in association with:

Implications of Climate Change for RI Wastewater Collection & Treatment Infrastructure

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COMMITMENT & INTEGRITY DRIVE RESULTS

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Rhode Island Department of Environmental Management

March 2017

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EXECUTIVE SUMMARY

By their very nature, wastewater facilities are sited in flood prone areas. In Rhode Island, as elsewhere, increasing storm intensities have damaged wastewater treatment plants and pump stations. The state is home to nineteen major wastewater treatment facilities (WWTFs) that treat approximately 120 million gallons of wastewater per day. Because wastewater facilities and associated pump stations are located at low elevations, many are within riverine or coastal floodplains and are at risk to inundation and other natural hazards.

Recognizing that many necessary modifications to these systems would require long-term planning, the Rhode Island Department of Environmental Management (RIDEM) is working in collaboration with the state's Division of Planning and other agencies to integrate climate change considerations into wastewater system planning, as well as current operations. The first step towards this goal was to evaluate the implications of key natural hazards associated with climate change on the major wastewater infrastructure in the state. This report is the result of that initial effort.

The study included assessments of all nineteen treatment plants to identify vulnerabilities to flooding, storm surge, and other severe weather and climate change related impacts. The assessments were based on two types of data:

1. Predictive scientific investigations of the likely consequences of continued climate change in Rhode Island; and
2. Historic records of past events.

The predictive scientific investigations consisted of statewide assessments of coastal and riverine hazards and sea level rise, and local assessments of shoreline change and wave hazards in the vicinity of the vulnerable WWTFs. The results of the statewide assessments are available for use by the public. The coastal data is accessible through the STORMTOOLS web GIS at http://www.beachsamp.org/resources/stormtools/ and as well as through the Rhode Island Geographic Information System (RIGIS) at http://www.rigis.org/data/ScaledSLR_NACCS. The riverine data is available at http://www.rigis.org/data/ridem_RiverineFlooding. A RIDEM Mapper is also available with simplified access to the riverine and coastal change imaging that is used in this report: http://arcg.is/2mlL2bF. Climate change science is continuing to advance as new predictive tools and measures are being developed. The scope of this study was altered early on to take advantage of some new information that became available, but as the work progressed, it inevitably became necessary to use the data in place to progress to conclusion.

The historic data provided by WWTF operators and RIDEM are limited to recent events, the effects on the individual WWTF systems, and the extent they were recorded. Recorded information from the flooding experienced in March 2010 was a good example of extreme riverine flood hazards that was used to correlate the predictive results of the riverine hazard assessment. Historic records also proved useful to identify areas prone to localized flooding that were not captured on the statewide scale used for the riverine hazard assessment. Conversely, for numerous reasons, the historic records could not fully capture the effects from the major hurricanes experienced in the 20th century on wastewater infrastructure to allow a similar comparison to the theoretical extreme coastal storms assessed in this study. Most notable is that the severest coastal storms occurred prior to the existence of WWTFs and associated shoreline alterations, hardening, etc. Together, the historic and predictive data sources used in this study provide a basis for wastewater infrastructure resiliency planning.

Concurrently with the development of this report, the New England Interstate Water Pollution Control Commission (NEIWPCC) revised *TR-16, Guides for the Design of Wastewater Treatment Works in 2016* to address resiliency and adaptation standards for extreme storm events. Woodard & Curran met with representatives from RIDEM and the Coastal Resources Management Council (CRMC) to assimilate the information from this study and the TR-16 recommendations into design guidance for future WWTF upgrades. Two levels of resiliency were identified as targets for future upgrades:

1. Improvements that would provide for continuous operation up to a specified flood elevation, and
2. Improvements that would consider survivability of the structural and electrical components of the facilities up to a higher specified flood elevation.

The basis of the flood elevations (with or without some components of surge, wave action, and sea level rise) should consider the cost-benefit of the improvements.

This study provides each of the WWTFs with a simplified ranking of their systems for use in prioritizing repairs if multiple systems fail at any time. This tool could be particularly useful for the seven WWTFs that were predicted to become predominantly inundated under the hazard situations modeled. Coincidentally, NEIWPCC published a guide for wastewater managers in September 2016 entitled "Preparing for Extreme Weather at Wastewater Utilities: Strategies and Tips". This guide is an excellent source for facilities to use in conjunction with this report to update facility specific emergency management plans.

Adaptive strategies are suggested for each of the WWTF systems that were identified as being vulnerable. Consistent with the intent of this report to support planning efforts, the adaptive strategies are proposed to provide guidance for future system upgrades. They fall within one of five categories:

1. Hardening (e.g., constructing walls and dikes, flood-proofing);
2. Relocating (e.g., elevating or relocating equipment or systems);
3. Readily repairable or replaceable (e.g., standardizing equipment or stocking spare parts);
4. Redundancy (e.g., providing means to convey wastewater to two pump stations or using portable, temporary pumps); or as a last resort
5. Wet weather bypass (e.g., controlling flow to surface waters to avoid flooding public ways).

Estimated cost ranges were identified for each of the recommended adaptation strategies to assist communities with planning and budgeting for future improvements to their wastewater infrastructure. The majority of the suggested adaptation strategies fall into the category of hardening with corresponding implementation costs of under $50,000 each[1].

Finally, communicating the information within this report is important so it can be used in planning and policy development. Accordingly, customized briefs were prepared for each WWTF to summarize the climate change implications to that infrastructure. These are provided immediately following this executive summary.

[1] The cost of hardening projects varies significantly depending upon the scope; for instance, berm construction such as in Warwick or Bucklin Point would be much greater.

Bristol Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

Bristol WWTF is located at 2 Plant Street in Bristol, approximately 1,000 feet inland from Bristol Harbor. It treats an average of 2.8 million gallons of wastewater per day, serving approximately 20,700 customers in the community. Additional information is on the back of this summary.

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TOP 3 HAZARD MODELING RESULTS

1 Coastal Flood Hazard

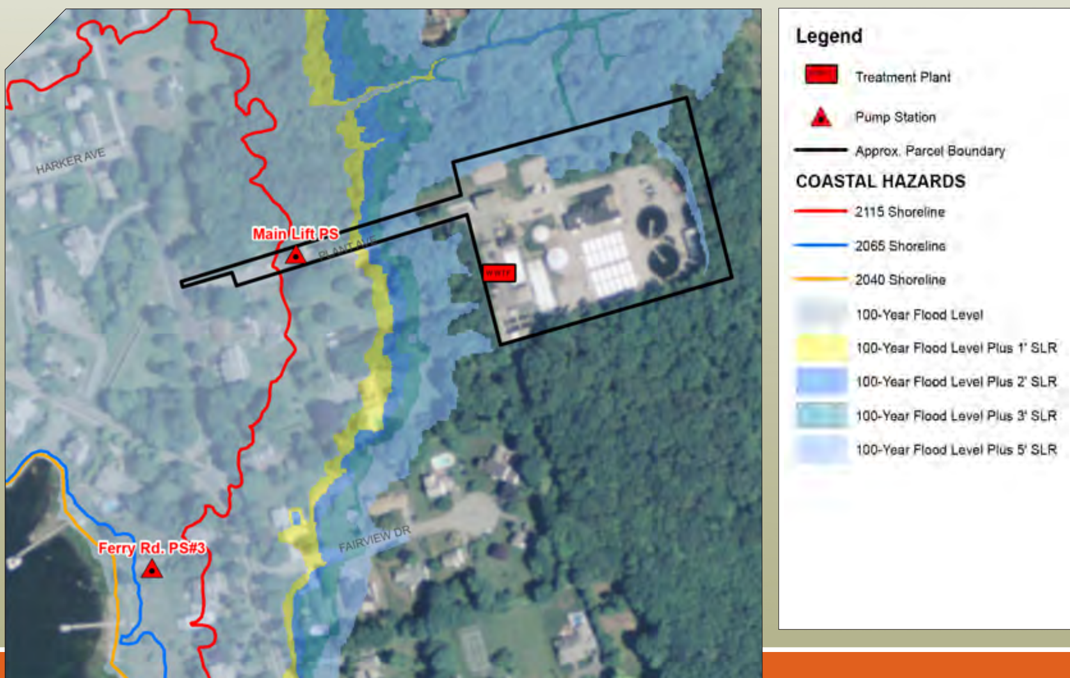
The facility itself will not be inundated during a 100-year storm but the access road will be with a water depth of 5-6 feet at the driveway entrance.

2 Coastal Flood Hazard

Main Lift Pump Station inundated by 100-year storm.

3 Shoreline Change

100-year shoreline is predicted to encroach on the access road unless active protection measures are implemented.



CLIMATE CHANGE ADAPTATION MEASURES UNDERWAY

Design and permitting is underway to construct drainage infrastructure on the south side of the property to mitigate local flooding experienced during recent rain events.

BRISTOL, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Town of Bristol
Operator	Town of Bristol
Facility Address	2 Plant Avenue Bristol, RI 02809
Contact Name	Jose DaSilva, Superintendent
Phone	401.253.8877
Design Flow Capacity	3.8 MGD
Average Daily Flow	2.8 MGD
Receiving Water	Bristol Harbor
Extreme Weather Related SSO Events 2010 - 2014	14 out of 24 events or 58%

The WWTF experiences localized flooding from Tanyard Brook to the north, west, and adjacent wetlands to the south. New drainage infrastructure is planned to mitigate this flooding source.

Inflow and/or infiltration into the collection system is of significant concern. WWTF operators note rapid increases in flow from 4 MGD up to 14 MGD during storm events. The treatment facility regulates influent by allowing only one of two 14 MGD screw pumps to operate at any one time.

I&I, combined with limited plant capacity, leads to sewage overflows during wet weather throughout town, which have negative impacts on Bristol Harbor, Narragansett Bay, Kickemuit River, and Mount Hope Bay.

Sump pumps connected to the Town sewer system are a major cause of the overflows. The Town was ordered by RIDEM and EPA to start a program to remove sump pump discharges from entering the sewer system.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Main LIft PS (Influent Screw Pumps)					C	Provide alternate route for influent from second screw pump to disinfection and discharge if primary and secondary treatment is flooded.
Disinfection System (Chlorine Contact Tanks)	B					Protect building with flood barriers and elevate critical equipment. Raise contact tank perimeter walls.
Operations Building / Generator	A	C				Protect building with flood barriers and elevate critical equipment. Provide alternative access road to facility from higher ground.
Constitution PS	A	D				Elevate pump station building above flood elevation, or relocate pump station inland.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

NBC-BUCKLIN POINT - CLIMATE VULNERABILITY SUMMARY

Bucklin Point is located at 102 Campbell Avenue in East Providence. It treats approximately 23 million gallons of wastewater per day in dry weather, serving approximately 130,000 customers in Pawtucket, Central Falls, Lincoln, and portions of Providence and East Providence. Bucklin Point is a combined system that treats stormwater flows during rain events up to about 46 million gallons per day. Additional information is on the back of this summary.

TOP 3 HAZARD MODELING RESULTS

Coastal Flood Hazard

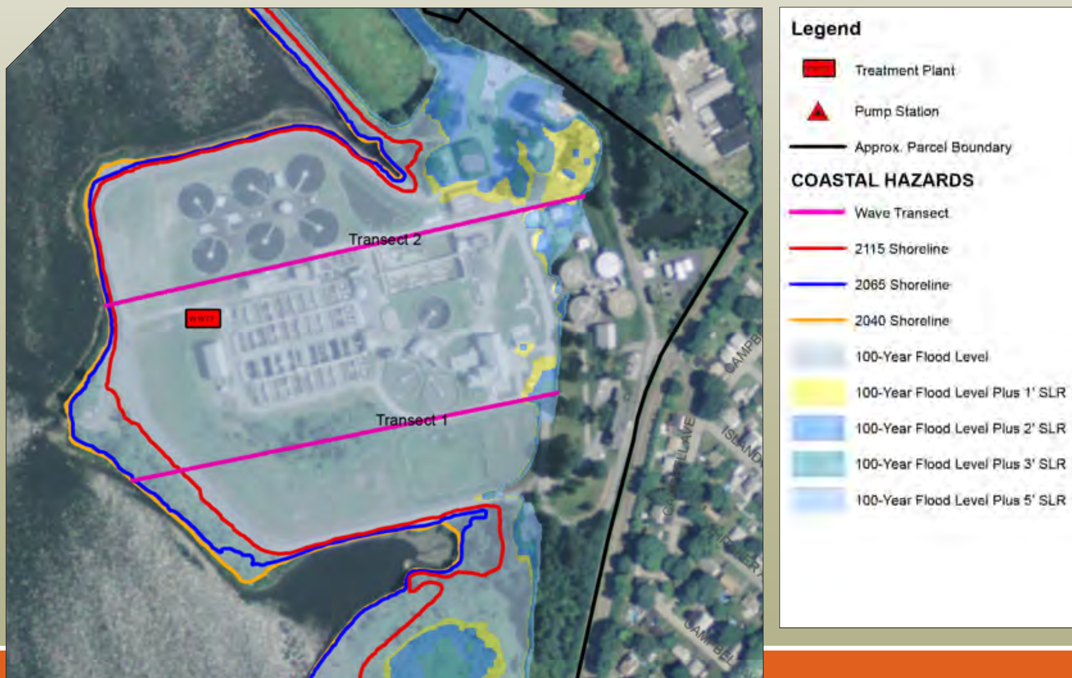
The 100-year storm would overtop the newly raised protective berm surrounding the WWTF. Water depth would be 10+ feet at center driveway.

Significant Wave Height for 100-year Event

5 feet approaching berm will overtop berm with storms less severe than 100-year event.

Inland Flood Hazard

Saylesville PS inundation at 100-year level plus 2 feet.



COMPLETED CLIMATE CHANGE ADAPTATION MEASURES

The berm surrounding the WWTF was raised an additional 12 to 18 inches in 2014 to above the 500-year flood elevation mapped on the FIRM. This berm protection incorporates tide gates for the plant effluent and storm water from the north and south retention ponds.

NBC-BUCKLIN POINT - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Narragansett Bay Commission
Operator	Narragansett Bay Commission
Facility Address	102 Campbell Avenue East Providence, RI 02914
Contact Name	Carmine Goneconte, Superintendent
Phone	401.434.6350
Design Flow Capacity	46.0 MGD
Average Daily Flow	23.1 MGD
Receiving Water	Seekonk River
Extreme Weather Related SSO Events 2010 - 2014	2 in Sewershed (Town of Lincoln Responsibility)

The WWTF is surrounded by the tidally-influenced Seekonk River on 3 sides. An earthen berm, raised in 2014 offers some protection from storm surge and wave action.

The facility's Emergency Action Plan does not address procedures for rising floodwaters, however, when the river level exceeds EL8 NAVD88, the operators direct the outfall tide gates to be closed and pump the effluent out to the river.

During storm events, operators close the tidegates on the discharge lines from the onsite stormwater collection ponds.

During wet weather conditions, the facility may direct up to 70 MGD of flow in excess of design capacity to 2.4 MG wet weather holding tanks. Wastewater directed to the holding tanks receive disinfection only, and subsequently begin discharging to the river when the tanks are full. Wastewater remaining in the tanks following the event are pumped back into the system. Total flows exceeding 2.4 MG trigger a sewer overflow event.

NBC stores an abundance of back-up pumping systems including multiple dry-prime pumps and hydraulic submersibles.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Readily **Repairable/ Replaceable**	Redundancy	Mitigation Strategy
Influent Pump Station (Screw Pumps)	D		B		Raise and extend perimeter berm.[1] Store replacement pump components on-site.
Primary Clarifiers	D		B		Raise and extend perimeter berm.[1] Pumps may be easily augmented. Replace sludge pumps with submersibles. Store replacement drive components on-site.
Disinfection System	D	B		B	Raise and extend perimeter berm.[1] Relocate critical components to high ground. Maintain back-up temporary chemical storage and pumping.
Effluent Pump Station	D	B			Raise and extend perimeter berm.[1] Relocate drive systems to high ground.
Saylesville PS	A				Protect building with flood barriers, and seal penetrations.

1. Raising and extending the perimeter berm will address multiple systems under one project.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

Burrillville Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

The Burrillville WWTF is located at 141 Clear River Drive in Burrillville. It treats an average of 0.83 million gallons of wastewater per day in dry weather, serving approximately 9,700 customers in the community. Additional information is on the back of this summary.

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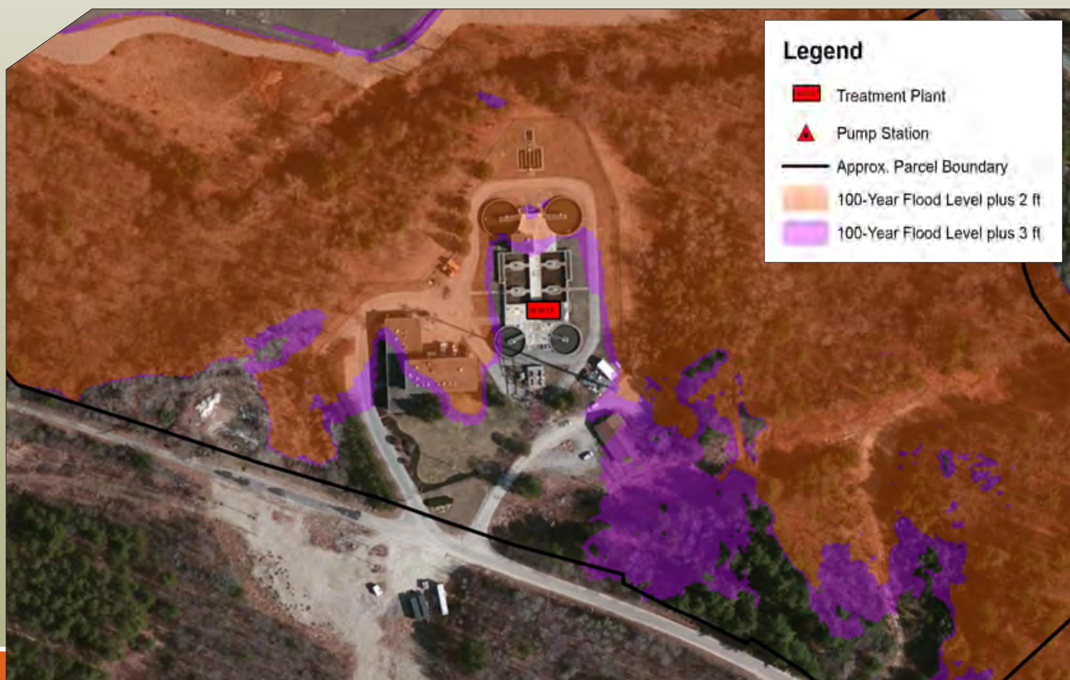
TOP 2 HAZARD MODELING RESULTS

Inland Flood Hazards 1

Partial inundation of the facility at the 100-year level plus 2 feet. Water depth would be about 1 foot at access road between chlorine contact tanks.

Inland Flood Hazards 2

School Street Ejector Station and Beach Road Ejector Station would be inundated at the 100-year level plus 2 feet.



BURRILLIVILLE, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Town of Burrillville
Operator	Town of Burrillville
Facility Address	141 Clear River Drive Burrillville, RI 02830
Contact Name	John Martin, Superintendent
Phone	401.568.9463
Design Flow Capacity	1.5 MGD
Average Daily Flow	0.83 MGD
Receiving Water	Clear River
Extreme Weather Related SSO Events 2010 - 2014	None reported

Rock Avenue and Beach Road ejector stations lack permanent back-up power.

School Street ejector station is often not accessible during rain events because of roadway flooding

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Mitigation Strategy
Primary **Clarifiers**	B		A	B	Store replacement drive components on-site. Protect entrances with flood barriers. Replace sludge pumps with submersibles. Pumps may be temporarily augmented.
Aeration Tanks			B		Store replacement drive components on-site.
Disinfection System (Chlorine Contact Tanks)	A				Protect building with flood barriers and elevate critical equipment.
Operations / Chemical / Generator Building	A				Protect building with flood barriers and elevate critical equipment.
Beach Road ES		C		B	Provide permanent back-up power. Relocate ES when existing equipment reaches the end of its useful life.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

Cranston Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

Cranston WWTF is located at 140 Pettaconsett Avenue in Cranston. It treats an average of 13.2 million gallons of wastewater per day, serving approximately 73,200 customers in Cranston. The WWTF shares the site with an incinerator capable of processing 66 dry tons of sludge per day. Additional information is on the back of this summary.

TOP 3 HAZARD MODELING RESULTS

1 Inland Flood Hazard

Inundation of six pump stations (Allard, Burnham, Mayflower, Pontiac, Randall, and Youlden) at the 100-year plus 2’ event.

