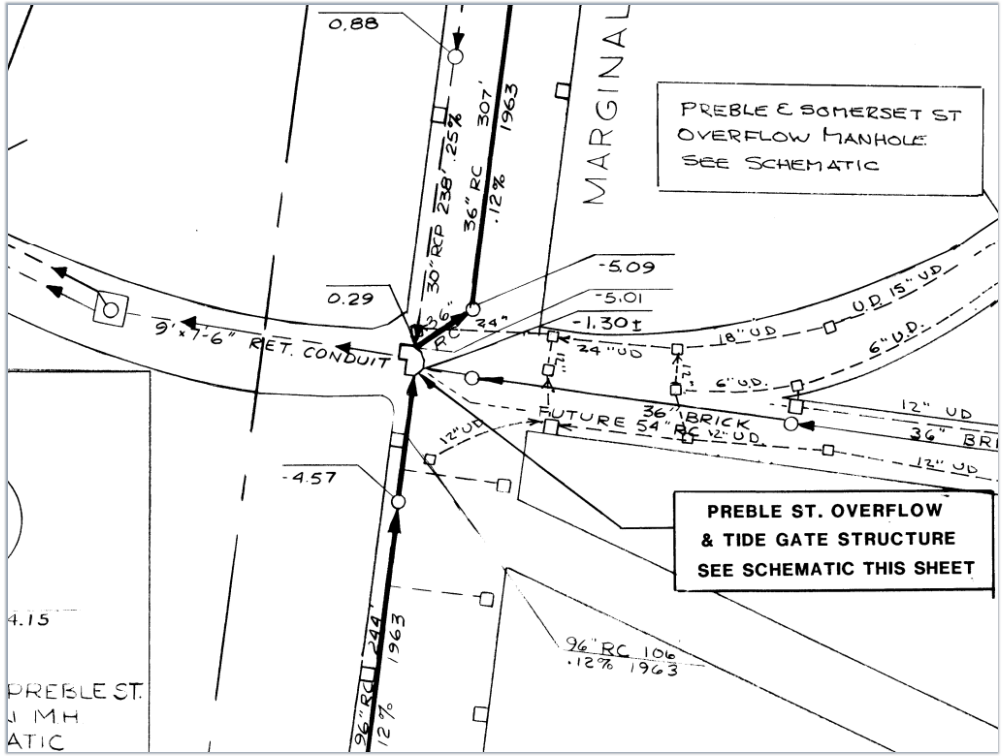
Preble Street & Marginal Way

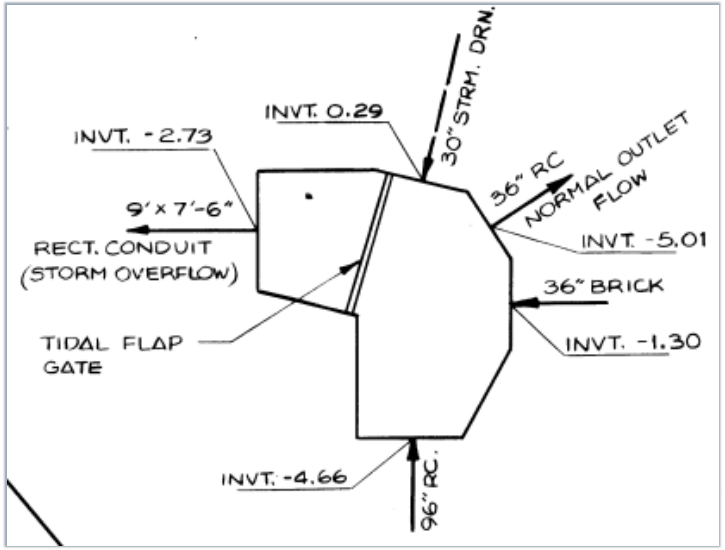
GIS Info	
ID No:	SSNS-0082
Feature Class:	ssNetworkStructure
Structure Type:	<Null>
Comment:	Preble St CSO outfall & tide gate
Reference Document	<Null>
Install Date	<Null>

Estimated Rim Elevation: 10.35' NGVD29
(based on LiDAR data)