2 Inland Flood Hazard

Inundation of chlorine contact tanks at the 100-year plus 2’ event and inundation of the disinfection and sludge thickening buildings at the 100-year plus 3’ event.

3 Coastal Flood Hazard

Seaview PS and Youlden PS inundation at 100-year level. Mayflower PS inundation at 100-year level plus 1 foot.

COMPLETED CLIMATE CHANGE ADAPTATION MEASURES

A permanent emergency generator was installed for the aeration blowers in 2014. Other recent mitigation efforts include flood proofing all pump stations and their respective generators that are located in the floodplain.

CRANSTON, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	City of Cranston
Operator	Veolia Water
Facility Address	140 Pettaconsett Avenue Cranston, RI 02920
Contact Name	Earl Salisbury, Superintendent
Phone	401.467.7210
Design Flow Capacity	20.2 MGD
Average Daily Flow	13.2 MGD
Receiving Water	Pawtuxet River
Extreme Weather Related SSO Events 2010 - 2014	3 out of 17 events or 18%

The Cranston WWTF has an extensive underground pipe gallery system. Equipment previously stored in the flood-vulnerable basements and pipe galleries have been moved to the higher points within the pipe gallery system.

The vast majority of concern with the Cranston process is with the collection system where multiple pump stations have experienced either flooding or flows exceeding the PS capacity.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Mitigation Strategy
Primary Clarifiers	A		B	B	Protect pipe gallery with flood barriers. Store replacement drive components on site. Pumps may be temporarily augmented.
Disinfection System (Chlorine Contact Tanks)	A	B			Elevate critical equipment or relocate critical equipment and tanks to elevated location.
Solids Handling	A				Protect building with flood barriers.
Pontiac Avenue PS	A				Protect building with flood barriers. Elevate generator equipment.
Randall PS	A				Protect building with flood barriers. Elevate generator equipment.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

East Greenwich Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

East Greenwich WWTF is located at 21 Crompton Avenue in East Greenwich. It treats an average of 0.8 million gallons of wastewater per day, serving approximately 6,000 customers in the community.
Additional information is on the back of this summary.

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TOP 3 HAZARD MODELING RESULTS

Coastal Flood Hazard

Most of the facility would be inundated by storm surge at the 100-year return period.

Significant Wave Height for 100-year Event

5 feet at the existing shoreline during 100-year event.

Shoreline Change

100-year shoreline is predicted to encroach on the access road unless active protection measures are implemented.

COMPLETED CLIMATE CHANGE ADAPTATION MEASURES

The plant's influent pump station and tertiary treatment systems were recently upgraded with dry-mounted submersible pumps.

EAST GREENWICH, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Town of East Greenwich
Operator	Town of East Greenwich
Facility Address	21 Crompton Avenue East Greenwich, RI 02818
Contact Name	Shawn O'Neill, Superintendent
Phone	401.886.8619
Design Flow Capacity	1.7 MGD
Average Daily Flow	0.8 MGD
Receiving Water	Greenwich Cove
Extreme Weather Related SSO Events 2010 - 2014	1 out of 22 events or 5%

The facility arrangement is unusual in that while the access roads that surround the facility are at a relatively low elevation, many of the process components are operated from elevated locations within a main building on the site, protecting them from flood hazards.

The Cedar Heights pump station is adjacent to a small stream, which could potentially hinder access to the site during significant rain events, due to the lack of a paved access road and the low access bridge crossing the stream.

The main facility and pump stations have permanent pumping redundancy and back-up power systems although
operators identified a need for a new generator to improve standby power capabilities at the plant and pump stations.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Mitigation Strategy
Influent Pump Station (Dry-Pit Submersibles)	A				Protect facility entrances with flood barriers.
Primary Clarifiers	A		B	B	Protect facility entrances with flood barriers. Store replacement drive components on-site. Pumps may be temporarily augmented.
Disinfection System (UV)	A	A			Elevate disinfection equipment and relocate electrical equipment (transformer) to higher elevation.
Operations Building	A				Protect facility entrances into critical areas (generator room) with flood barriers.
Cedar Heights PS	A				Elevate electrical equipment above grade.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

East Providence Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

WOODARD &CURRAN

East Providence WWTF is located at Crest Avenue in Riverside. It treats an average of 2.5 million gallons of wastewater per day, serving approximately 46,100 customers in East Providence and Barrington. Additional information is on the back of this summary.

TOP 3 HAZARD MODELING RESULTS

Coastal Flood Hazard

Inundation of most of the facility during a 100-year storm with water depth between the aeration tanks and secondary clarifiers at 5-6 feet.

Coastal Flood Hazard

Inundation of Sabin Point PS and Silver Street PS during a 100-year storm.

Significant Wave Height for 100-year Event

4-5 feet approaching the shoreline.

COMPLETED CLIMATE CHANGE ADAPTATION MEASURES

Recent flood mitigation projects include constructing the new Watchemoket pump station above the FEMA designated 100-year floodplain, and upgrading and elevating multiple generators at the WWTF site on belly tanks.

EAST PROVIDENCE, RI - CLIMATE VULNERABILITY SUMMARY

WOODARD & CURRAN

FACILITY SUMMARY

Owner	East Providence
Operator	Suez
Facility Address	Crest Avenue Riverside, RI 02915
Contact Name	Tom Azevedo, Superintendent
Phone	401.433.6363
Design Flow Capacity	14.2 MGD
Average Daily Flow	6.7 MGD
Receiving Water	Providence River
Extreme Weather Related SSO Events 2010 - 2014	9 out of 24 events or 38%

East Providence has extensive infiltration and inflow issues that are being addressed by a variety of means including raising manhole covers and epoxy lining the collection system piping.

The new (2012) Watchemoket Cove pump station capacity was increased to 10 MGD to mitigate SSOs.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Mitigation Strategy
Aeration Tanks (Circular)	A				Protect facility entrances with flood barriers.
Secondary Clarifiers	B		B	B	Replace glass entranceway with flood resistance walls. Protect facility entrance with flood barriers. Store replacement drive components on-site. Pumps may be temporarily augmented.
Disinfection System (Chlorine Contact Tanks)	A				Protect facility entrances with flood barriers.
Operations Building	A				Protect facility entrances with flood barriers.
Silver Street PS	A	B			Protect facility entrances with flood barriers. Relocate fuel tank.

A = < $50,000   B = $50,000 to $250,000   C = $250,000 - $1,000,000   D = > $1,000,000

NBC - Fields Point Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

Fields Point is located at 2 Ernest Street in Providence. It treats approximately 45.5 million gallons of wastewater per day in dry weather, serving approximately 226,000 customers in portions of Johnston, North Providence, Providence, and Cranston. Fields Point is a combined system that treats stormwater flows during rain events up to about 65 million gallons per day. Additional information is on the back of this summary.

WOODARD & CURRAN

TOP 3 HAZARD MODELING RESULTS

Coastal Flood Hazard

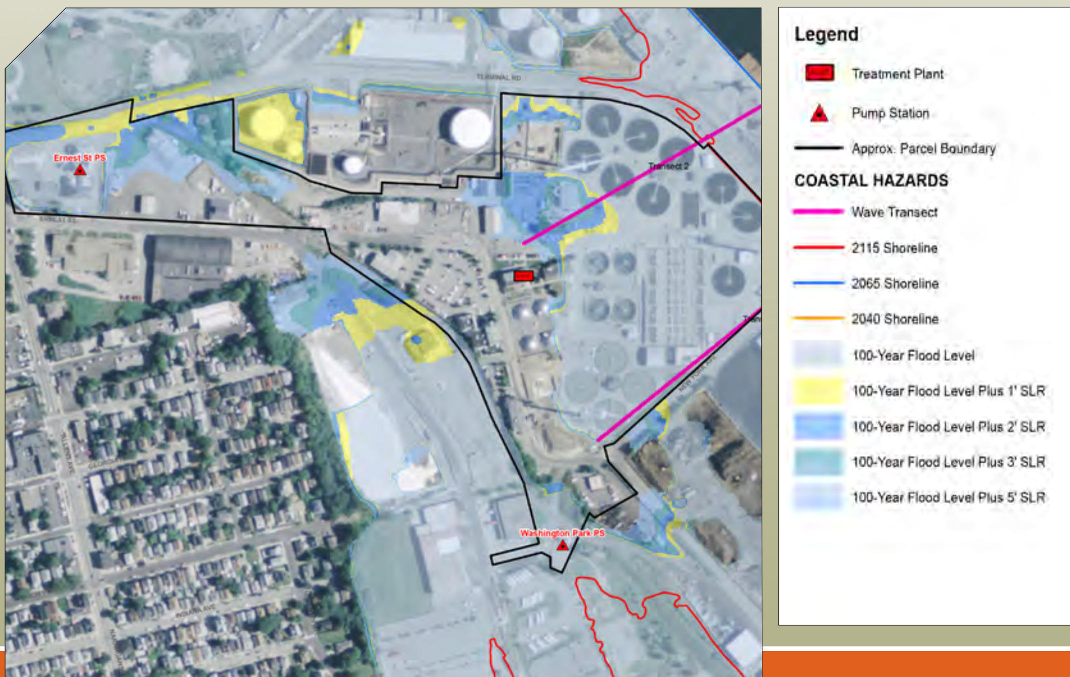
Most of the WWTF components and the Ernest Street pump station would be inundated by storm surge at the 100-year return period.

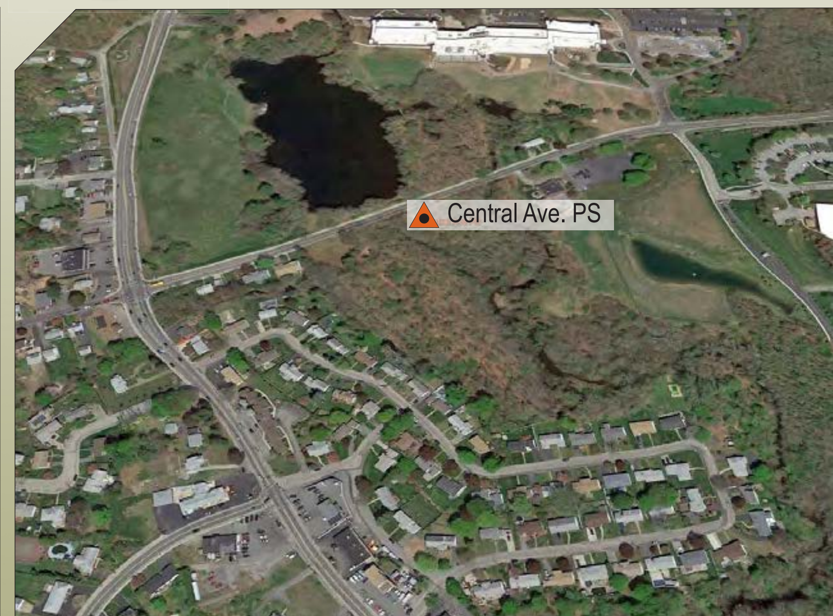
Significant Wave Height for 100-year Event

5 feet at the existing shoreline during 100-year event.

Inland Flood Hazard

The Central pump station in Johnston would be inundated at the 100-year level plus 2 feet.





NBC - FIELDS POINT, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Narragansett Bay Commission
Operator	Narragansett Bay Commission
Facility Address	2 Ernest Street Providence, RI 02905
Contact Name	Paul Desrosiers, Superintendent
Phone	401.461.8848
Design Flow Capacity	65.0 MGD
Average Daily Flow	45.5 MGD
Receiving Water	Providence River
Extreme Weather Related SSO Events 2010 - 2014	8 out of 74 events or 11%

During wet weather conditions, the WWTF can reach secondary-level treatment for up to 77 MGD and route additional flows through primary treatment and disinfection up to 123 MGD.

The total treatment capacity at the Fields Points WWTF is 200 MGD and influent flows in excess of 200 MGD are discharged directly to the Providence River.

To equalize high wet weather influent flows, the facility operates off a main interceptor carrying roughly 3 MG of capacity and a "deep rock tunnel" designed to hold 65 MG of excess influent.

Operator's primary concern is discharging plant and CSO flow during extreme high tides, which they recognize will become more critical as sea level rises.

The NBC maintains six permanent flow metering stations and is responsible for 38 Combined Sewer Overflows, 32 tide gates, and 80 miles of interceptors in the Fields Point service area.

The site has three wind turbines that generate up to 1.5 MW each; or 40% of the power necessary to operate the facility.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Readily Repairable/ Replaceable	Redundancy	Mitigation Strategy
Influent Pump Station (Ernest Street PS)	A			Protect facility entrances with flood barriers.
"Deep Rock Tunnel" System	A			Protect facility entrances with flood barriers.
Intermediate Pump Station (Screw Pumps)	A			Protect facility entrances with flood barriers.
Disinfection System (Chlorine Contact Tanks)	A			Protect facility entrances with flood barriers.
Generators	A			Protect facility entrances with flood barriers and elevate generator equipment.
Primary Clarifiers	B	B	B	Protect facility entrances with flood barriers. Replace sludge pumps with submersibles. Pumps may be temporarily augmented. Store replacement drive components on-site.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

Jamestown Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

Jamestown WWTF is located at 165 Freebody Drive in Jamestown. It treats an average of 0.3 million gallons of wastewater per day, serving approximately 2,100 customers on the island. Additional information is on the back of this summary.

TOP 3 HAZARD MODELING RESULTS

Coastal Flood Hazard

WWTF and several pump stations would be inaccessible from the mainland during a 100-year storm

Coastal Flood Hazard

Maple Avenue pump station inundation by 100-year storm.

Coastal Flood Hazard

Beavertail and Narragansett pump stations inundation by 100-year storm plus 3 feet SLR.

JAMESTOWN, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Town of Jamestown
Operator	Town of Jamestown
Facility Address	165 Freebody Drive Jamestown, RI 02835
Contact Name	Douglas Ouellette, Superintendent
Phone	401.423.7295
Design Flow Capacity	0.73 MGD
Average Daily Flow	0.3 MGD
Receiving Water	Dutch Island Harbor/ Narragansett Bay East Passage
Extreme Weather Related SSO Events 2010 - 2014	8 of 8 or 100%

Bayview Drive PS and Beavertail Road PS have dry-pit submersible pumps, which will survive flood inundation but are subject to failure during a flood event because of electrical system vulnerabilities.

Operators report the Narragansett Avenue Pump Station more frequently requires augmentation with a portable pump during wet weather.

All four pump stations are subject to subject to extreme precipitation events as evidenced by their inundation by influent flow or floodwaters during the March 2010 storm events.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Redundancy	Mitigation Strategy
Control and Solids Handling Building		C		Provide alternative emergency access road on Route 138 between the toll booth facility and bridge to access the WWTF and the portion of the island south of Great Creek.
Maple Avenue PS	C		B	Provide enclosed elevated pump station equipment structure. Provide permanent back-up power.
Narragansett Avenue PS	A			Protect facility entrances with flood barriers. Relocate generator louver building penetrations.
Beavertail Road PS	A			Protect facility entrances with flood barriers. Relocate generator and ventilation louver building penetrations.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

Narragansett Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

Scarborough WWTF is located at 990 Ocean Road in Narragansett. It treats an average of 1.4 million gallons of wastewater per day, serving approximately 7,300 customers in the southern portion of Narragansett. Additional information is on the back of this summary.

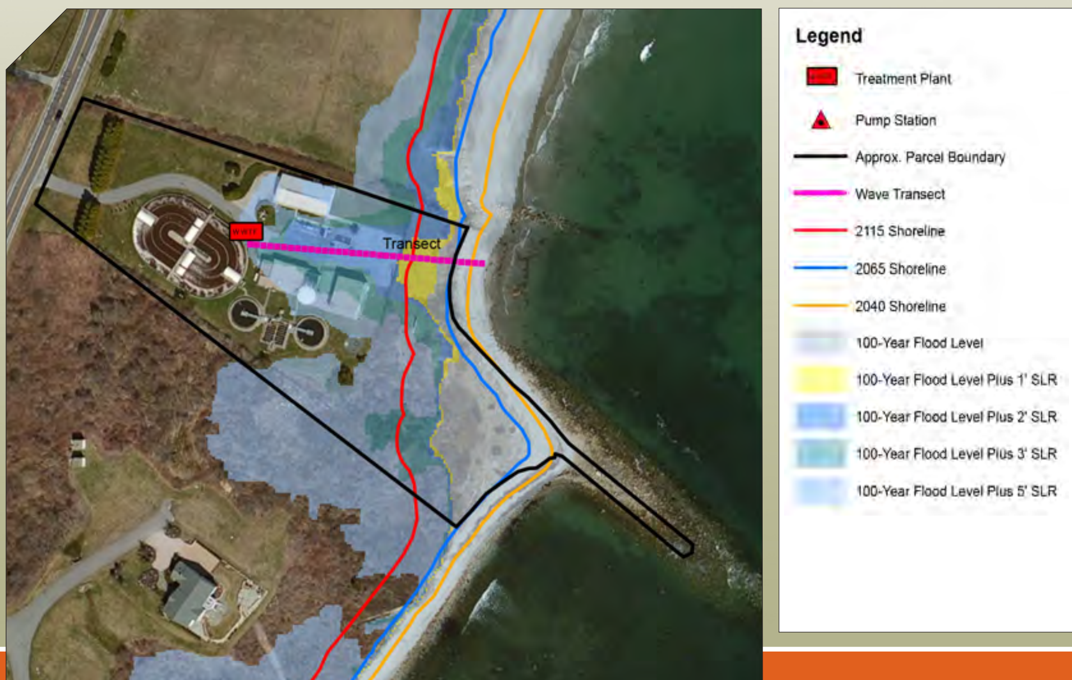
TOP 2 HAZARD MODELING RESULTS

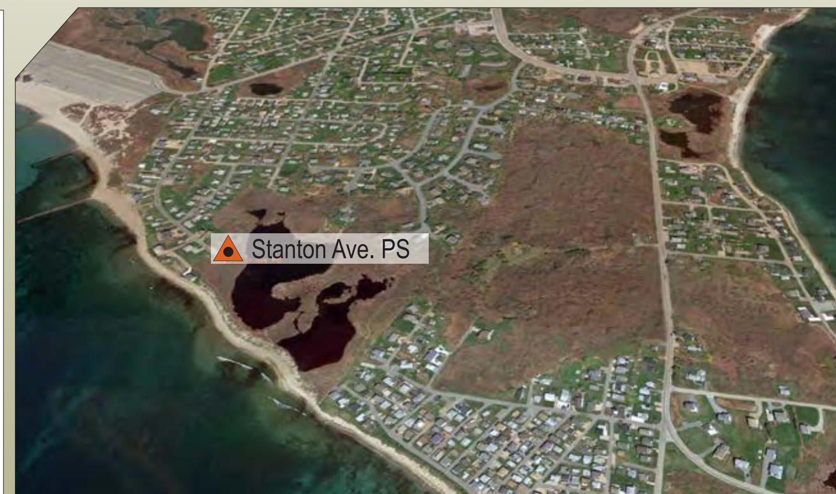
1 Coastal Flood Hazard

Stanton Ave, Galilee, and Mettatuxet pump stations inundated during a 100-year storm.

2 Coastal Flood Hazard

The proposed WWTF flood barrier will impede shoreline erosion and dampen waves but inundation will become a factor during a 100-year storm with 5 feet of SLR if adjacent properties do not harden and protect their shoreline.





PLANNED CLIMATE CHANGE ADAPTATION MEASURES

Construction of a flood-proofing barrier is planned for 2017 to protect the facility from damaged caused by storm surge.

NARRAGANSETT, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Town of Narragansett
Operator	Town of Narragansett
Facility Address	990 Ocean Road Narragansett, RI 02882
Contact Name	Peter Eldridge, Superintendent
Phone	401.782.0682
Design Flow Capacity	1.4 MGD
Average Daily Flow	0.6 MGD
Receiving Water	Rhode Island Sound
Extreme Weather Related SSO Events 2010 - 2014	4 out of 18 events or 22%

The Scarborough WWTF is located on a coastal bluff adjacent to Rhode Island Sound, which makes it susceptible to storm surge and other severe weather impacts.

The Stanton Avenue PS is isolated and floods regularly because of its location adjacent to a salt-water marsh. Access to the Stanton Avenue PS has been restricted during seasonal high tides and heavy rainfalls.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Readily Repairable/ Replaceable	Mitigation Strategy
Influent Pump Station and Preliminary Treatment (Screening / Grit Removal)	B			Replace influent pumps with submersibles.
Aeration Tanks	A		B	Protect facility entrances with flood barriers. Store replacement drive components on-site.
Disinfection System (Chlorine Contact Tanks)	A			Protect facility entrances from contact tank surcharge with flood barriers.
Generator	A			Protect facility entrances from contact tank surcharge with flood barriers.
Mettatuxet PS	B	C		Protect slab penetrations and equipment with flood barriers or slab perimeter wall. Relocate pump station inland.

A = < $50,000   B = $50,000 to $250,000   C = $250,000 - $1,000,000   D = > $1,000,000

New Shoreham Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

New Shoreham WWTF is located at 252 Spring Street in New Shoreham (Block Island). It serves approximately 300-700 customers during the winter and approximately 4,000 customers during the summer. Additional information is on the back of this summary.

WOODARD &CURRAN

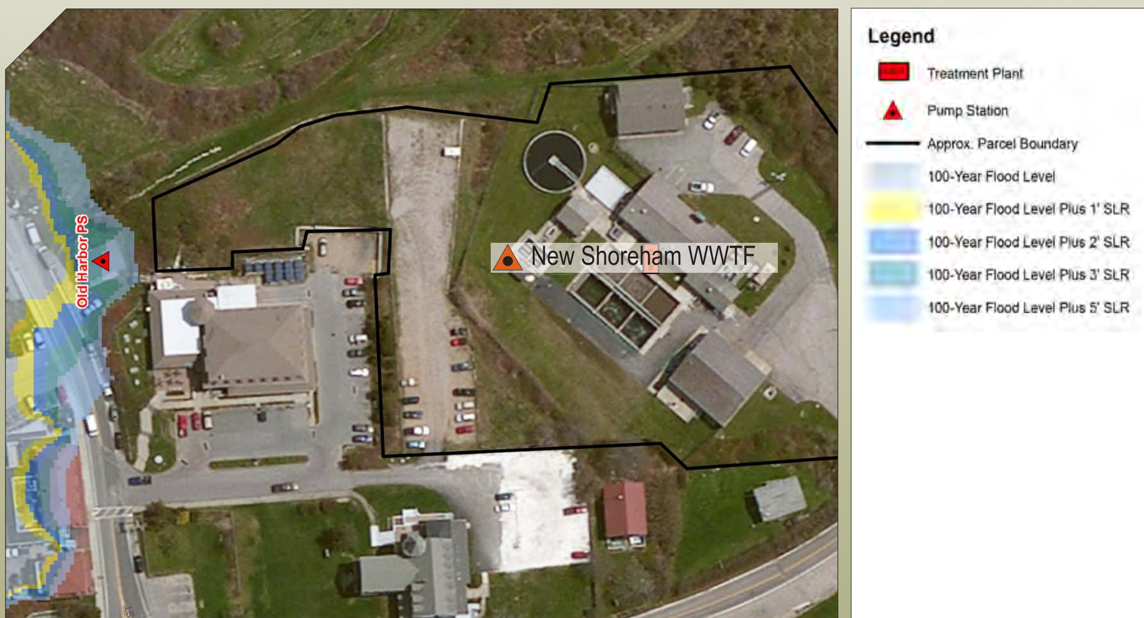
TOP 2 HAZARD MODELING RESULTS

1 Coastal Flood Hazard

Ocean Ave. PS #1, Ocean Ave. PS #2, are inundated at the 100-year flood event.

2 Coastal Flood Hazard

Old Harbor (Main) PS is inundated at the 100-year flood event with 1 foot of SLR.



NEW SHOREHAM, RI - CLIMATE VULNERABILITY SUMMARY

WOODARD & CURRAN

FACILITY SUMMARY

Owner	Town of New Shoreham
Operator	Town of New Shoreham
Facility Address	252 Spring Street New Shoreham, RI 02807
Contact Name	Chris Blane, Superintendent
Phone	401.466.3231
Design Flow Capacity	0.3 MGD
Average Daily Flow	0.2 MGD Summer / 0.05 MGD Winter
Receiving Water	Rhode Island Sound
Extreme Weather Related SSO Events 2010 - 2014	None reported

Transportation vessels supplying the island terminate operation approximately 72 hours prior to major storm events, isolating the island so the facility stores chlorinating/dechlorinating chemicals and sodium hydroxide for alkalinity adjustment on-site, and maintains a stock of lime for back-up alkalinity adjustment.

The facility has two old rectangular clarifiers used to hold press filtrate; in the winter time these tanks can hold up to 2 days' worth of influent flow in case of system failure.

The treatment facility isolates itself from the power grid under winds exceeding 45 mph; power is cut off at the grid at 75 mph.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Readily Repairable/ Replaceable	Bypass	Mitigation Strategy
Preliminary Treatment (Screening / Grit Removal)				Unneccessary or low priority
Aeration Tanks				Unneccessary or low priority
Secondary Clarifiers		A		Store replacement drive components on site.
Old Harbor (Main) PS	B		A	Modify structure to withstand wave impact and elevate building penetrations. Establish station shutdown plan for implementation during conditions of seawater inundation.
Ocean Avenue #1 PS	A			Elevate control panels above grade.
Ocean Avenue #2 PS	A			Elevate control panels above grade.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

Newport Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

Newport WWTF is located at 250 J.T. Connell Highway in Newport, approximately 1,000 feet inland from Coasters Harbor. It treats an average of 8.4 million gallons of wastewater per day in dry weather, serving approximately 41,600 customers in Newport, Middletown, U.S. Naval Station Newport, and a portion of Portsmouth. Newport is a combined system that treats stormwater flows during rain events with capacity up to 19.7 million gallons per day. Additional information is on the back of this summary.

WOODARD & CURRAN

TOP 3 HAZARD MODELING RESULTS

1 Coastal Flood Hazard

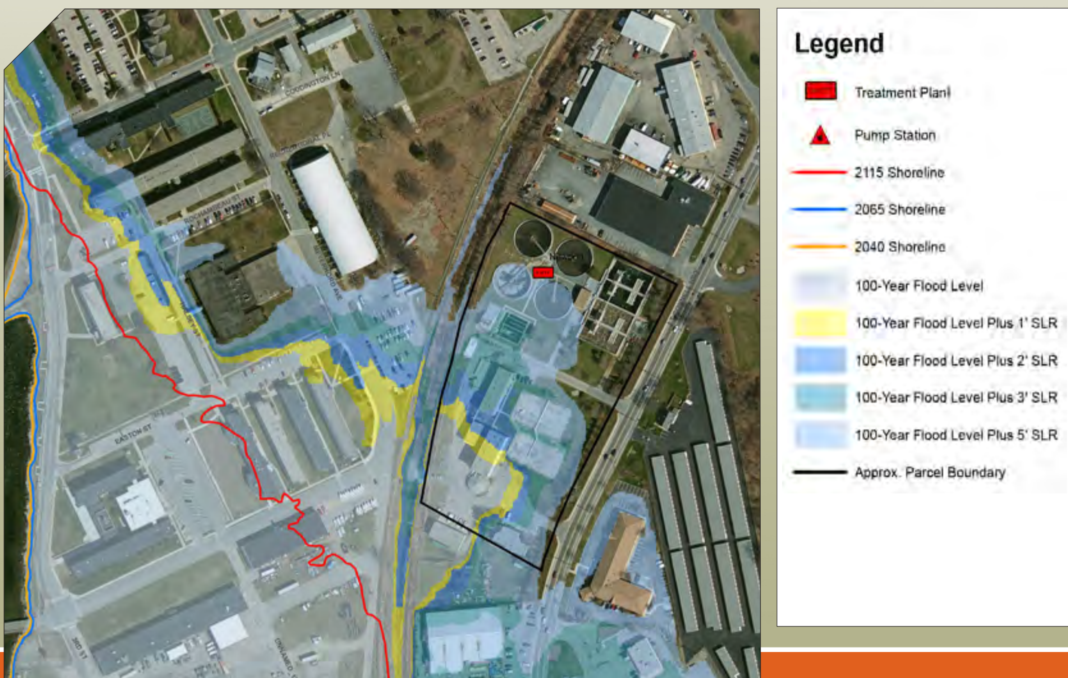
Partial inundation of the WWTF during a 100-year storm.

2 Coastal Flood Hazard

Main power disconnect inundated during 100-year storm event with 2-3 feet of SLR.

3 Coastal Flood Hazard

Dyre Street, Goat Island, Long Wharf, and Wellington pump stations and Washington CSO facility inundated during a 100-year storm.



NEWPORT, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Town of Newport
Operator	Suez
Facility Address	250 J.T. Connell Highway Newport, RI 02840
Contact Name	Thomas Ciolfi, Superintendent
Phone	401.845.2000
Design Flow Capacity	10.7 MGD
Average Daily Flow	8.4 MGD
Receiving Water	Narragansett Bay East Passage
Extreme Weather Related SSO Events 2010 - 2014	21 out of 85 events or 25%

The WWTF has an effluent pumping system used during high surface water conditions at the outfall. Operators estimate the effluent pumping frequency averages one event per month.

Newport operates two CSO facilities.

Facility upgrades are underway to increase treatment capacity and eliminate CSOs. The upgrades will impact preliminary, primary and secondary treatment as well as solids handling and will raise the maximum daily flow capacity from 19.7 MGD to 30 MGD.

Efforts are on-going to separate catch basins from the sanitary system.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Readily Repairable/ Replaceable	Redundancy	Mitigation Strategy
Primary Clarifiers	B	B	B	Protect facility penetrations (and electrical equipment) with flood barriers. Store replacement drive components on site. Replace sludge pumps with submersibles. Pumps may be temporarily augmented.
Disinfection System (Chlorine Contact Tanks)	A			Protect facility entrances with flood barriers.
Effluent Pump Station (Screw Pumps)	A			Protect facility entrances with flood barriers.
Long Wharf PS	A			Protect facility entrances with flood barriers and relocate building penetrations for louvers.
Wellington Avenue PS/CSO	A			Protect facility entrances with flood barriers.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

Quonset Point Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

Quonset Point WWTF is located at 150 Zarbo Avenue in North Kingstown. It treats an average of 0.49 million gallons of wastewater per day, serving approximately 10,000 commercial and industrial customers in the Quonset Business Park. New connections are expected to contribute up 200,000 gpd over the next 5 years. Additional information is on the back of this summary.

TOP 4 HAZARD MODELING RESULTS

Coastal Flood Hazards

WWTF inundation by storm surge at the 100-year return period with a water depth of 1-5 feet throughout the site.

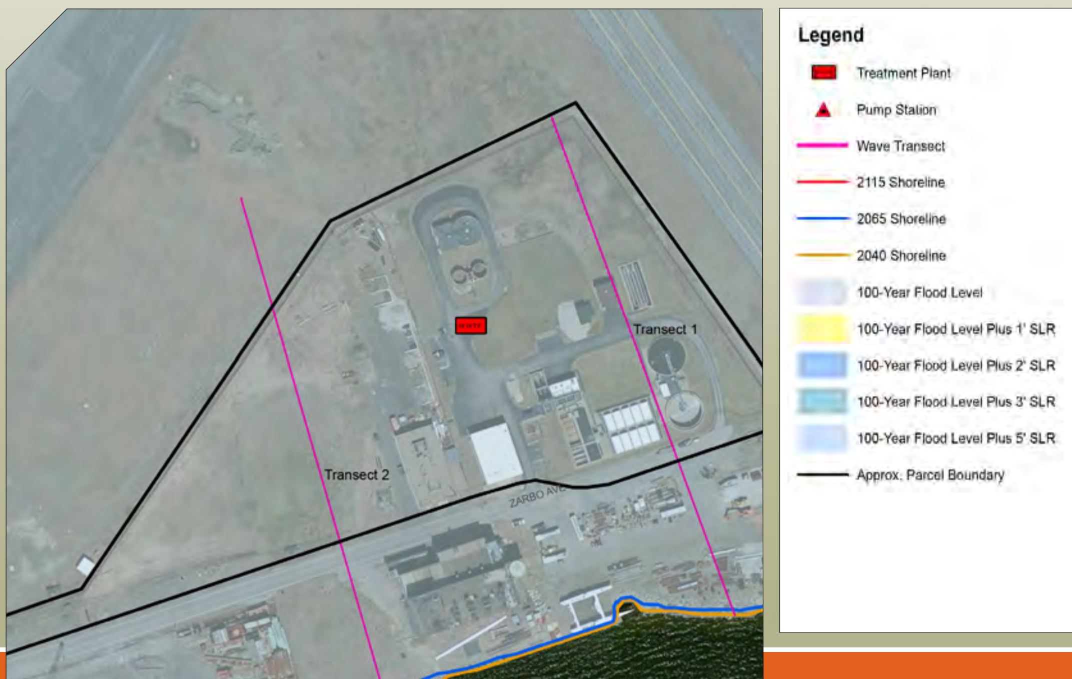
Davisville Pier PS and Burlingham PS would be inundated by storm surge at the 100-year return period with water depths at 3± feet. Davisville PS would also be inundated.

Significant Wave Height for 100-year Event

3-4 feet at the shoreward structures.

Shoreline Change

100-year shoreline is predicted to be more than 1,200 feet inland of the WWTF unless active protection measures are implemented.



COMPLETED CLIMATE CHANGE ADAPTATION MEASURES

All sections of the WWTF were built to withstand FEMA mapped 100-year peak flood levels.

QUONSET POINT, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Quonset Development Corporation
Operator	Quonset Development Corporation
Facility Address	150 Zarbo Avenue North Kingstown, RI 02852
Contact Name	Dennis Colberg, Superintendent
Phone	401.294.6342
Design Flow Capacity	1.78 MGD
Average Daily Flow	0.49 MGD
Receiving Water	Narragansett Bay West Passage
Extreme Weather Related SSO Events 2010 - 2014	None reported

Many of the treatment process components are protected by elevated tank walls and many of the facility entryways are elevated several feet above the ground. The sludge pump building has a stop-log system installed for a higher level of protection. Although these protective measures may allow the facility to successfully function during a natural hazard event, it would likely be unsafe for personnel to be onsite during such conditions.

Pumping systems around the site are located below grade and would be vulnerable if water were to pass through the entryways.

The louvers supporting the aging generator system are elevated but are on the bayside of the building and may be vulnerable to wave action or run-up during a major storm event.

Spare pumps and generators are stored on-site and additional stand-by equipment is available through other QDC departments.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Redundancy	Mitigation Strategy
Influent Pump Station (Submersibles)	A		Protect facility entrances with flood barriers. Extend perimeter walls upward.
Preliminary Treatment (Grinder / Screening / Grit Removal)	A		Protect facility entrances with flood barriers. Pumps may be temporarily augmented. Replace sludge pumps with submersibles.
Primary Clarifiers (Rectangular)	A	B	Protect facility entrances with flood barriers. Pumps may be temporarily augmented.
Disinfection System (Chlorine Contact Tanks)	A		Protect facility entrances with flood barriers.
Generator	A		Protect facility entrances with flood barriers and relocate building penetrations for louvers.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

Smithfield Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

The Smithfield WWTF is located at 20 Esmond Mill Drive in Smithfield. It treats an average of 3.5 million gallons of wastewater per day, serving approximately 14,000 customers in Smithfield. Additional information is on the back of this summary.

WOODARD &CURRAN

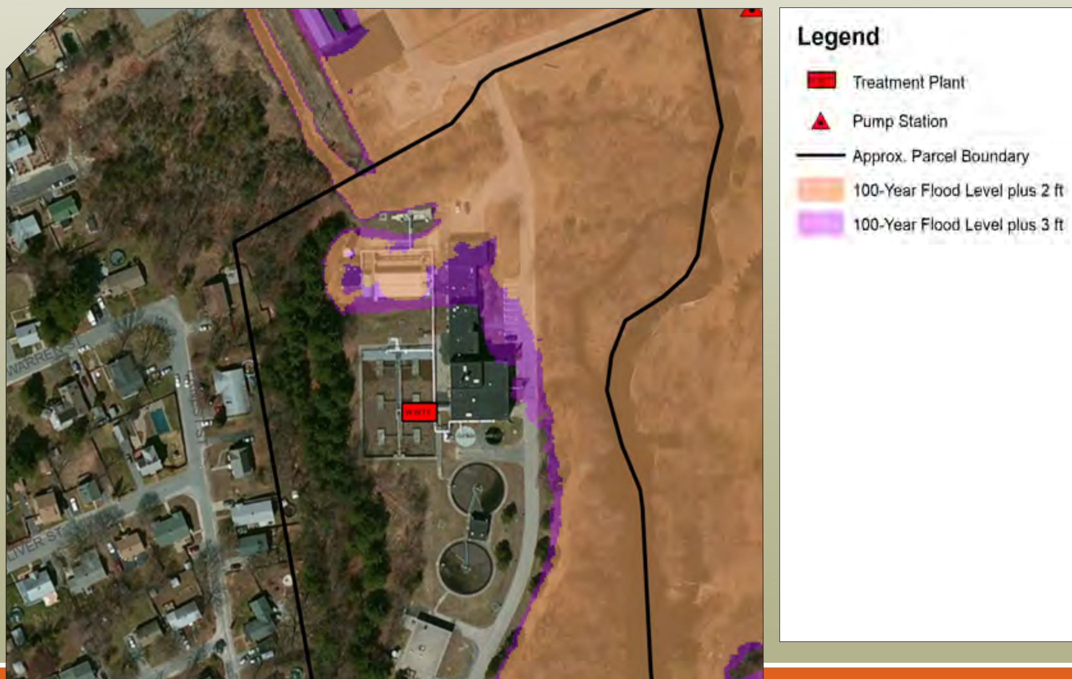
TOP 2 HAZARD MODELING RESULTS

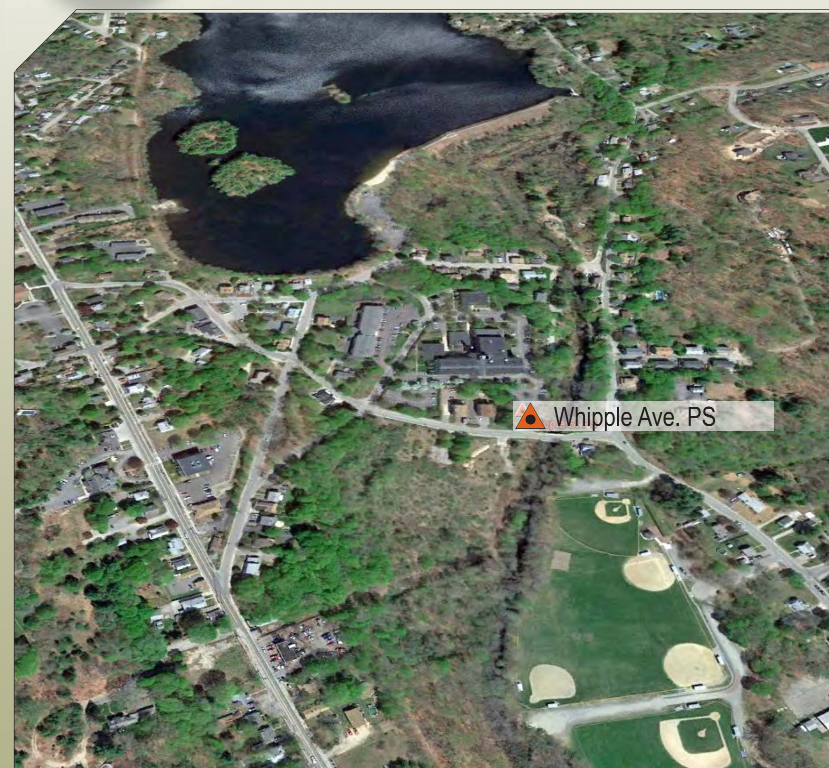
1 Inland Flood Hazard

Partial inundation of the WWTF at the 100-year level plus 2 feet, with a water depth of 5 feet in the access road

2 Inland Flood Hazard

Inundation of the Whipple Ave. PS and Camp Street PS at the 100-year level plus 2 feet





SMITHFIELD, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Town of Smithfield
Operator	Veolia Water
Facility Address	20 Esmond Mill Drive Smithfield, RI 02917
Contact Name	Karen Goffe, Superintendent
Phone	401.231.1506
Design Flow Capacity	3.5 MGD
Average Daily Flow	1.4 MGD
Receiving Water	Woonasquatucket River
Extreme Weather Related SSO Events 2010 - 2014	1 out of 10 events or 10%

The March 2010 storms caused multiple operational failures with the collection and treatment systems, including:

- Inundation of the Whipple Ave. PS and Camp Street PS
- Capacity shortfalls with the Roger Williams Drive PS and the Farnum Pike PS, which required augmentation with vacuum trucks
- Inundation of the WWTF access road, which necessitated access via a property easement
- Inundation of the disinfection system

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Readily Repairable/ Replaceable	Redundancy	Mitigation Strategy
Primary Clarifiers (Rectangular)	B	B	B	Protect facility entrances with flood barriers. Extend tank perimeter wall upward. Store replacement drive components on site. Pumps may be temporarily augmented. Replace sludge pumps with submersibles.
Intermediate Pump Station	A			Protect facility entrances with flood barriers.
Operations/Administration Building	A			Protect facility entrances with flood barriers.
Whipple Avenue PS	A			Protect facility entrances with flood barriers.
Camp Street PS	A			Protect facility entrances with flood barriers.