I&I Map Info	
Map No:	IV-13
Structure Type	Overflow and Tidegate Structure





Google street view:
https://www.google.com/maps/@43.6621188,-70.2654362,3a,75y,152.19h,59.49t/data=!3m6!1e1!3m4!1sCG3YhbeBiQaYeO1ZcmYidg!2e0!7i13312!8i6656!6m1!1e1

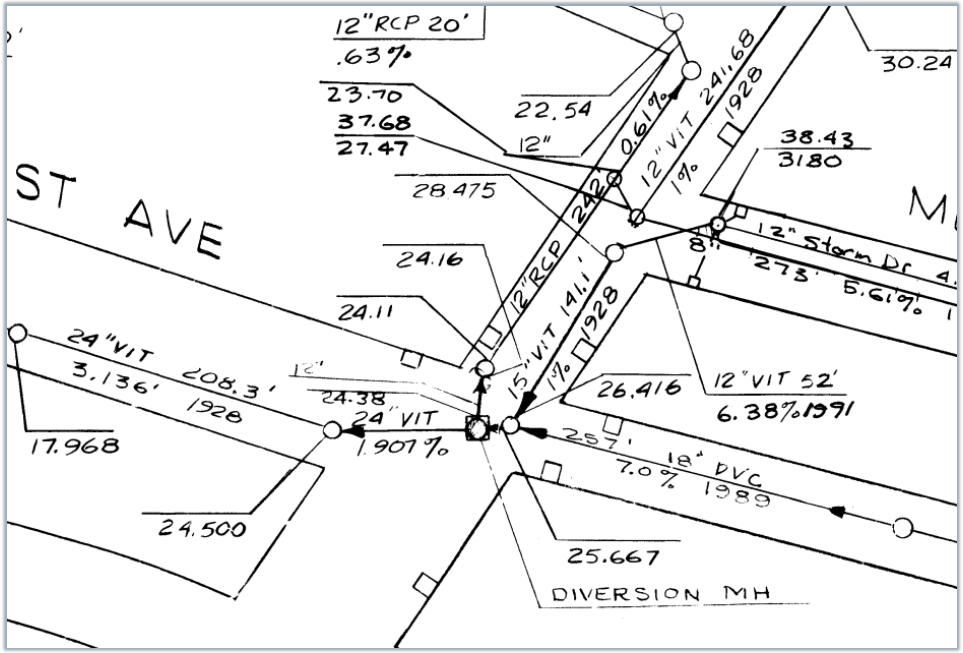
SSNS-0088

Forest Ave & Portland Street

GIS Info	
ID No:	SSNS-0088
Feature Class:	ssNetworkStructure
Structure Type:	<Null>
Comment:	see vault plan 945_006__002
Reference Document	00697_001__001
Install Date	1/1/1965

Estimated Rim Elevation: 36.16' NGVD29
(based on LiDAR data)

I&I Map Info	
Map No:	IV-13
Structure Type	Diversion MH
Schematic Available?	No



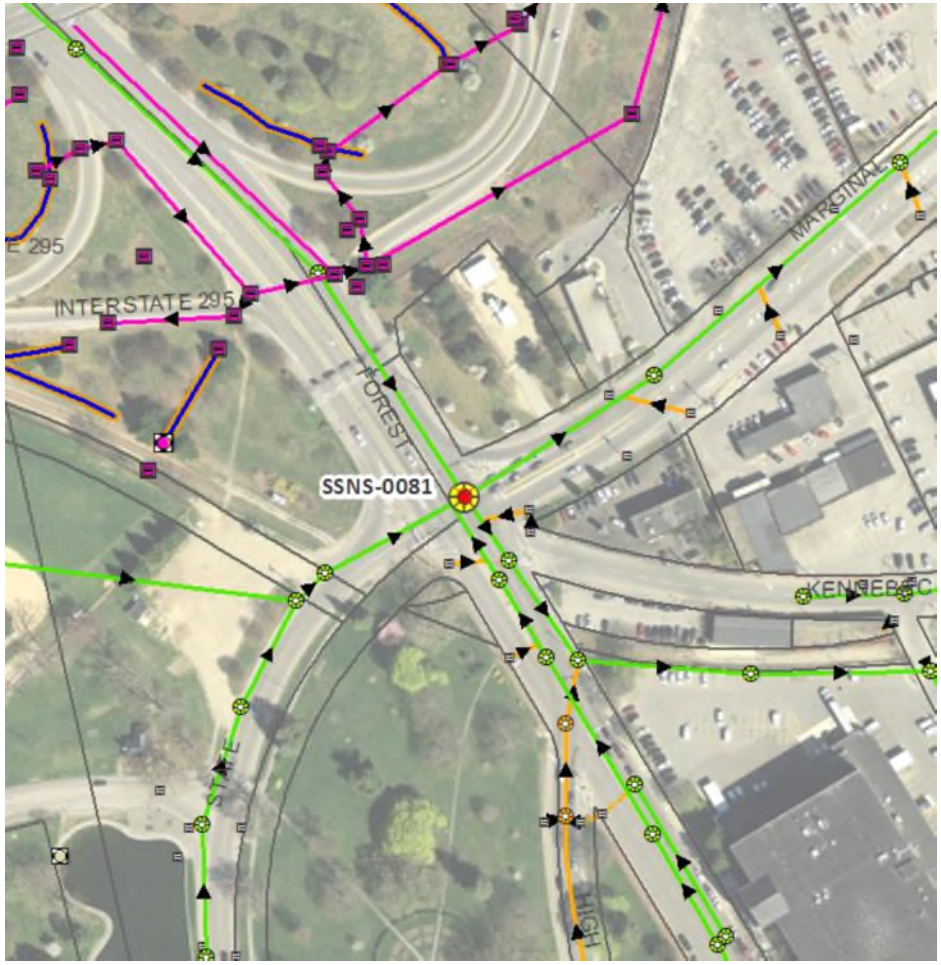
SSNS-0081 Forest Ave

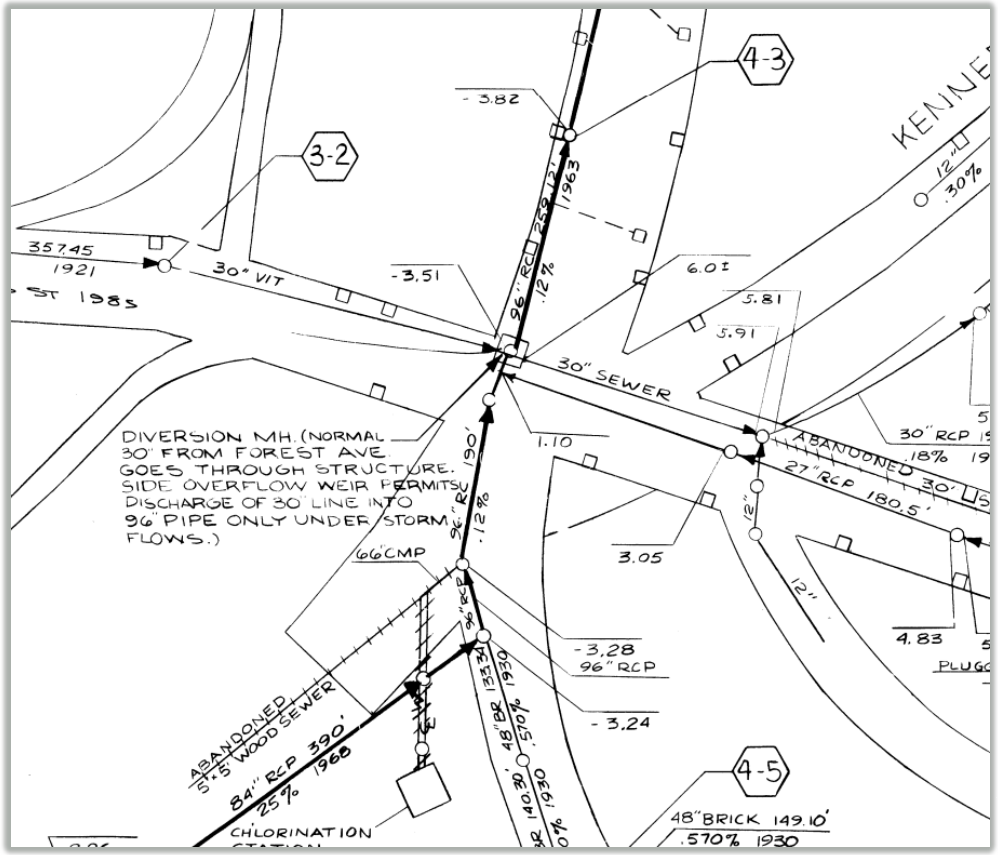
Forest Ave & Marginal Way

GIS Info	
ID No:	SSNS-0081
Feature Class:	ssNetworkStructure
Structure Type:	
Comment:	Overflow structure/diversion structure
Reference Document	00488_005__005
Install Date	