A = < \$50,000 B = \$50,000 to \$250,000 C = \$250,000 - \$1,000,000 D = > \$1,000,000

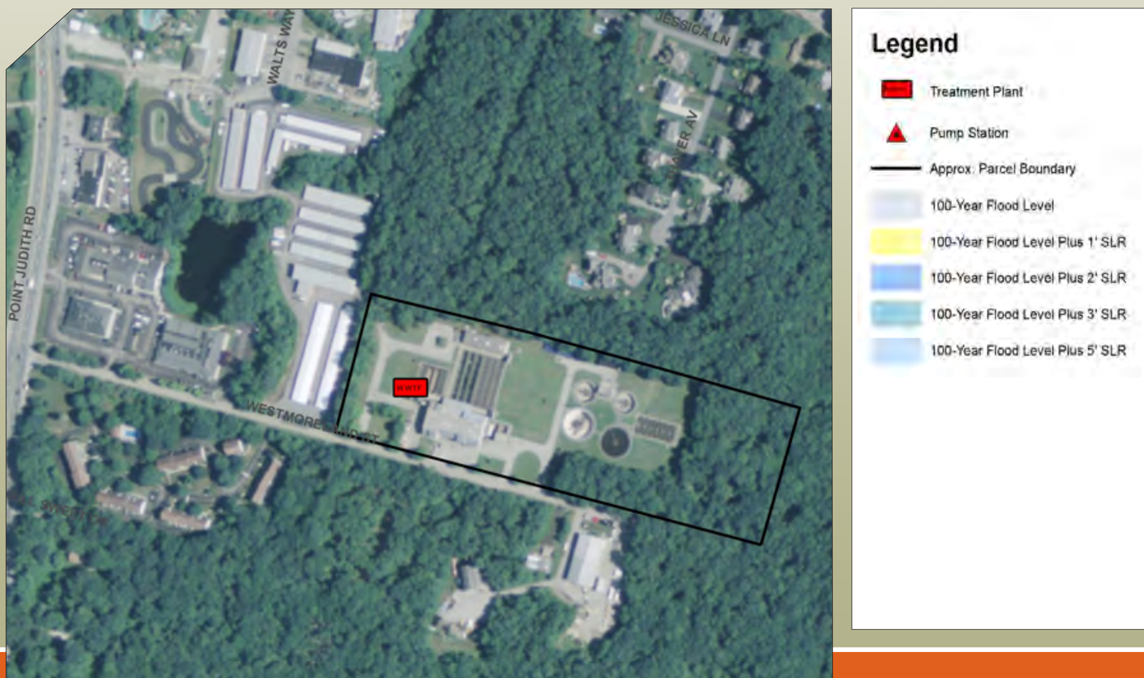
South Kingstown Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

South Kingstown WWTF is located at 275 Westmoreland Street in Narragansett. It treats an average of 2.4 million gallons of wastewater per day, serving approximately 29,400 customers in South Kingstown, Narragansett, and the University of Rhode Island. Additional information is on the back of this summary.

TOP HAZARD MODELING RESULT

Coastal Flood Hazard

Silver Lake PS, Middlebridge North PS, Middlebridge South PS, and Salt Pond PS inundated by 100-year storm



SOUTH KINGSTOWN, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Town of South Kingstown
Operator	Town of South Kingstown
Facility Address	275 Westmoreland Street Narragansett, RI 02882
Contact Name	Kathy Perez, Superintendent
Phone	401.788.9771
Design Flow Capacity	5.0 MGD
Average Daily Flow	2.4 MGD
Receiving Water	Rhode Island Sound
Extreme Weather Related SSO Events 2010 - 2014	3 out of 8 events or 38%

High flows from the Kingston PS during rain events indicate I&I originating from the University of Rhode Island.

Fluctuations in flow received by the WWTF caused by I&I correspond to fluctuations in concentration, which complicates treatment.

The WWTF appears well protected from climate change related event.

Several pump stations are adjacent to coastal waters and lack back-up power.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Mitigation Strategy
Silver Lake PS	A				Protect facility entrances with flood barriers. Elevate electrical equipment above grade.
Salt Pond PS	A				Elevate fuel tank, ventilation pipe, and electrical equipment.
Middlebridge North PS	A				Protect facility entrances with flood barriers and relocate building penetrations for louvers.
Middlebridge South PS	A				Protect facility entrances with flood barriers and relocate building penetrations for louvers.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

Warren Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

WOODARD & CURRAN

Warren WWTF is located at 427 Water Street in Warren. It treats an average of 1.8 million gallons of wastewater per day in, serving most of the densely populated portions of Warren. The plant also accepts approximately 400,000 gallons per year of septage from in-town systems only. Additional information is on the back of this summary.

TOP 4 HAZARD MODELING RESULTS

Coastal Flood Hazards

Inundation of the entire WWTF during a 100-year storm with a stillwater depth of 7+ feet and flooding beyond Water Street will prevent vehicular access to the surrounding area.

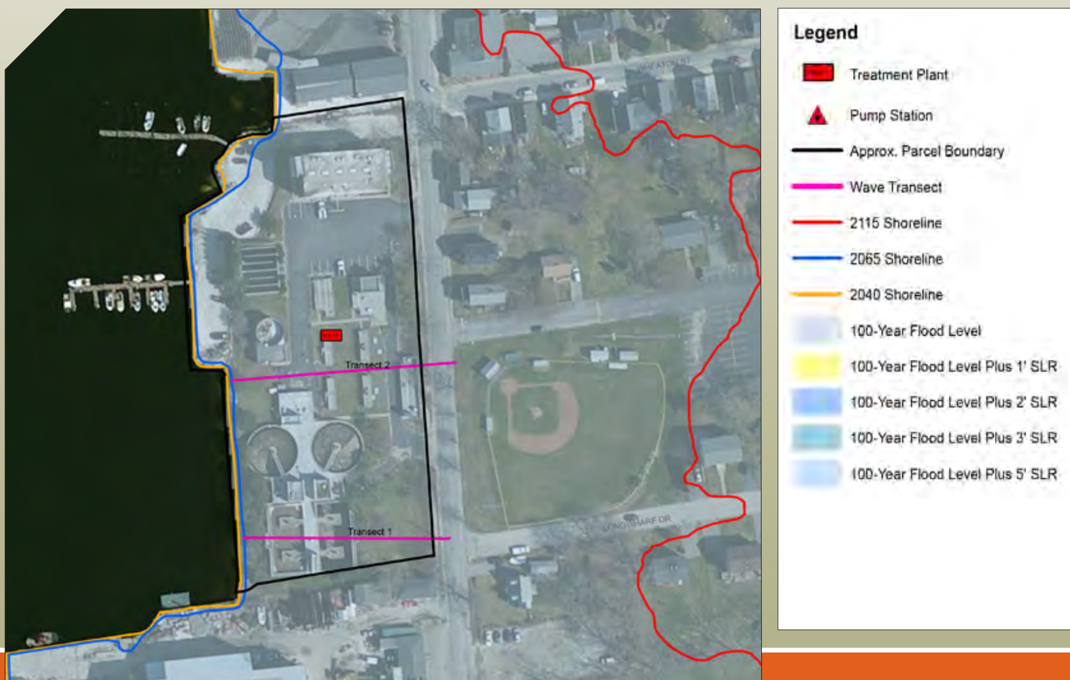
North PS, Wood Street PS, Asylum PS, Patterson Ave PS, and Locust Terrace PS would be inundated during a 100-year storm.

Significant Wave Height for 100-year Event

5 feet at the shoreward structures.

Shoreline Change

100-year shoreline is predicted to be more than 300 feet inland of Water Street unless active protection measures are implemented.



PLANNED CLIMATE CHANGE ADAPTATION MEASURES

The WWTF is undergoing design of a major upgrade that is incorporating several climate change resiliency measures as a result of this assessment.

WARREN, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Town of Warren
Operator	Suez
Facility Address	427 Water Street Warren, RI 02885
Contact Name	David Komiega, Superintendent
Phone	401.245.8326
Design Flow Capacity	2.01 MGD
Average Daily Flow	1.8 MGD
Receiving Water	Warren River
Extreme Weather Related SSO Events 2010 - 2014	2 out of 10 events or 20%

The most flood prone pump stations have dry-pit submersible pumps or entryways that are either flood proof or elevated.

Planned redevelopment of an old manufacturing facility would increase flows to the WWTF on the order of 0.1 MGD, close to capacity.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Readily Repairable/ Replaceable	Mitigation Strategy
Primary Settling Tanks		B		Allow primary settling tanks to flood. Locate collector drives above flood elevation.[1] Replace sludge pumps with submersibles. Store replacement drive components on site. Pumps may be temporarily augmented.[2]
Electrical Switchgear and Motor Control Centers		C		Relocate above flood elevation.[1]
Disinfection System (Chlorine Contact Tanks)		B		Locate mixer drive above flood elevation or install submersible mixer.[1]
Operations Building		B	B	Allow pumps in station basement to flood. Electrical switchgear, MCCs and SCADA equipment above flood elevation.[1]

[1] Adaptive measures planned for implementation in the near term as part of the proposed WWTF Upgrades project.

[2] Adaptive measures that the Town of Warren may consider implementing at a future time.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

Warwick Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

Warwick WWTF is located at 125 Arthur W. Devine Blvd. in Warwick. It treats an average of 4.5 million gallons of wastewater per day, serving approximately 60,200 customers in Warwick. Additional information is on the back of this summary.

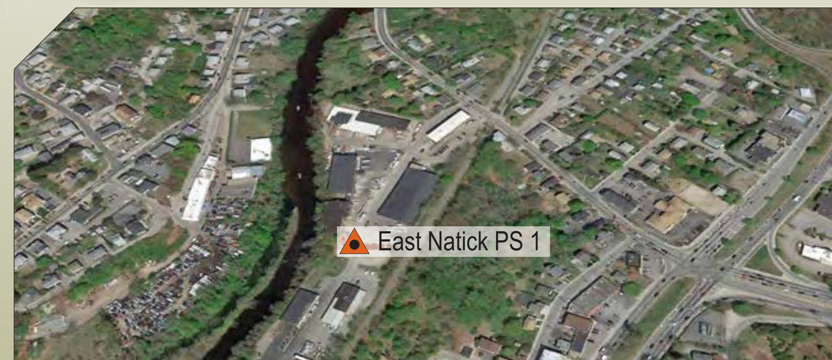
WOODARD &CURRAN

TOP 3 HAZARD MODELING RESULTS

1 – Inland Flood Hazard: Inundation of the entire WWTF site at the 100-year plus 2' event (without planned raised levee)

2 – Inland Flood Hazard: Inundation of East Natick PS 1, East Natick PS 2, and Knight Street PS at the 100-year flood level plus 2' event.

3 – Coastal Flood Hazard: Inundation of most of the WWTF site at the 100-year event plus 5' of SLR (without planned raised levee)



PLANNED AND COMPLETED CLIMATE CHANGE ADAPTATION MEASURES

The Warwick Sewer Authority undertook a project to raise the 2,300-foot long levee surrounding the WWTF, which was originally installed in the mid-1980's. The levee was raised by five and a half feet in 2017. The URI Pawtuxet River modeling team demonstrated that the levee will protect the WWTF from inundation caused by a 500-year flood event. Several flood hardening projects have also recently been implemented or are planned for some of the flood-prone pump stations.

WARWICK, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	City of Warwick
Operator	Warwick Sewer Authority
Facility Address	125 Arthur W. Devine Blvd., Warwick, RI 02886
Contact Name	Scott Goodinson, Superintendent
Phone	401.739.4949
Design Flow Capacity	7.7 MGD
Average Daily Flow	4.5 MGD
Receiving Water	Pawtuxet River
Extreme Weather Related SSO Events 2010 - 2014	2 out of 19 events or 11%

The WWTF has an effluent pumping system that operates approximately four to six weeks per year.

The facility maintains an abundance of back-up pumping and power generation equipment.

The Knight Street PS is unusual in that it can function continuously when completely submerged by rising levels of the Pawtuxet River, and remains accessible through a roof hatch.

Several of the newer pump stations were intentionally designed to be above the current 100-year flood elevation standards and the new Bellows Street pump station was recently constructed and elevated to protect it from the 500-year flood.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Redundancy	Mitigation Strategy
Disinfection System (Chlorine Contact Tanks)		D	B	Maintain back-up temporary chemical storage and pumping system. Pump influent to Cranston WWTF.[1]
Effluent Pump Station	C	D		Replace effluent pumps with submersibles and relocate drive systems to high ground. Pump influent to Cranston WWTF.[1]
Generator	B	D		Elevate back-up electrical systems above berm elevation. Pump influent to Cranston WWTF.[1]
Knight Street PS		C		Relocate pump station inland.
East Natick 1 PS	A			Protect facility entrances with flood barriers and relocate building penetrations for louvers.

1. Redirecting influent flow to the Cranston WWTF would address multiple systems under one project. This long term plan should be considered in conjunction with West Warwick.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

West Warwick Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

West Warwick WWTF is located at 1 Pontiac Avenue in West Warwick. It treats an average of 5.2 million gallons of wastewater per day, serving approximately 31,600 customers in Coventry, Cranston, East Greenwich, Warwick, and West Greenwich. Additional information is on the back of this summary.

TOP 3 HAZARD MODELING RESULTS

Inland Flood Hazards

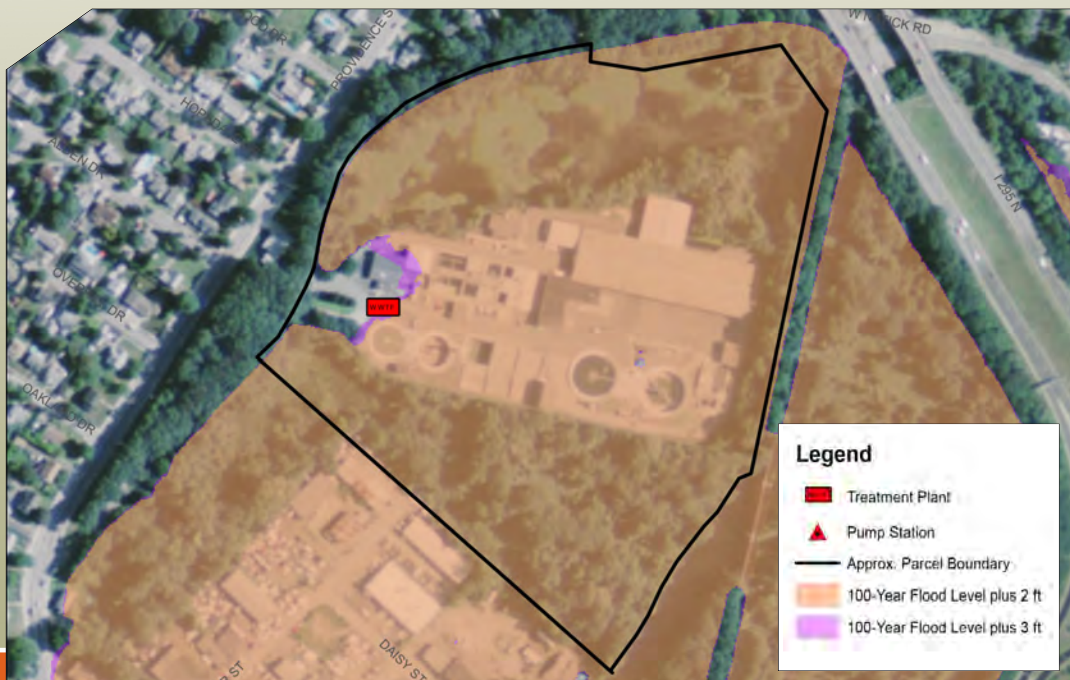
Inundation of almost the entire WWTF site at the 100-year plus 2' event with a water depth of 4-5 feet near the solids processing building.

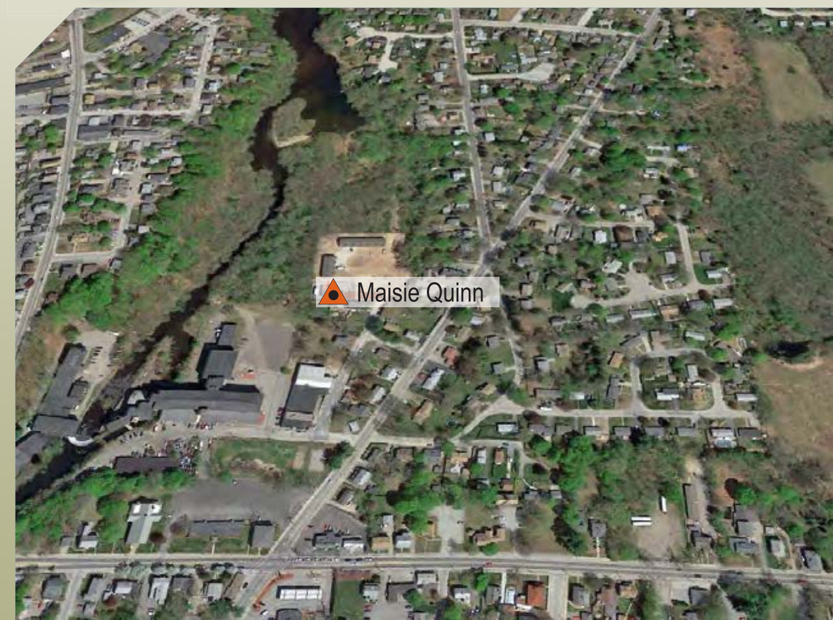
Inland Flood Hazards

Inundation of Clyde PS at the 100-year flood level plus 2' event.

Inland Flood Hazards

Inundation of Maisie Quinn PS at the 100-year plus 3' event.





WEST WARWICK, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Town of West Warwick
Operator	Town of West Warwick
Facility Address	140 Pettaconsett Avenue Cranston, RI 02920
Contact Name	Bernard Bishop, Interim Superintendent
Phone	401.822.9228
Design Flow Capacity	11 MGD
Average Daily Flow	5.2 MGD
Receiving Water	Pawtuxet River
Extreme Weather Related SSO Events 2010 - 2014	2 out of 6 events or 33%

Numerous process components throughout the facility were replaced following the storm events of March 2010, however very few incorporated flood mitigation efforts to protect new equipment because of code restrictions.

According to the U.S. Fish & Wildlife Service National Wetlands Inventory, approximately two-thirds of the perimeter of the WWTF abut wetlands of various classifications.

Atypical chemicals stored on the WWTF site would be subject to flotation or inaccessibility during a flood event.

Clyde PS is adjacent to the Pawtuxet River with the generator louver close to grade. Flood waters were observed flowing into Clyde PS through the generator louver during previous flood events, but the station maintained functionality.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Mitigation Strategy
Primary Clarifiers	B	D	B	B	Protect facility entrances with flood barriers. Extend tank perimeter wall upward. Pump influent to Cranston WWTF.[1] Store replacement drive components on site. Pumps may be temporarily augmented. Replace sludge pumps with submersibles.
Disinfection System (UV)	A	D			Protect facility entrances with flood barriers. Pump influent to Cranston WWTF.[1]
Effluent Pump Station	A	D			Protect facility entrances with flood barriers. Pump influent to Cranston WWTF.[1]
Generator	A	D			Protect facility entrances with flood barriers. Pump influent to Cranston WWTF.[1]
Operations Building	A	D			Protect facility entrances with flood barriers. Pump influent to Cranston WWTF.[1]

1. Redirecting influent flow to the Cranston WWTF would address multiple systems under one project. This long term plan should be considered in conjunction with Warwick.

A = < $50,000 B = $50,000 to $250,000 C = $250,000 - $1,000,000 D = > $1,000,000

Westerly Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

Westerly WWTF is located at 87 Margin Street in Westerly. It treats an average of 2.5 million gallons of wastewater per day, serving approximately 16,500 customers in Westerly.
Additional information is on the back of this summary.

TOP 3 HAZARD MODELING RESULTS

Coastal Flood Hazards

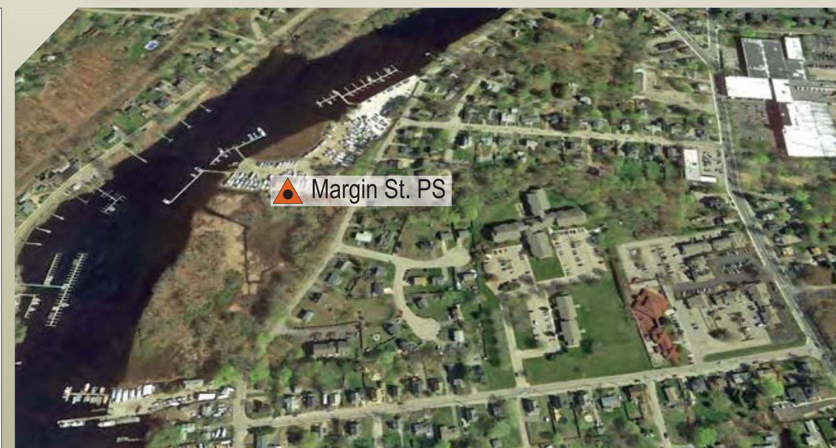
New Canal, Old Canal and Margin Street Pump Stations would be inundated by storm surge at the 100-year return period.

Coastal Flood Hazards

With 3 to 5 feet of SLR, the plant's secondary clarifiers, chlorine contact tank and operations building would be impacted during a 100-year storm.

Significant Wave Height for 100-year Event

5± feet approaching the site with reduced wave heights moving inland.



COMPLETED CLIMATE CHANGE ADAPTATION MEASURES

Recent climate change resiliency improvements include installing new generators and sealing low-elevation exterior building penetrations at the pump stations adjacent to the Pawcatuck River.

WESTERLY, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	Town of Westerly
Operator	Suez
Facility Address	87 Margin Street Westerly, RI 02891
Contact Name	Scott Duerr, Superintendent
Phone	401.596.2847
Design Flow Capacity	3.5 MGD
Average Daily Flow	2.5 MGD
Receiving Water	Pawcatuck River
Extreme Weather Related SSO Events 2010 - 2014	3 out of 5 events or 60%

The Margin Street Pump Station has a pumping capacity greater than the capacity of the treatment facility's headworks. If all 3 pumps at the pump station are operating simultaneously, the grit chamber at the WWTF will overflow causing an SSO event.

Some of Westerly's pump stations are subject to inundation from both coastal and inland flooding. The riverine hazard assessment, however, does not include coverage of those locations because they are in the Coastal AE zone.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Mitigation Strategy
Secondary Clarifiers	B		B	B	Protect facility entrances with flood barriers. Replace sludge pumps with submersibles. Store replacement drive components on site. Pumps may be temporarily augmented.
Disinfection System (Chlorine Contact Tanks)	A	B			Elevate or relocate disinfection system components.
New Canal PS	A				Protect facility entrances with flood barriers and relocate building penetrations for louvers. Elevate back-up generator systems.
Old Canal PS	A				Protect facility entrances with flood barriers. Elevate back-up generator systems.
Margin Street PS	A				Protect facility entrances with flood barriers .

A = < \$50,000 B = \$50,000 to \$250,000 C = \$250,000 - \$1,000,000 D = > \$1,000,000

Woonsocket Wastewater Treatment Facility - CLIMATE VULNERABILITY SUMMARY

WOODARD &CURRAN

The Woonsocket WWTF is located at 11 Cumberland Hill Road in Woonsocket. It treats an average of 9.3 million gallons of wastewater per day, serving approximately 51,400 customers in Woonsocket and North Smithfield, RI and Bellingham and Blackstone, MA. Additional information is on the back of this summary.

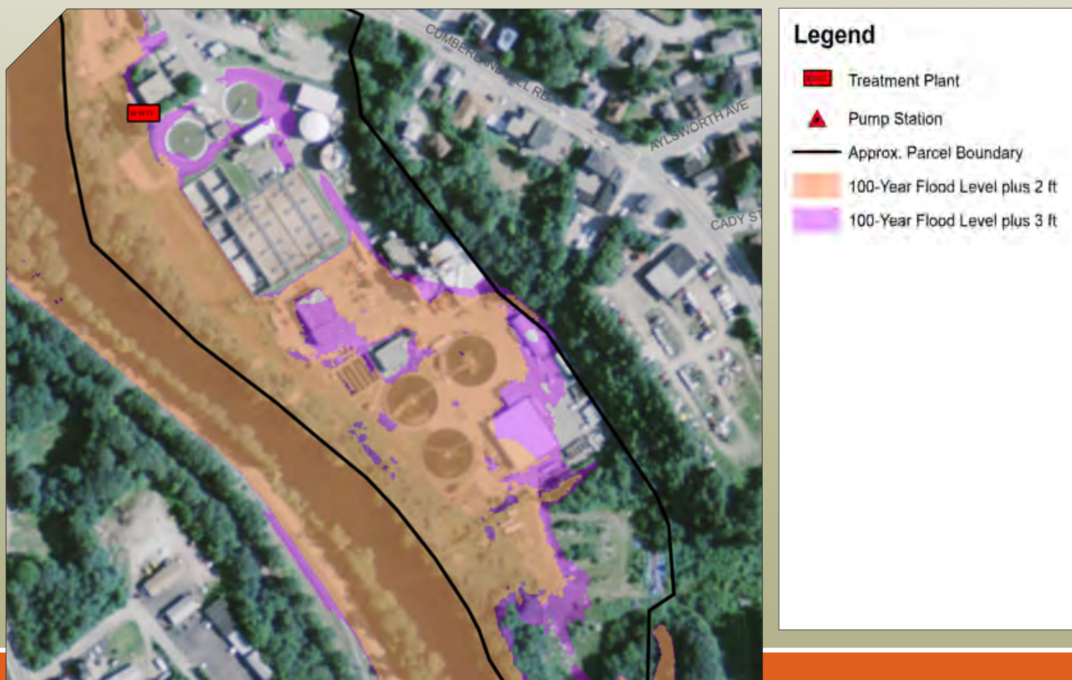
TOP 2 HAZARD MODELING RESULTS

1 Inland Flood Hazards

Partial inundation of the facility at the 100-year level plus 2 feet. Water depth would be about 10 inches at driveway between secondary clarifiers and effluent filter building.

2 Inland Flood Hazards

St. Louis pump station possible inundation at the 100-year level plus 3 feet.



COMPLETED CLIMATE CHANGE ADAPTATION MEASURES

Recent and on-going electrical system improvements improve the plant's electrical system resiliency.

WOONSOCKET, RI - CLIMATE VULNERABILITY SUMMARY

FACILITY SUMMARY

Owner	City of Woonsocket
Operator	CH2M Hill
Facility Address	11 Cumberland Hill Road Woonsocket, RI 02895
Contact Name	Jim Lauzon, Superintendent
Phone	401.356.1468
Design Flow Capacity	16.0 MGD
Average Daily Flow	9.3 MGD
Receiving Water	Blackstone River
Extreme Weather Related SSO Events 2010 - 2014	2 of 23 or 9%

The WWTF site is shared with an incinerator system operated by Synagro which uses approximately 3 MGD of recovered wastewater flow for incinerator use.

The facility experiences immediate inflow when a steady rain is present possibly caused by inflow from street flooding and the submergence of manholes and pump station wet wells.

Recent and on-going electrical system improvements include re-wiring with redundant power distribution systems, and replacement of the two existing 500kW generators with a new 2500kW generator installed in a standalone building approximately 4 feet above grade.

ADAPTIVE STRATEGIES (SEE REPORT FOR COMPLETE LIST)

SYSTEM	Hardening	Redundancy	Mitigation Strategy
Aeration Tanks	A		Protect facility entrances with flood barriers
Secondary Clarifiers	A	B	Protect facility entrances with flood barriers. Pumps may be temporarily augmented.
Disinfection System (Chlorine Contact Tanks)	A		Protect facility entrances with flood barriers.
Chemical Feed Building	A		Protect facility entrances with flood barriers.
St. Louis PS	B		Protect facility entrances with flood barriers and relocate building penetrations for louvers. Replace pumps with dry-pit submersibles.

A = < $50,000   B = $50,000 to $250,000   C = $250,000 - $1,000,000   D = > $1,000,000

1. INTRODUCTION

The Rhode Island Department of Environmental Management (RIDEM), in collaboration with the state's Division of Planning and other agencies recognized the need to integrate climate change considerations into wastewater system planning and initiated this study to understand the implications of climate change on the state's nineteen public wastewater treatment facility (WWTF) systems. The study focused on the treatment plants and the pump stations owned by the same entities. It did not include wastewater infrastructure owned by other municipalities or private entities.

The study was undertaken in five steps, which are summarized below.

1. Assess the potential for impacts to Rhode Island caused by natural hazards associated with climate change;
2. Preliminarily assess climate change impacts to Rhode Island wastewater infrastructure;
3. Refine the assessment and the risk of impacts on Rhode Island wastewater infrastructure;
4. Develop recommendations for adaptive strategies; and
5. Compile the work in a report and summary outreach materials.

Observed and projected climate change impacts to Rhode Island are described in Section 2. This section examines climate change science and summarizes extensive published data on climate change related trends experienced in Rhode Island such as an increase in average air and ocean temperatures, more extreme weather events, and an acceleration in the rate of local sea level rise. This information is consistent with the Rhode Island Executive Climate Change Coordinating Council (EC4) Annual Report published in June 2016.

Section 3 presents a preliminary assessment of climate change impacts to Rhode Island wastewater infrastructure. It includes assessments of all nineteen publically owned treatment plants to identify vulnerabilities to flooding, storm surge, and other severe weather and climate change related impacts. The assessments were based on historic records and observations provided by RIDEM and facility operators as well as predictive scientific models and exercises to forecast the likely consequences of continued climate change in Rhode Island. The coastal and riverine hazard assessments and sea level rise analysis were performed statewide and public access to that data was provided so that it can be used by others for a variety of purposes. Fifteen of the nineteen WWTFs were assessed for coastal hazards and sea level rise. Ten of these sites were also assessed for coastal erosion. A wave hazard assessment was conducted at eight of the coastal WWTFs. Six WWTFs were assessed for riverine hazards, two of which were among the fifteen assessed for coastal hazards.

A refined risk assessment was then performed on each of the WWTFs based on the information assimilated from the preliminary assessment. The purpose of the refined assessment was to identify the systems within the WWTFs, including major pump stations, that are vulnerable to climate change impacts. Suggested priorities for repair were also established, should more than one system fail at any time. This information is presented in Section 4.

The vulnerable systems were then assessed to identify adaptive strategies that would improve resiliency to climate change impacts. The cost to implement these strategies was roughly estimated to assist WWTF owners and operators with budgetary planning for future upgrades. The results of this exercise are presented in Section 5. There are publically available tools for assessing costs of damages associated with natural hazards.

Finally, a summary of the information related to each WWTF was compiled into a WWTF specific brochure for use in outreach to utility managers, operators, and other stakeholders to drive home the importance of integrating this information into their planning efforts.

2. ASSESSMENT OF POTENTIAL CLIMATE CHANGE IMPACTS TO RHODE ISLAND

The impacts of climate change to Rhode Island's wastewater treatment facilities (WWTFs) are expected to be wide-ranging. The state is home to nineteen major WWTFs that treat approximately 120 million gallons of human and industrial sewage a day (RI DEM). Because WWTFs and pump stations in Rhode Island are generally located at low elevations and within freshwater or coastal floodplains in order to discharge treated wastewater, they are at increased risk for inundation by flooding or sea level rise (RIEC4, 2012).

Changes to the global climate during the next century are predicted to lead to increases in sea levels, higher intensity storms and their corresponding effects (e.g., increased storm surge), increases in surface and ocean temperatures, and changes in precipitation patterns. Although these processes are occurring at a global scale, all have the potential of impacting WWTFs in Rhode Island. Concurrently with the development of this study, the Rhode Island Executive Climate Change Coordinating Council (EC4) Science & Technical Advisory Board (STAB) prepared a report on the Current State of Climate Science in Rhode Island, which was published in the June 2016 EC4 Annual Report. A member of the RPS ASA team for this assessment served on the EC4 STAB and contributed consistent information to both reports.

The purpose of this assessment is to employ existing data and reports to describe the current state of climate change science as researched by international, national, and state entities and use this information to characterize potential impacts on Rhode Island's wastewater collection and treatment infrastructure. This section presents:

1. A literature review to assess and synthesize the best available data and information on climate change science and trends in Rhode Island. The literature review was performed as the first task in this assessment with the results established for use in progressing with the subsequent tasks. Although climate change science continues to be studied, the scientific analysis results were fixed to enable this study to move forward.
2. A literature review detailing the implications of climate change on wastewater utilities.
3. An inventory of existing public domain data that can be used to quantify risks to wastewater infrastructure during subsequent modeling efforts.

2.1 SUMMARY OF CLIMATE CHANGE SCIENCE AND TRENDS IN THE NORTHEAST UNITED STATES AND RHODE ISLAND

To understand how a warming world may impact Rhode Island's wastewater infrastructure, this report first examines how climate variables are expected to change in the region, and how these changes compare with historical trends. For the purposes of this report, an excellent starting point for this review was published by Heffner et al. (2012) as part of the Rhode Island Sea Grant funded Climate Change Collaborative Project. The report presents a comprehensive summary of recent climate change trends at global, regional, and state-wide levels **(Table 2-1: Climate Change Trends)**. The findings of this research shows that Rhode Island has experienced an increase in average air and ocean temperatures, more extreme weather events (e.g. more droughts, more intense rainfall, more intense storms and flooding), an acceleration in the rate of local sea level rise, shorter winters and longer summers, less snowfall and more rainfall during the last century.

This report addresses the impacts of these climate change related experiences; it does not examine the probability of increased precipitation, storms, etc. Probability studies continue to be refined as we move further into the 21st century. Regardless, this study was initiated because climate change trends are being observed. Furthermore, irrespective of climate change impacts, these types of natural hazards will continue to occur and must be planned for.

Table 2-1: Climate Change Trends

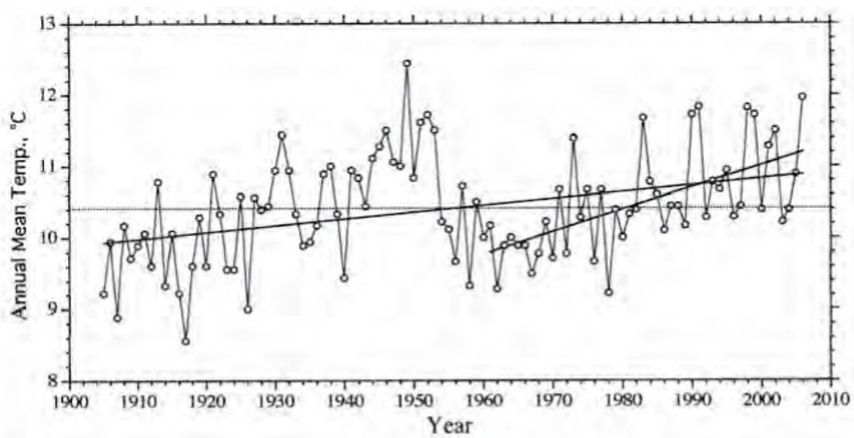
Climate Change Variable	Geographic Scale	Observations of Recent Change
Air Temperature	Global	• Global mean temperature has increased 0.74°C (1.33°F) over the last 100 years.
	U.S. Northeast	• Since 1900, the annual mean temperature has risen 0.83°C (1.5°F).
	Rhode Island	• Average annual temperature rose 0.94°C (1.7°F) from 1905 to 2006.
Sea Surface Temperature	Global	• The ocean has been warming consistently over the past 50 years, with 2007 as the warmest on record.
	U.S. Northeast	• Annual average temperatures in the waters off the southern New England coast have increased by about 1.2°C (2.2°F) since the 1970s.
	Rhode Island	• In Narragansett Bay, winter sea-surface temperatures have risen 2.2°C (4°F) since the 1960s.
Sea Level Rise	Global	• Globally, sea level rose in the 20th century at an average rate of 1.8 mm (0.07 in) per year, a rate greater than that of the preceding eight centuries. • Between 1993 and 2003 this rate almost doubled to 3.4 mm (0.13 in) per year.
	U.S. Northeast	• In Newport, sea level has risen an average of 2.6 mm (0.1 in) per year since 1930.
Storm Intensity/ Frequency	Global	• The severity of tropical cyclones has increased since the 1970s.
	U.S. Northeast	• The severity of tropical cyclones in the North Atlantic has increased.
Precipitation and Weather	Global	• Rainfall has decreased in the Northern Hemisphere subtropics and increased in mid-latitudes over the last 50 years.
	U.S. Northeast	• Studies have found a 5 to 17 percent increase in regional precipitation during roughly the last 100 years.
	Rhode Island	• Over the past 100 years, Rhode Island precipitation has increased by 3 mm (0.12 in) per year. • Annual mean wind speed at T.F. Green Airport has significantly declined since at least the 1960s.
Note: Table 2-1 is a summary of observed and documented climate change trends at the global, regional, and state levels (Heffner et al. 2012).		

Sections below expand upon the work of Heffner et al. (2012) to include updated trends and new research. Where new observations have become available (e.g. sea level data for Rhode Island) the most recent data are reported. The discussion is organized by climate variables likely to impact wastewater infrastructure either directly (sea level rise, precipitation, storminess) or through related secondary processes (air temperature, sea surface temperature). Recent observations of climate changes at the global and local scale are summarized. Each section also includes discussion of the projected change during the coming century and (where available) the range of projections from recent climate modeling studies.

2.2 AIR TEMPERATURE

Temperature at the Earth's surface is perhaps the most well documented and apparent indicator of a changing climate. In the United States, average air temperatures have increased between 1.3 and 1.9 °F since 1895 (when record keeping first began), with the majority of this increase occurring since 1970 (Melillo et al. 2014). Similar trends have been observed in the US Northeast (average increase of 1.5 °F; Frumhoff et al., 2007) and in Rhode Island (1.7 °F; Pilson, 2008) with a marked increase in the rate of warming during the last several decades (Figure 2-1). Frumhoff et al. (2007) report that temperatures in the Northeast US have increased by an average of 0.5°F per decade since 1970 and winter temperatures have risen even faster at about 1.3°F per decade. Coincident with this warming are observations of more frequent days above 90°F, longer growing seasons, earlier first-bloom dates, reduced snow cover, and rising sea surface temperatures in the region (Frumhoff et al., 2007).

Figure 2-1: Annual Mean Air Temperature, Providence, RI (1905 – 2006)



*Note**: Figure 2-1: Annual Mean Air Temperature, Providence, RI (1905-2006)** illustrates the annual mean air temperature at the official Weather Bureau station for Providence, RI between 1905 and 2006 (Pilson, 2008). Note the increased rate of temperature change since ~1960.*

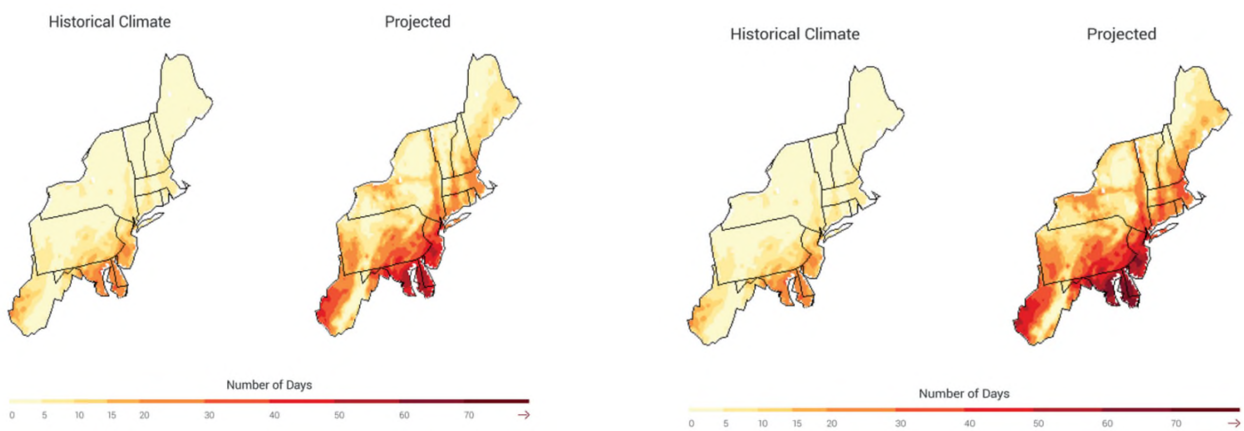
Continued warming in the region is expected during the coming century, although the magnitude of temperature rise will depend largely on global emissions of greenhouse gasses, population growth, land use, and technological developments that may mitigate warming. Using emissions scenarios developed by the Intergovernmental Panel on Climate Change (IPCC)[2] , Horton et al. (2014) presented a range of future warming conditions for the US Northeast. Under a scenario where global emissions continue to increase in the future, warming of 4.5 to 10°F is projected by 2080. For scenarios where global emissions are reduced substantially, projected warming is limited to 3 to 6°F for the

[2] The IPCC has published two types of greenhouse gas emissions scenarios that are commonly used to model future climate conditions: the 2000 Special Report on Emission Scenarios (SRES) and the 2010 Representative Concentration Pathways (RCP). This summary includes results from recent literature that utilize both types of emission scenarios. The SRES scenarios are organized by family (A1, A2, B1, and B2), where each family has an associated storyline to describe the trajectory of world development in the 21st century. The SRES A2 scenario represents a world with high population growth, low economic growth, and other factors that contribute to high emissions. At the lower end of the range, the SRES B1 scenario represents a world with lower population growth, higher economic development, more environmental and social consciousness, and a general transition to alternative energy systems globally. In contrast, the RCP scenarios were developed for the most recent IPCC assessment report (AR5) and are simply numbered according to the change in radiative forcing (from +2.6 to +8.5 watts per square meter) that results from increased greenhouse gas concentrations by 2100. More details on emissions scenarios can be found in Nakicenovic et al. (2000) and IPCC (2013).

same region. Under all scenarios, the frequency, intensity and duration of heat waves is expected to increase (Figure 2-2).