Estimated Rim Elevation: 10.94' NGVD29
(based on LiDAR data)

I&I Map Info	
Map No:	IV-13
Structure Type	Diversion Manhole
Schematic available?	No

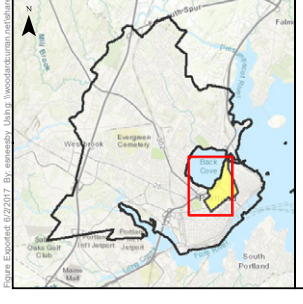




Google street view:
https://www.google.com/maps/place/Forest+Ave,+Portland,+ME/@43.6603501,-70.2680244,3a,64.5y,284.39h,68.2t/data=!3m6!1e1!3m4!1sLfTeIAa0C3jo8X7xSmSMPg!2e0!7i13312!8i6656!4m5!3m4!1s0x4cb29ba1f4021e8d:0x5949c4d528a86b42!8m2!3d43.6812207!4d-70.2897337!6m1!1e1

Appendix C

Existing SWMM Model Schematic



LEGEND

SWMM Schematic Data

- Conduit
- Junction
- Outfall
- Pump Station

Stormwater System

Discharges to or below Special Structure (Sewer Network Structure or Sewer Diversion Chamber)

- Stormwater Gravity Main
- Under Drain

Sewer System

- Sewage
- Combined Waste Water
- Sewer Pressurized Mains
- Sewer Network Structure (Other)
- Sewer Diversion Chamber
- Sewer Pump Station
- Sewer Tide Chamber

Stormwater System

- Storm Gravity Mains
- Under Drain
- Storm Virtual Drainlines
- Storm Open Drains

Existing SWMM Schematic

City of Portland, ME

FIGURE 3 of 3

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Portland, Maine 04102
800.426.4262 | www.woodardcurran.com
COMMITMENT & INTEGRITY DRIVE RESULTS