Figure 2-2: Projected Days Annually – Maximum Temperature >90F (2041-2070)

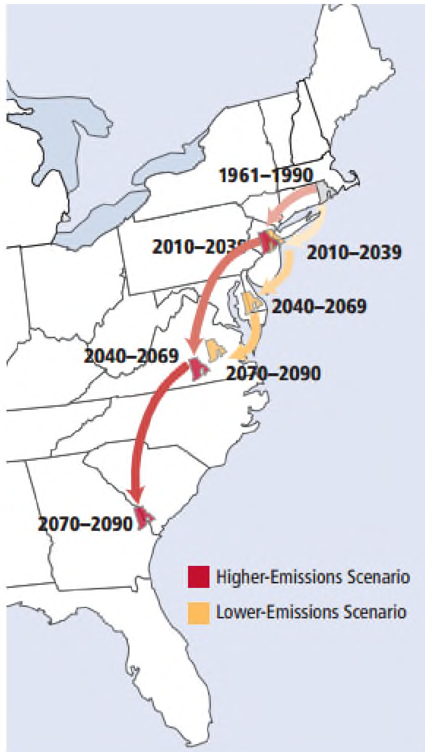
Low Emissions Scenario ***High Emissions Scenario***



Note: ***Figure 2-2: Projected Days Annually – Maximum Temperature >90F (2041-2070)*** *illustrates a projected number of days a year with maximum temperature greater than 90F averaged between 2041 to 2070 (right panel), compared to 1971 to 2000 (left panel) assuming (a) substantial reductions in future emissions (scenario B1) and (b) continued increases in global emissions (scenario A2). Figure adapted from Horton et al. 2014.*

Similar ranges of future warming in the Northeast US were published in a 2007 report by the Union of Concerned Scientists (Frumhoff et al., 2007) using an average of global climate models developed by the National Oceanic and Atmospheric Administration (NOAA), the UK Meteorological Office and the National Center for Atmospheric Research (NCAR). To illustrate how a warmer climate may be perceived, the authors also presented changes in the average summer heat index (a measure of how heat is "felt" for a given temperature and humidity combination) for individual US states. The predictions for Rhode Island are shown in Figure 2-3. Red and yellow arrows show how the summer heat index would change over the course of the century under both a higher emissions scenario (assumes continued increases in future emissions) and a lower emissions scenario (assumes a substantial decrease in future emissions). Under the highest emissions scenarios, Rhode Island's summers could "feel" like Georgia's by the end of the 20th century.

Figure 2-3: Changes in Average Summer Heat Index, Rhode Island

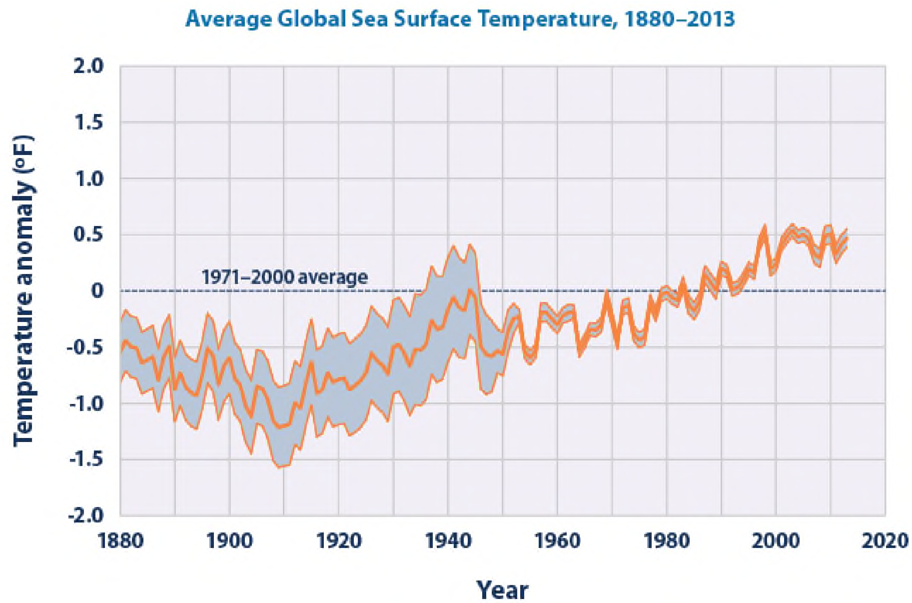


*Note: **Figure 2-3: Changes in Average Summer Heat Index, Rhode Island** illustrates changes in average summer heat index in Rhode Island for both high and low emissions scenarios (Frumhoff et al. 2007).*

2.3 SEA SURFACE TEMPERATURE

The global ocean has a critical role in climate variability and change. The ocean's mass and high heat capacity (approximately 1,000 times that of the atmosphere) allow it to absorb large amounts of energy from the Earth's atmosphere, land, and melted ice, hence the changes in global ocean temperatures can be directly linked to greenhouse warming. To that end, ocean temperatures at the sea surface are one of the most important diagnostics for climate change on earth. Using data from NOAA, EPA (2014) showed that global sea surface temperatures rose an average of 0.13°F per decade between 1901 to 2013 and that temperatures during the past three decades were higher than at any other time since reliable observations began in 1880. The IPCC (2013) reported that global sea surface temperatures increased 0.2°F per decade between 1971 and 2010.

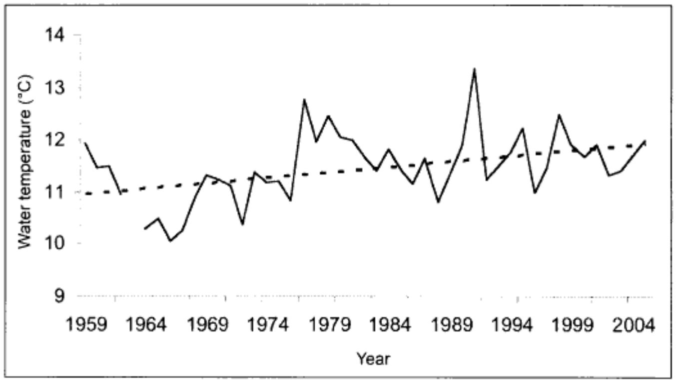
Figure 2-4: Average Global Sea Surface Temperature Anomaly (1880-2013)



Note: ***Figure 2-4: Average Global Sea Surface Temperature Anomaly (1880-2013)*** *illustrates average global sea surface temperature anomaly (1880 – 2013). The graph uses 1971 to 2000 as a baseline for depicting change. The shaded band shows the range of uncertainty in the data (EPA, 2014).*

Observations of warming sea surface temperatures vary considerably around the globe. In the North Atlantic, warming of the surface ocean has occurred at twice the rate of the global average during recent decades (Levitus et al., 2009), and Oviatt (2004) reported that annual average water temperatures in southern New England rose approximately 2.2°F since the 1970s. Nixon et al. (2004) note similar warming at an average rate of 0.07°F per year near Woods Hole, MA between 1960 and 2002. Temperatures in Narragansett Bay have increased even faster than those in the North Atlantic during the 20th century, which has led to several changes in ecological populations including cold water fish species and changes in the phenology of phytoplankton blooms (Smith et al., 2010 and references therein). Annual average surface water temperatures at Fox Island (lower West Passage of Narragansett Bay) are plotted in Figure 2-5 (Smith et al. 2010). The data were collected as part of a weekly fish trawl survey conducted by the URI Graduate School of Oceanography.

Figure 2-5: Mean Surface Winter Water Temperatures - Fox Island, RI



Note: ***Figure 2-5: Mean Surface Winter Water Temperatures – Fox Island, RI*** *illustrates the mean surface winter water temperatures at Fox Island, in the mid-West Passage of Narragansett Bay, R.I. (Smith et al. 2010).*

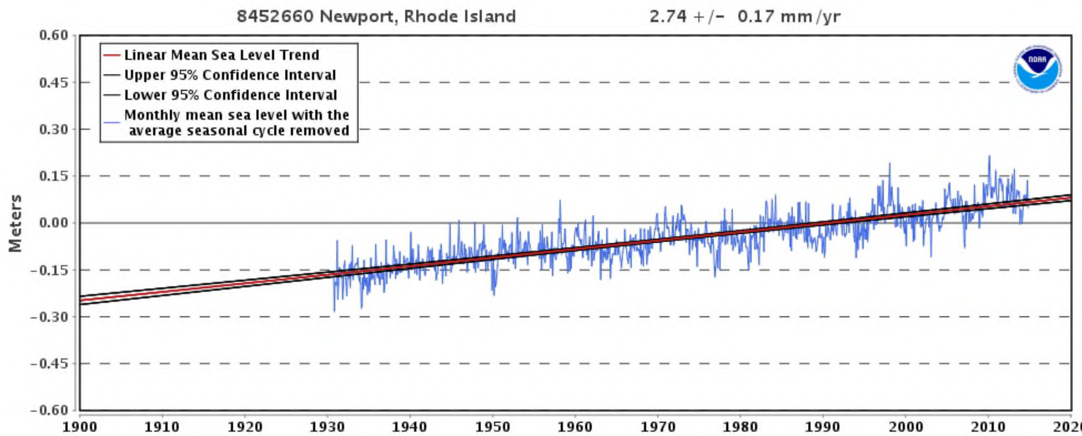
The fifth assessment report of the IPCC asserted with high confidence that global ocean will continue to warm during the 21st century. The best estimates based on a series of future emission scenarios range from 1.1°F to 3.6°F of warming for the upper 100 m of the global ocean (IPCC, 2013). In the US, future sea surface warming will accelerate sea level rise (due to the thermal expansion of seawater), lead to increased water vapor in the atmosphere (producing weather systems with increased precipitation), intensify tropical cyclone activity, and contribute to drought or increased storm activity for different regions (EPA, 2014). An additional impact to the Northeast US is the very likely (greater than 90% probability) slow-down in the Atlantic Meridional Overturning Circulation (AMOC) during the 21st century due to the warming (and freshening) of the North Atlantic (IPCC, 2013). A slowing AMOC could further enhance the rate of sea level rise off of the US east coast.

2.4 SEA LEVEL

For coastal states such as Rhode Island, sea level rise (SLR) is expected to be one of the largest and most sustained climate change impacts of the next century (Nicholls et al., 2007). Rising sea levels have the potential to drown coastal wetlands, intensify erosion and flooding in low-lying areas, threaten coastal infrastructure and drinking water supplies, and ultimately displace human populations. Globally, sea levels have been rising since the last ice age, although the IPCC (2013) suggests that the rate of rise in the 20th century (average of 1.7 mm/yr) is a marked departure from the low rates of sea level change experienced during the last several thousand years (order tenths of mm/yr). Much of this increase has been attributed to the loss of glacier mass, and thermal expansion of the oceans from warming. This acceleration has also been observed in long term tide gauge records which show the rate of global sea level rise has nearly tripled during the course of the 20th century (Church and White, 2011; Cazenave and Nerem, 2004).

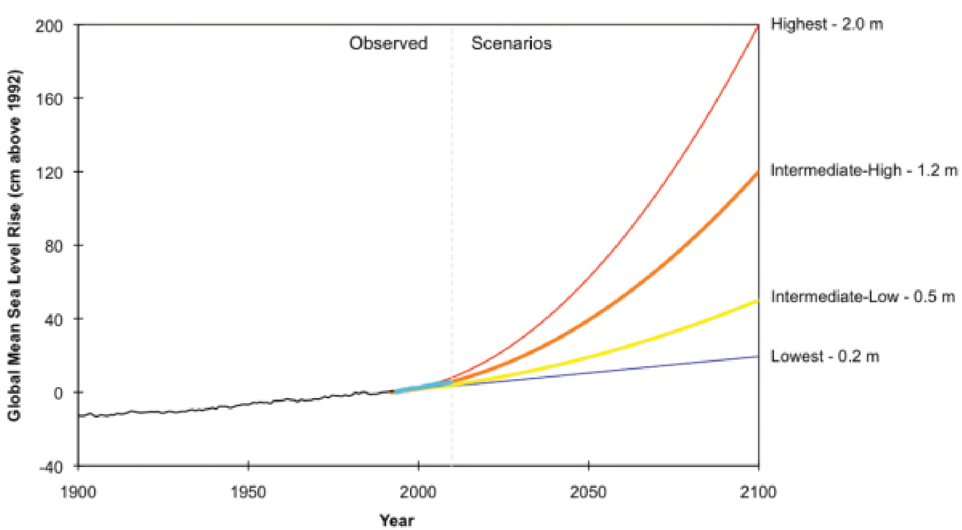
Both the magnitude and effects of changing sea levels are not globally uniform. Relative sea level (measured by a tide gauge with respect to the land upon which the gauge is situated) is the result of both changes in water levels and movements of the continental crust. Rhode Island in situated in a portion of the continent that is experiencing sinking because of isostatic adjustment of the mantle to the melting of ice sheets at the end of the last ice age. In addition, Sallenger et al., (2012) report a sea-level rise “hotspot” in the Northeastern US due to the slowing of Atlantic Ocean circulation. Since 1950, the rate of SLR in the northeast has been 3–4 times higher than the global average. The cumulative result of these factors can be seen in the mean sea level trend at the NOAA Tide Gauge in Newport, RI (8452660), where the current rate of SLR is 2.74 mm/year, substantially higher than the global average **(Figure 2-6: Mean Sea Level Trends in Newport, RI)**. This estimate is based on monthly mean sea level data from 1930 to 2013, which is equivalent to approximately 0.9 ft. over 100 years.

Figure 2-6: Mean Sea Level Trends in Newport, RI



Regardless of efforts to stabilize atmospheric greenhouse gas concentrations, SLR is expected to continue during the next century due to the feedbacks associated with global climate processes. The overwhelming consensus from the research community is that the rate of sea level rise will continue to accelerate during the next century, though the range of future SLR projections is quite variable depending upon the climate scenarios and the extent to which Greenland and the West Antarctic Ice Sheet experiences substantial melting. The most recent Assessment Report (AR5) from the IPCC presents estimates of sea levels in 2100 rising between 28-98 cm (0.9–3.2 ft.) above the reference period of 1986-2005. Pariss et al. (2012) published estimates of global sea level rise for use in the US National Climate Assessment ranging between 1 and 4 feet but suggest that SLR as high as 6.6 feet by 2100 may be useful for planning purposes **(Figure 2-7: Projections of Global Sea Level Rise – National Climate Assessment (Pariss et al., 2012)**. A growing number of semi-empirical studies have predicted similar sea level changes up to and exceeding one meter (3.3 ft.) by 2100 (Rahmstorf, 2010, and references therein).

Figure 2-7: Projections of Global Sea Level Rise - National Climate Assessment (Pariss et al., 2012)

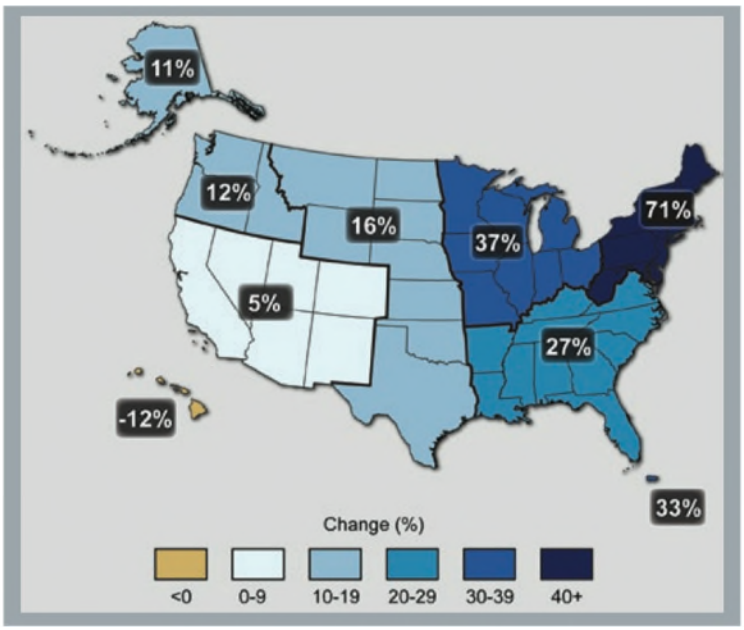


Horton (2014) emphasizes that future sea level rise in the Northeast US is likely to exceed the global average because of local land subsidence and dynamic effects due to changing ocean currents and redistribution of mass in the ocean (e.g. Yin et al., 2009; Bamber et al., 2009). Although estimates vary, these factors have the potential to raise the relative sea level by 25% or more in the Northeast U.S.

2.5 PRECIPITATION

Both globally and across the US, average precipitation over land has been increasing during the last century. At a global scale, precipitation has increased at a rate of 0.2 percent per decade, while in the contiguous 48 states the rate of increase was 0.5 percent per decade (EPA, 2014). There has been a coincident increase in the amount of precipitation falling in heavy events throughout the country, with the Northeast experiencing a greater increase in extreme precipitation than any other US region **(Figure 2-8: Percent Increase in Precipitation by US Region (1958-2012)**; Melillo, 2014). Pilson (2008) notes that total annual precipitation (rain plus snow) in Rhode Island increased by 32 percent, or 3 mm/yr, between 1905 and 2006.

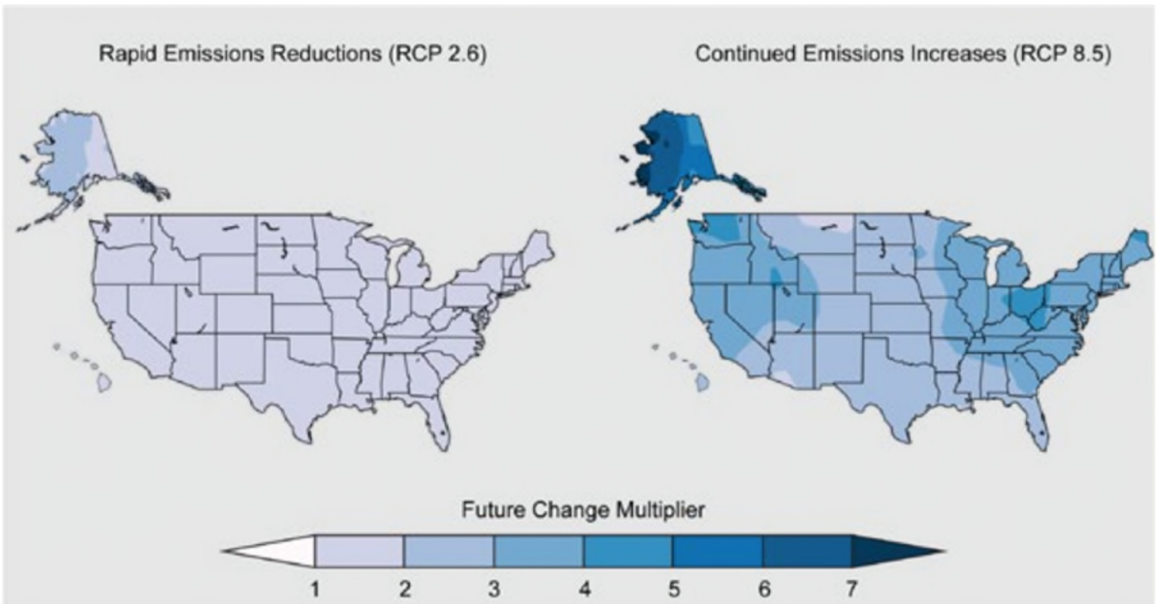
Figure 2-8: Percent Increase in Precipitation by US Region (1958-2012)



*Note: **(Figure 2-8: Percent Increase in Precipitation by US Region (1958-2012)** illustrates the percent increase in the amount of precipitation falling in heavy events (the heaviest 1% of daily events) from 1958 to 2012 by US region (from Melillo et al., 2014).*

Globally, the contrast in precipitation between wet and dry regions is expected to increase during the next century. Annual mean precipitation is projected to increase in higher latitudes, and decrease in dry subtropic regions. In the mid-latitudes and in wet tropical regions extreme precipitation events are expected to become more intense and frequent (IPCC, 2013). Walsh et al. (2014) suggest that similar trends are forecast for most regions of the United States (i.e. wet areas are expected to get wetter and dry areas will get drier). Although projections of precipitation are less certain than air temperatures, winter and spring precipitation is projected to increase in the Northeast during the next century. Projected changes during summer and fall months are less significant when compared to natural variations (Horton et al., 2014). Frumhoff et al. (2007) predict that annual precipitation will increase steadily in the Northeast, up to 10 percent (4 inches per year) by the end of the century. The frequency of heavy precipitation events is projected to increase in all regions of the US - a consequence of both a warmer atmosphere (which holds more moisture) and associated changes in large scale weather patterns, both of which are projected to continue in the next century (Walsh, 2014). As shown in Figure 2-9, the scale of this increase will be dependent on future emissions scenarios (Melillo et al., 2014).

Figure 2-9: Projected Increase in Heavy Precipitation By End of 21st Century

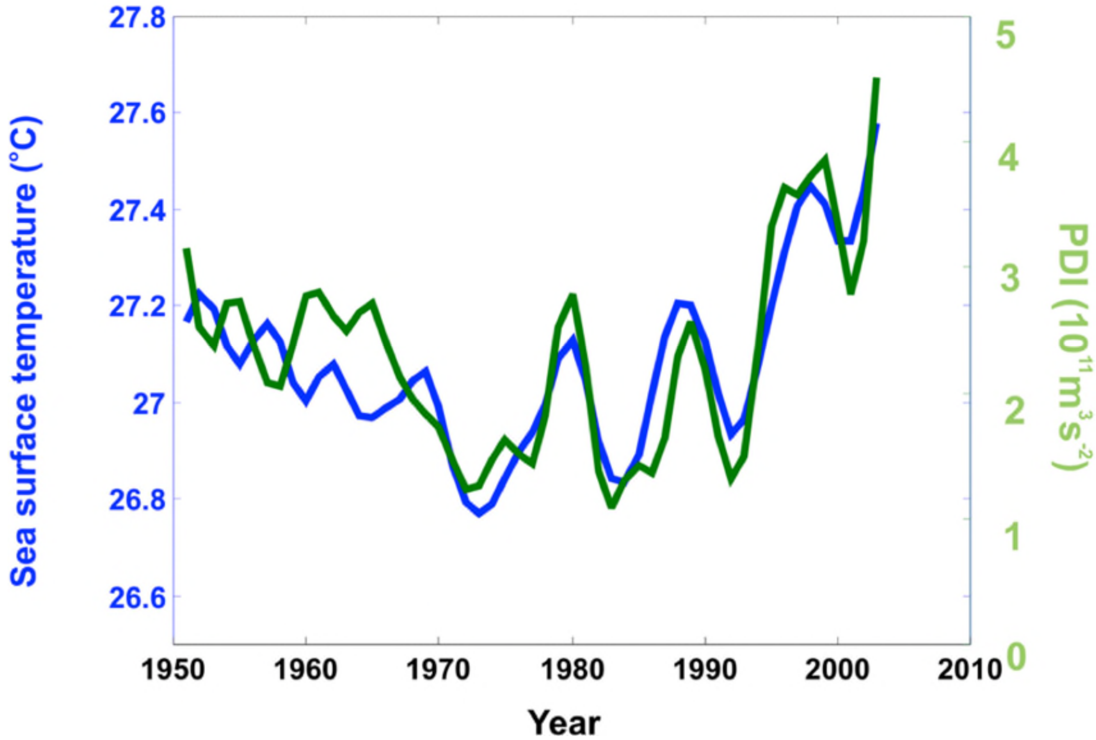


*Note: **Figure 2-9: Projected Increase in Heavy Precipitation By End of 21st Century** illustrates the projected increase in heavy precipitation events (daily amount that now occur once every 20 years) by the end of the 21st century. Changes are shown for two emissions scenarios: rapid emissions reductions (left) and continued increases in emissions (right), from Melillo et al., (2014).*

2.6 TROPICAL CYCLONE ACTIVITY

The impact of past and future warming on storm activity is an area of active climate change research. According to science summarized in the most recent IPCC Assessment Report (AR5) as well as the Third National Climate Assessment for the US, there has been a marked increase in the frequency of intense tropical cyclone activity in the North Atlantic since 1970 (the period during which high-quality satellite data are available). The data suggest that longer storm duration and greater intensity are strongly linked with the rise in sea surface temperature in the tropical region over which these storms develop. Indeed, Emanuel (2005; 2007) has shown that the power dissipation of Atlantic hurricanes (an aggregation of storm frequency, duration, and intensity) has increased in close correlation with sea surface temperatures over the same period **(Figure 2-10)**. There is less certainty in how tropical cyclone activity has varied during periods before 1970 because of the potential undercounting of events when observing capabilities were not as robust (Knutson et al., 2010).

Figure 2-10: Tropical Atlantic Sea Surface Temperature and the Power Dissipation Index

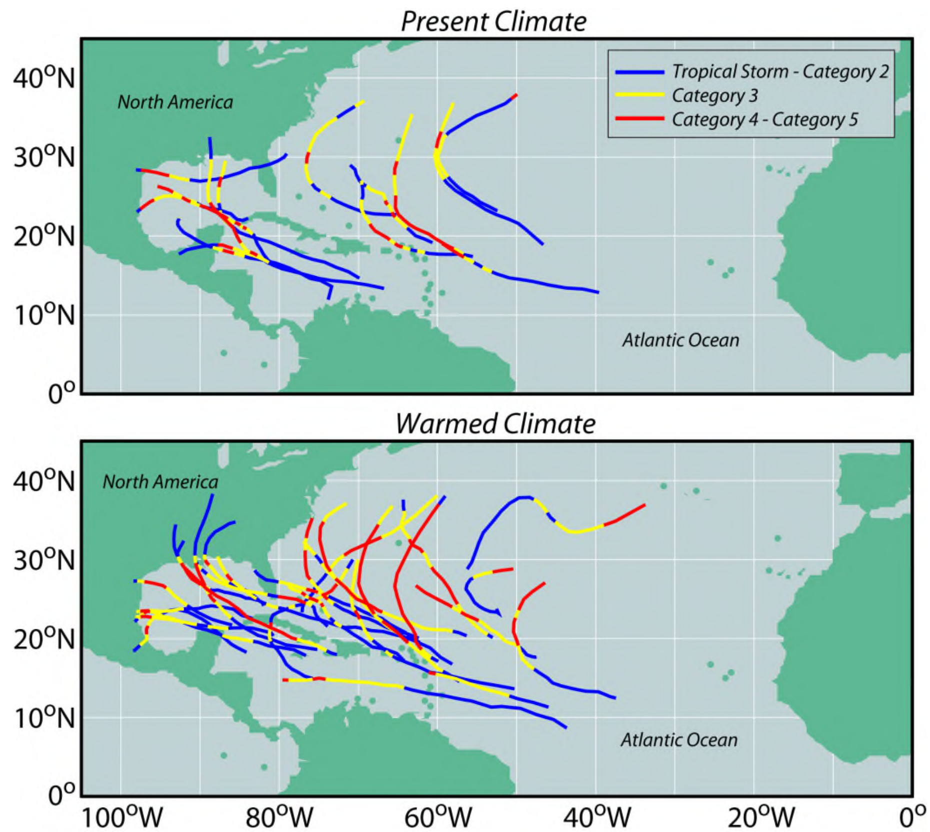


Note: ***Figure 2-10: Tropical Atlantic Sea Surface Temperature and the Power Dissipation Index*** *illustrates the late summer tropical Atlantic sea surface temperature (blue) and the Power Dissipation Index (green), a measure of hurricane activity which depends on the frequency, duration, and intensity of hurricanes over a season. (after Emanuel, 2007).*

Although their occurrence is rare, southern New England is typically affected by late-stage tropical cyclones that form at lower latitudes and approach from the south. The Atlantic hurricane database (HURDAT) maintained by the National Hurricane Center provides the most extensive and up-to- date track and wind speed data for all known tropical cyclones occurring in the North Atlantic since 1851, including those that have made landfall in New England (Landsea et al., 2004; Blake et al., 2011). During that time, 19 hurricanes (category 1 or greater on the Saffir-Simpson scale) passed within 100 km of Rhode Island, yet only 9 of these storms were considered direct strikes (Blake et al. 2011). Long-term observations of water levels from the Newport, RI tide gauge show that two of these events (in 1954 and 1938) produced water levels (storm surge + astronomical tide) greater than 2.7 meters (8.9 feet) above the local sea level datum (http://tidesandcurrents.noaa.gov/stationhome.html?id=8452660).

Despite the increase in storm activity over the past several decades, there is general agreement that the overall frequency of Atlantic hurricanes will either decrease or remain unchanged as the global climate continues to warm (e.g. Knutson et al., 2010). During this same time, however, the occurrence of the most intense hurricanes (Category 4 and 5 storms) is projected to increase, particularly in the North Atlantic (IPCC, 2013). Bender et al. (2010) used an ensemble of global climate models to predict a near doubling of the frequency of the strongest hurricanes in the Atlantic by the end of the century **(Figure 2-11: Modeled Category 4 and 5 Hurricane Tracks**). The authors suggest that the effect of increasing category 4-5 storms outweighs the reduction in overall hurricane numbers and estimates a 30% increase in potential damage in the Atlantic basin by 2100. This estimate does not include the influence of future sea level rise which will allow storm surge and waves access to increasingly higher coastal elevations over time. An increase in intense hurricane-induced storm surges coupled with the potential for significant SLR in the Northeast US is very likely to increase the frequency of storm related impacts to coastal environments and infrastructure.

Figure 2-11: Modeled Category 4 and 5 Hurricane Tracks



*Note**: Figure 2-11: Modeled Category 4 and 5 Hurricane Tracks** illustrates the tracks of simulated Atlantic Category 4 and 5 hurricanes for the present climate (top) and for a warmer climate condition projected for the late 21st century (bottom) (Bender et al., 2010).*

2.7 POTENTIAL IMPACTS TO WASTEWATER TREATMENT INFRASTRUCTURE

The impetus for this study was the Rhode Island Climate Change Commission's (subsequently Executive Climate Change Coordinating Council or EC4) 2012 progress report on adaptation, which found that climate change puts Rhode Island's wastewater infrastructure at risk from sea-level rise, more frequent storm events, increased precipitation and flooding. The EC4's June 2016 Annual Report included a report by the Science & Technical Advisory Board (STAB) on the Current State of Climate Science in Rhode Island, which further supports these findings. Since wastewater treatment facilities are often located in floodplains and along shorelines, flooding from increased precipitation, rising groundwater levels or storm surge can cause sanitary sewer overflows (SSOs) where improperly treated wastewater flows directly into the state's ponds, rivers and bays.

According to a July 2010 report by the Natural Resources Defense Council, human exposure to waterborne diseases is of particular concern where communities use combined sewer systems (stormwater and sanitary wastewater are carried in the same pipe). Climate change variables such as increased precipitation, intensity, and storm frequency cause more frequent combined sewer overflows (CSOs) where untreated wastewater is discharged into receiving surface waters (rivers, lakes and oceans).

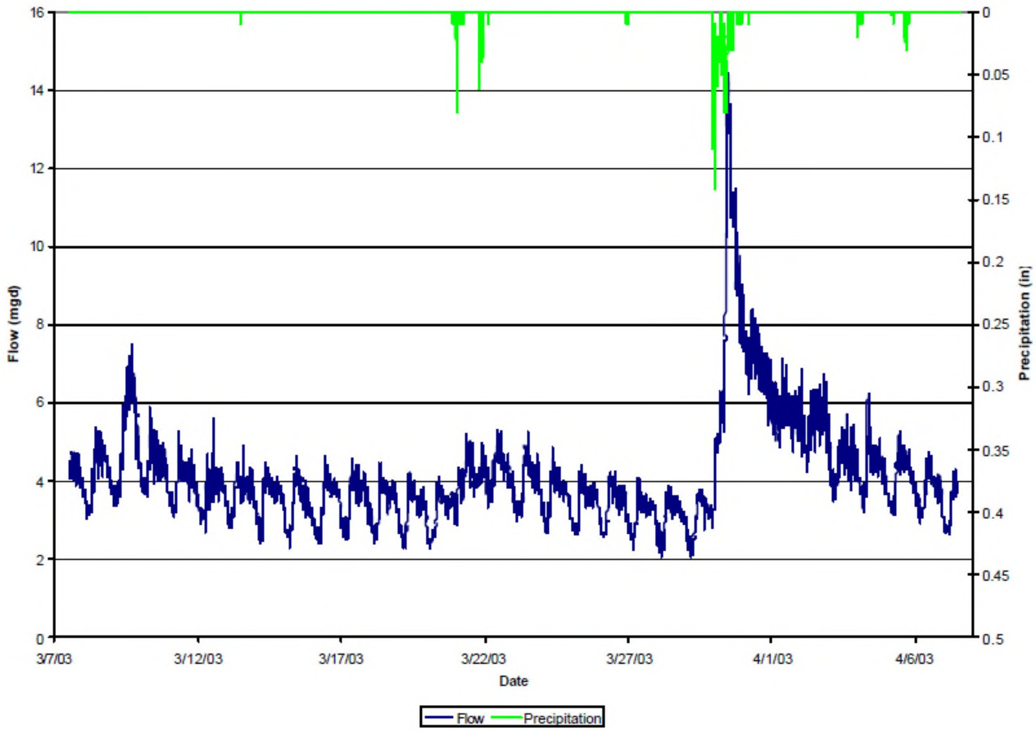
Contaminated surface waters from SSOs and CSOs may then be used for recreation or irrigation purposes, leading to harmful exposure for both humans and animals. Human exposure is also a concern during flood events because untreated wastewater can flow out of the sewer system and impact public health by entering basements and causing groundwater contamination. The negative impacts of this include human and animal exposure to contaminants that can cause skin, respiratory or intestinal infections. Contaminated water and groundwater also could result in contaminated food supply.

The Environmental Protection Agency (EPA) Adaptation Strategies Guide for Water Utilities identified many challenges that will be faced by wastewater utilities throughout the country as a result of climate change. Those that particularly apply to the resiliency of Rhode Island wastewater treatment facilities and infrastructure systems include flooding caused by high flows and coastal storm surges, and loss of coastal landforms and wetlands. While much of the existing wastewater infrastructure in Rhode Island will be exposed to new risks caused by the impacts of climate change, current challenges are also likely to be intensified. Understanding the specific impacts that these weather related events can have on wastewater facilities and their infrastructure will help inform appropriate mitigation planning and actions. The challenges to Rhode Island wastewater treatment facilities are discussed in the sections below.

2.7.1 Increased Wastewater Collection System Flows

Wastewater collection systems typically experience spikes, of varying degrees, in flow rates during and following storm events. These spikes in flow are referred to as inflow and infiltration (I&I) and represent the flow of storm water and/or groundwater into a wastewater collection system. Primary sources of I&I commonly include illicit roof and sump pump connections, storm water system cross connections and deteriorating piping systems. Less common forms of I&I include floodwaters entering into wet-wells or manholes under the most severe conditions; an infrequent occurrence but a vulnerability that may impact an apparently sound collection system.

Figure 2-12: Inflow & Infiltration Impacts on a Collection System



*Note: **Figure 2-12: Inflow & Infiltration Impacts on a Collection System** illustrates the total sanitary sewer wastewater flows for the Town of Middletown, RI and hourly precipitation rates (The Louis Berger Group. Town of Middletown, RI: SSES Phase I – Summary Report, 2003).*

Figure 2-12 illustrates the extent of the impact I&I can have on a collection system. While the collection system illustrated in the figure above conveys flows that are typically stable and predictable during dry weather, the 2.26-inch rainfall event shown on March 30, 2003 increased the collection system flows by over 400%. For reference, the 24-hour design rainfall amount for a 1-year return period in Newport County is 2.8 inches. As storm events become more frequent and more severe, and groundwater levels rise, I&I will become an increasingly large component of the wastewater composition in these systems.

Infiltration and inflow can be detrimental to wastewater collection and treatment systems and even small quantities of I&I can negatively influence the treatment process. As excessive amounts of cool "clean" water enter into a collection system, the fragile balance of microbiological treatment processes may be disturbed, effectively reducing the capacity of the treatment works. In more severe cases, large quantities of I&I can exceed collection and treatment system capacities. Exceeding the capacity of the collection system may lead to back-ups and sewer overflows. Exceeding the capacity of the treatment system may reduce hydraulic residency times to inadequate levels or may even wash the biological treatment organisms out of various treatment system components. I&I assessments may provide clear insight into existing or future system vulnerabilities, but reducing or eliminating existing or potential sources of I&I could be a prohibitively challenging or costly endeavor.

2.7.2 Flooding of Wastewater Facilities and Equipment

As gravity collection systems inherently converge into treatment works or pump stations at low elevations, the possibility for complete inundation of wells, structures and equipment is of significant concern. Inundation of these systems may lead to overflow discharges into adjacent surface waters. Avenues for system failure caused by flooding include:

- Mechanical or back-up **power failures** caused by the infiltration of water into mechanical or electrical equipment not designed for submersion.
- **Floodwater flows into wet wells**, through means other than those typical of I&I such as indoor or above grade access points, may also lead to the immediate failure of pump systems if influent flow rates exceed the capacity of the pumps. This is a condition that is exacerbated by existing collection system I&I.
- **Tanks and containers** within the facility may become **buoyant** under flood conditions posing a hazard to associated equipment, as well as adjacent equipment and personnel.
- A longer-term impact involves the potential for **permanent damage to electrical equipment** that may occur over multiple exposures to water, or with a delayed effect, especially near brackish or salt water bodies. Structural or foundational damage may also become a long-term concern after a single or repeated exposure to water.

2.7.3 Wave and Storm Surge Damage

Waves and storm surges pose a serious physical hazard to collection system and treatment operations when this infrastructure is located in at risk areas. **The force behind wave impacts and storm surges may physically damage critical equipment, immediately disabling equipment or exposing sensitive equipment to flood water damage.** High water velocities from waves and storm surges can quickly erode loose soils, especially where there is a lack of vegetation, potentially weakening building foundations. The **eroded soil** will remain in the water until there is a velocity drop, at which point the suspended solids will drop in depressions in the ground and behind obstructions to the water flow. Collection system pits and wells, especially those located on piers, if not protected from waves and storm surges, may be exposed to large quantities of damaging debris and sand.

The combination of increasing storm frequency and SLR will increase damages associated with waves and storm surges. Facilities not currently prone to exposure to sea water may become prone in future years.

2.7.4 Long-Term, Permanent Inundation (Loss of Property Caused By Sea Level Rise)

With the propensity for wastewater treatment facilities and accompanying collection system components to be located at low elevations, wastewater infrastructure located in a coastal area is at serious risk for complete and permanent submersion in salt or brackish waters. Rising surface waters and the submersion of infrastructure components carry extensive impact potential including:

- Existing infrastructure components, such as pump stations, may become permanently disabled.
- The hydraulic capacity of treatment facilities may be significantly and catastrophically reduced.
- Vehicular or pedestrian access routes to treatment facility or collection system components may be cut off.
- Above-ground tanks may be removed from their foundations by buoyant forces, or in-ground tanks may be filled by infiltration waters.
- Encroaching surface waters may carry waves inland to structures incapable of absorbing the impacts or erosion they bring.
- Buildings could become inundated.

2.7.5 Wind Damage

In addition to the impacts caused by precipitation/flooding during storm events, wind poses a significant hazard to collection and treatment system operation. While the force of wind may be quick and short lived, unlike the lingering impact that flood waters may present, wind damage may be even more serious. **Strong winds**, and the **debris** that it carries, can damage buildings and facility equipment, with roof-mounted equipment being the most vulnerable. While electrical supply equipment may be able to withstand high winds and impacts from debris, telemetry equipment may be less resilient. Ensuring functionality of telemetry and sensitive control equipment during storm events may be difficult, if less critical. A critical component of collection system resiliency is ensuring it will continue function at a minimal state without outside communication.