SCALE: 1 " = 225 '	PROJECT #: 0230429.00
DATE: JUNE 2017	DRAWN BY: ES

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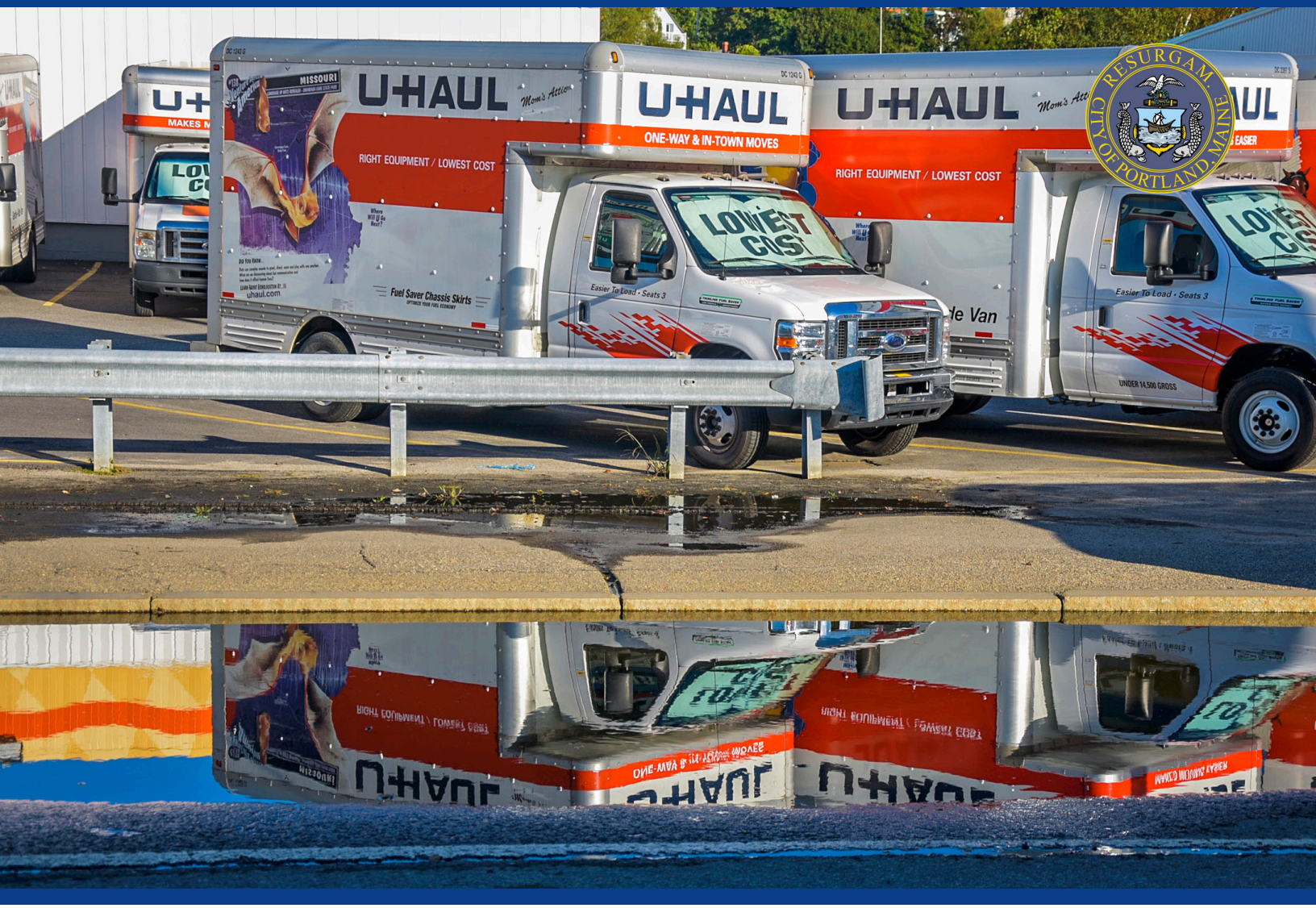
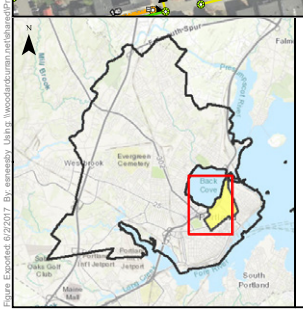


Appendix D

Areas Recently Surveyed



LEGEND

Stormwater System

Discharges to or below Special Structure (Sewer Network Structure or Sewer Diversion Chamber)

- StormGravity Main
- Storm Under Drain
- Storm Discharge Points
- Storm Inlets
- Storm Manholes

Sewer System

- Sewage
- Combined Waste Water
- Sewer Pressurized Mains
- Sewer Manholes
- Sewer Network Structure (Other)
- Sewer Diversion Chamber
- Sewer Pump Station
- Sewer Tide Chamber

Stormwater System

- Storm Gravity Mains
- Under Drain
- Storm Virtual Drainlines
- Storm Open Drains
- Storm Inlets
- Storm Discharge Points
- Storm Manholes

- Recent Survey Available (Approx.)
- Future Survey (Next 2 years)

Areas Recently Surveyed

City of Portland, ME

FIGURE 2 of 3

Woodard & Curran shall assume no liability for any of the following; 1. Any errors, omissions, or inaccuracies in the information provided regardless of how caused or; 2.Any decision or action taken or not taken by the reader in reliance upon any information or data furnished hereunder. Data Sources:

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COMMITMENT & INTEGRITY DRIVE RESULTS

SCALE: 1 " = 225 '	PROJECT #: 0230429.00
DATE: JUNE 2017	DRAWN BY: ES

Figure Exported: 6/2/2017 By: esnessby Using: \\woodardcurran.net\shared\Projects\0230429.00 Portland Bayside Adapts Planning Svcs\wip\GIS\Projects\BaysideAdapt_Areas Recently Surveyed.mxd