2.8 DATA INVENTORY AND ASSESSMENT

Existing and publically available data for use in subsequent modeling tasks were compiled by RPS ASA and are listed in **Table 2-2**. The table includes a brief description of the data, the source, year of development, and expected use in upcoming assessment and screening activities. Further details for each dataset are provided below.

Table 2-2: Datasets Collected to Support Task 2 Modeling Activities

Modeling Task	Dataset	Year	Source	Data Type
Sea Level Rise	STORMTOOLS	2014	URI EDC	Raster Grid
	RI TopoBathy DEM	2012	URI EDC	Raster Grid
Erosion	DSAS Transects	2007, 2016	CRMC	Vector Polyline Shapefile
	Historic shorelines	2006, 2016	CRMC	Vector Polyline Shapefile
	RI TopoBathy DEM	2012	URI EDC	Raster Grid
Coastal Flooding	STORMTOOLS	2014	URI EDC	Raster Grid
	RI TopoBathy DEM	2012	URI EDC	Raster Grid
Riverine Flooding	RI Statewide LiDAR	2011	URI EDC	Raster Grid
	National Hydrography Dataset	2014	USGS	Vector Shapefiles
	National Flood Hazard Layer	Effective July 2014	FEMA	Vector Polygon and Polyline Shapefiles
Waves	NACCS Save Points	2015	USACE	Point – Model Output
	STORMTOOLS	2014	URI EDC	Raster Grid
	2011 RIDEM Multispectral Orthophotography of Rhode Island	2011	RIDEM	Digital Orthoimagery
	National Land Cover Database 2011	2011	USGS	Raster Grid

Additional Data	Dataset	Year	Source	Data Type
Rhode Island Wastewater Infrastructure	Treatment Plants	2015	RIDEM	Vector Point Shapefile
	Pump Stations		RIDEM	Vector Point Shapefile
	Sewer Lines	2012	RIDEM	Vector Polyline Shapefile
	Sewered Areas	2012	RIDEM	Vector Polygon Shapefile

STORMTOOLS Inundation and Coastal Flooding

The University of Rhode Island's Environmental Data Center provided a series of ArcGIS raster grids showing the extents and depths of flood predictions across the state of Rhode Island. Predictions of storm-induced water levels are provided for return periods between 1- and 100-years with accompanying sea level rise of 1-, 2-, 3-, 5-, and 7-feet above mean higher high water (MHHW). The flood surfaces were produced by spatially interpolating extreme values between NOAA National Ocean Service (NOS) water level stations in Newport and Providence, RI and New London, CT. The underlying data (water levels with associated return periods and confidence intervals) were statistically derived from thousands of hydrodynamic model runs conducted by the U.S. Army Corps of Engineers (USACE) in 2015 for the North Atlantic Comprehensive Study (NACCS). These results were interpolated between NOS stations to account for the orientation of the Narragansett Bay basin and the resulting funneling effects on water levels during storm events.

RI TopoBathy Digital Elevation Model (DEM)

The digital elevation model was created in 2012 by the University of Rhode Island Environmental Data Center. The DEM is a composite of three separate datasets: (i) 2011 LiDAR data used to define the topography, (ii) 2010 LiDAR bathymetry used for the south coast and coastal ponds, and (iii) more than 120 NOAA NOS hydrographic surveys used for bathymetry. All bathymetry data were run through NOAA's VDatum conversion tool to change the reference from MLW, MLLW, MHW to NAVD88. The data provide seamless transition at the coastal zone and thus were used as a primary source of elevation for analyses of sea level rise, erosion, and coastal flooding.

DSAS Transects

Analysis of shoreline change for Narragansett Bay and the South Shore of Rhode Island was conducted by URI using the United States Geological Survey (USGS) Digital Shoreline Analysis System (DSAS) v.3.0-3.2 for ArcMap and historical shoreline positions (see description below). The analysis was conducted in 2007 and was updated for the RI south shore in 2016. The data were provided by the RI CRMC. Alongshore transects were cast using DSAS every 100 meters along a shore-parallel baseline (50 meters for areas included in the 2016 update). The intersections of transects with the historical shoreline positions are identified by intercept points. Using the DSAS extension, the rate of shoreline change is determined by measuring the differences in the distance to each historical shoreline position from the baseline along each transect.

Historic Shorelines

State-wide vector shorelines for the years 1939, 1951, 1963, 1975, 1985, 1995, 2004, 2012, and 2014 were digitized by URI and provided by the RI CRMC. Supplemental and partial shoreline coverage for the year 1997 was also provided. Polyline shoreline positions were derived from the interpretation of a wet/dry line (commonly referred to as the high water line) as observed in georeferenced aerial images and orthophotographs.

RI Statewide LiDAR

High resolution elevation data were collected state-wide in the Winter and Spring of 2011by Photo Science, Inc. The data collection effort was a component of the larger Northeast LiDAR Project – an effort lead by the USGS to provide data to support more accurate floodplain mapping in the Northeast U.S. In Rhode Island, airborne LiDAR data was collected at a 1 meter or better nominal post spacing at calibrated using 25 control points at ground locations established throughout the state. In addition to LAS point cloud files, the data were developed as a bare-earth digital elevation model (DEM) at 1-m resolution (used for this project). The DEM (developed in the NAD83 UTM Zone 19N meters horizontal coordinate system, and the NAVD88 vertical coordinate system) can be accessed through RIGIS on 1500 x 1500 m tiles. The dataset is the most current LiDAR elevation source available with an extent that covers the entire state of Rhode Island.

National Hydrography Dataset

The National Hydrography Dataset (NHD) is a feature-based database develop by the USGS to encode information about naturally occurring and constructed bodies of surface water (lakes, ponds, and reservoirs), paths through which water flows (canals, ditches, streams, and rivers), and related entities such as point features (springs, wells, stream gages, and dams). The dataset interconnects and identifies stream segments or reaches that make up the nation's surface water drainage system. The high-resolution NHD (used here) was originally developed using 1:24,000-scale data. The data was last updated in 2014.

National Flood Hazard Layer

The National Flood Hazard Layer (NFHL) dataset for each of Rhode Island's counties were downloaded from FEMA's Flood Map Service Center (http://msc.fema.gov/portal/). The NFHL is a compilation of data presented on FEMA's Flood Insurance Rate Maps (FIRMs) and Letters of Map Change (LOMCs). The data include inland and coastal areas that will be inundated by flood events having a 1-percent and 0.2-percent chance of being equaled or exceeded in any given year, and supporting files used to derive the flood zones (e.g. base flood elevations and transects). Data provided in the NFHL are developed at 1:12,000-scale. The NFHL is updated as new Flood Insurance Studies become effective. As of August 2015, NFHL data for counties within the state of Rhode Island corresponded to FIS updates between September 2013 and July 2014.

NACCS Save Points

The database includes a large catalog of storm surge, wave heights, and extremal statistics derived from hydrodynamic models and stored at high resolution stations along the coast of the Northeast U.S. The data were developed by the US Army Corps of Engineers as part of the North Atlantic Comprehensive Coastal Study (NACCS) in 2015. The NACCS was a broad effort to enhance coastal resilience for the North Atlantic region and included computer modeling of thousands of synthetic and historical storms using a coupled wave and storm surge modeling framework that included WAM (for offshore waves), STWAVE (Steady State Spectral Wave), and ADCIRC (Advanced Circulation Model). The results of this modeling have been made available at discrete stations ("save points") within the modeling domain. Statistical data from individual save points can be downloaded using the USACE Coastal Hazards System (https://chswebtool.erdc.dren.mil).

2011 State of Rhode Island Orthophotography

The most recent aerial photography for the state of Rhode Island was released in 2011. The Rhode Island Department of Environmental Management (RIDEM), Rhode Island Department of Transportation (RIDOT), and the USGS produced the multispectral digital orthoimagery. The orthoimagery has a raw pixel resolution of 0.15m (6 inches). The imagery was collected during a leaf-off period in late spring 2011, under cloud-free conditions. The digital data were obtained from Rhode Island Geographic Information System (RIGIS).

Land Cover Type

The 2011 National Land Cover Database (NLCD 2011) was developed by the United States Geological Survey (USGS) and published in 2013. The data were provided as a raster gridded product with a cell size of 30 meters. The NLCD was the result of a decision-tree classification of Landsat 5 and 7 satellite imagery collected in 2011. The digital data were obtained from mrlc.gov. Details of the classification system can be found in Jin (2013).

Rhode Island Wastewater Infrastructure

Wastewater infrastructure was obtained from the Rhode Island Department of Environmental Management (DEM). Shapefiles provided include treatment plants, pump stations, sewer lines, and sewered areas. The treatment plants layer represents the 19 wastewater treatment facilities across the state. It was created in 2015 using information found on the RIDEM Office of Water Resources website. The pump stations layer includes 239 stations, as well as information regarding the facility to which wastewater is pumped. The sewer lines layer was updated in January 2012, and was compiled from data collected by Rhode Island towns and utilities. The sewered areas layer was updated in 2012, and depicts areas served by sanitary sewers based on information supplied by municipal or regional sewer authorities.

3. INITIAL ASSESSMENT OF POTENTIAL CLIMATE CHANGE IMPACTS TO RHODE ISLAND WASTEWATER INFRASTRUCTURE

3.1 ASSESSMENT PROCESS

Woodard & Curran began the assessment process by collecting information on the nineteen wastewater treatment facilities included in this study. Facility operators provided specific information for their facilities, initially through responding to a questionnaire, and subsequently through direct communication with Woodard & Curran engineers either during a site visit and/or by telephone. **Section 3.1.1** describes the data collection process. Statewide modeling exercises were then performed as part of the initial assessment process to further identify and assess the wastewater infrastructure likely to be affected by sea level rise (SLR), coastal flood hazards, riverine flood hazards. Coastal erosion and wave hazards were assessed at specific facility locations. The modeling methodology is described in **Section 3.1.2**. The combined results of this initial assessment process are described for each facility in **Section 3.2**.

These results confirm the importance of evaluating the facilities in both a historic and predictive manner and using the historic to confirm the predictive to the extent possible. Data from each historical event relates to a specific set of conditions that is unlikely to be completely replicated. Conversely, statewide modeling applications cannot capture the nuances of localized conditions that would comprehensively predict hazard conditions. Considering these tools together, however, provides communities with a basis of information on which to make decisions regarding hazard protection, adaptation, and resiliency.

3.1.1 Facility Specific Data Collection

The questionnaire completed by the plant operators (provided in **Appendix A**) focused on identifying plant components and pump stations that are at risk for damage from climate change events. Woodard & Curran pre-populated the questionnaires with information from RIDEM's Sanitary Sewer Overflow (SSO) database from 2009 through February of 2015. The facility operators updated that information and provided additional information in response to the questions. Concurrently, Woodard & Curran reviewed readily available information on file at RIDEM and on line such as Facilities Plans, Emergency Response Plans, Comprehensive Plans, Natural Hazard Mitigation Plans, and Flood Insurance Rate Maps (FIRMs).

Upon review of the above information, Woodard & Curran prioritized the facilities for site visits based on the relative likelihood of climate related physical impacts. Woodard & Curran and RIDEM staff cooperatively selected the five parameters used in the ranking exercise, all of which were equally weighted. The parameters were applied to each facility and ranked on a scale of 1 to 3, with 3 being the highest level of risk for each parameter. The resulting scores ranged from five to fifteen. Facilities with a score of eight and higher were selected for site visits. Woodard & Curran conducted telephone interviews with the operators of the remaining facilities. **Table 3-1** summarizes the results. The parameters, ranking spreadsheet, and histogram are provided in **Appendix B**. The information provided by RIDEM, the facility operators, and on-line sources are compiled in **Appendix C,** which is comprised of twenty subsections, one for state-wide information provided by RIDEM, and one for each WWTF process. The individual WWTF subsections contain the compiled data that was collected for that process, including the relevant portion of the statewide SSO database, which identifies the location, estimated volume, and cause of the SSOs.

Table 3-1: Facility Site Visit Selection Results

Site Visits			Telephone Interview
Bristol	Narragansett	South Kingstown	Burrillville
Cranston	NBC Bucklin Point	Warren	New Shoreham
East Greenwich	NBC Fields Point	Warwick	Smithfield
East Providence	Newport	West Warwick	Woonsocket
Jamestown	Quonset	Westerly	

3.1.2 State-wide Modeling Applications Methodology

3.1.2.1 Coastal Flood Hazard Assessment

The goal of the coastal flood hazard assessment was to evaluate wastewater infrastructure that may be at risk from potential storm surges under current and future sea level rise scenarios. At the request of RIDEM, RPS ASA's approach was modified to be consistent with new statewide storm surge mapping being conducted by the University of Rhode Island STORMTOOLS team. Inundation from storms of varying return period was mapped for Narragansett Bay and the RI south shore with sea level rise of 1-, 2-, 3-, and 5-feet. The general methodology is described by Spaulding and Isaji (2014) and utilizes output from state of the art computer modeling of thousands of hurricane storm surges recently completed by the US Army Corps of Engineers as part of the North Atlantic Comprehensive Coastal Study (NACCS). The upper Narragansett Bay was modeled with the Fox Point Hurricane Barrier open.

The NACCS employed high fidelity atmospheric, wave and storm surge modeling and extremal statistical analysis techniques for a domain covering the Northeast US (Cialone et al., 2015). A suite of synthetic tropical storms was developed for the North Atlantic basin based on a joint probability model of tropical cyclone parameters (storm size, intensity, location, speed, and direction). Simulations of 1050 synthetic tropical storms were then performed using a coupled wave and storm surge modeling framework that included WAM (for offshore waves), STWAVE (Steady State Spectral Wave), and ADCIRC (Advanced Circulation Model). The final catalog of storm surge, wave heights, and extremal statistics from each model run has been stored at high resolution save points along the coast.

Spaulding and Isaji (2014) utilized the NACCS output for RI coastal waters to develop seamless maps of storm surge at the 100-year return period. The mapped water levels represent the upper 95% confidence level. The surfaces were produced by spatially interpolating extreme values between NOAA National Ocean Service (NOS) water level stations in Newport and Providence, RI and New London, CT. Comparison of the results with observational records (tide gauge) and modeling (SLOSH) confirms that the approach generally captures the spatial structure of extreme storm flooding for Rhode Island waters. The final products were developed as both raster and polygons map layers[3]. Data access is provided through the STORMTOOLS web GIS at http://www.beachsamp.org/resources/stormtools/ and through the Rhode Island Geographic Information System (RIGIS) at http://www.rigis.org/data/ScaledSLR_NACCS. A RIDEM Mapper is also available at http://arcg.is/2mlL2bF for simplified access to the coastal change imaging that is used in this report.

[3] The STORMTOOLS data layers used for the coastal flood hazard assessment are similar to flood zones shown on FEMA Flood Insurance Rate Maps (FIRMs), with several important distinctions. Both sources of data show extent and depth of flooding associated with a 100-year return period storm. FIRMs show a Base Flood Elevation (BFE), which includes both storm surge and wave effects, but do not include forecasted sea level changes. By contrast, flood elevations in STORMTOOLS do not include wave effects and can be presented with or without fixed SLR values. Another notable difference is the way that uncertainty is presented for each source. Confidence intervals are not reported on the FIRMs, whereas STORMTOOLS water levels are reported at the upper 95% confidence level to address some of the underlying uncertainty in the return period analysis.

3.1.2.2 Coastal Erosion

An analysis of coastal erosion was conducted to identify wastewater infrastructure that may be at risk from frontal erosion and to predict timeframes for potential relocation. Because the shoreline fronting most WWTFs has been altered through filling or emplacement of coastal engineering structures, historical rates of shoreline change often do not reflect natural processes. Accordingly, a method was developed that accounts for (i) future changes introduced by accelerated sea level rise, and (ii) historical rates of shoreline change, if applicable. The analysis was conducted for all coastal reaches adjacent to WWTFs (10 plants total). Data are presented as a series mapped polyline files corresponding the predicted shoreline at 25-, 50-, and 100-year time horizons.

To begin, the position of MHHW was mapped at each future time horizon for the segment of coastline fronting each plant. This was achieved by conducting a cell-by-cell analysis of coastal elevations (using the 2012 RI TopoBathy DEM) to identify where the coastal profiles intersected with elevations representing MHHW in the years 2040, 2065, and 2115. The SLR predictions used to define the future MHHW are described in Huber and White (2015) and are adjusted to include local rates of subsidence derived from the tide gauge at Newport, RI. Relative sea level rise curves for Newport can be viewed at the US Army Corps of Engineers sea level rise calculator (http://www.corpsclimate.us/ccaceslcurves.cfm); the curves published by Parris et al. (2012) are currently being incorporated in to Rhode Island's Coastal Resources Management Program (Section 145), and thus were used for this analysis.

Each future MHHW shoreline was then translated landward using a representative rate of erosion for the coastline fronting each plant. Historic shoreline changes in Narragansett Bay and the RI south shore have been assessed through mapping by URI (Boothroyd et al., 2016; Boothroyd and Hehre, 2007) and the USGS (Hapke et al., 2010). These studies utilized historic imagery and remote sensing data to calculate erosion rates at transects spaced every 50-100 m alongshore. At each transect, distances of shoreline movement have been calculated, and annual rates of shoreline change determined. Up to twenty transects were used to establish an average shoreline change rate for the coastline fronting each plant. The future MHHW shorelines were then migrated in a GIS environment by the corresponding retreat rates. For locations where shoreline armoring in front of the plant has resulted in a positive net shoreline movement (accretion), the erosion rate was set to zero. The final data are provided in GIS format (shapefiles) showing the projected shoreline orientation at each of the (3) time horizons.

3.1.2.3 Sea Level Rise

The effects of sea level rise on WWTF infrastructure were considered as part of both analyses described above. For the coastal flood hazard assessment, changes in sea level were considered in conjunction with storm surge at the 100-year return period to evaluate the extent of inundation under future conditions. In this case, the STORMTOOLS mapping included superposition of fixed SLR elevations (1-, 2-, 3-, and 5-feet) on top of the 100-year storm surge. (The effect of sea level rise alone was not mapped since moderate storms cause increased water levels up to and beyond a scenario with 5 feet of SLR.) The mapping was conducted by URI in 2014 and utilizes a protocol that combines a digital elevation model (DEM) and flood estimates to create inundation surfaces.

Sea level rise was also considered for the assessment of coastal erosion at the locations of the WWTF infrastructure. In this case, sea level change was evaluated for specific time horizons so the fixed SLR elevations from STORMTOOLS were not used. Instead, a series of ArcGIS processing steps was used to define the position of MHHW at multiple time horizons, and establish inundation for each period. Sea level changes at time horizons of 25-, 50-, and 100-years from 2015 were defined using the rates of Huber and White (2015). These values, superimposed with current MHHW were used to develop future MHHW shorelines for each time horizon. These layers were generated from a cell-by-cell analysis of coastal elevations derived from LiDAR and NOAA bathymetry surveys (RI TopoBathy DEM). The cell size for input data and inundation surfaces is 3.281 ft. (1m) and the horizontal/vertical units are feet.

3.1.2.4 Wave Hazard Assessment

FEMA's Wave Height Analysis for Flood Insurance Studies (WHAFIS) model was used to predict overland wave heights for WWTFs that were determined to be at risk of inundation following the Coastal Flood Hazard Assessment (8 locations). WHAFIS was used to predict the significant wave height (the average height of the highest 1/3 of waves, measured trough to crest, for a given period) and the wave crest elevation for a 100-year return period storm at representative transects for each plant. The analysis was conducted to predict the total flood elevation (the sum of storm surge, wave setup, and significant wave height) for present day conditions and for the 5-ft sea level rise scenario.

WHAFIS calculates the 'controlling wave height', which is 1.6 x significant wave height, along a user defined transects. Because a high degree of variability in flood depth (and associated wave height) exists across each site, transects were oriented in order to capture several representative flood conditions for each plant. (Note that initial flood conditions from STORMTOOLS are based on "bare earth" elevations that have been edited to remove above ground infrastructure and vegetation.) Transects are defined in an input file that contains a characterization of the initial conditions including:

- Transect segment type (inland fetch)
- Ground elevations (LiDAR DEM)
- Still water elevations representing storm surge (NACCS/STORMTOOLS)
- Incident wave height and period (NACCS/ STORMTOOLS)
- Wave setup (calculated as 8% of incident wave height)
- Wind speed (WHAFIS default for a 100-yr return period event)

WHAFIS calculations are output as a text file of wave parameters at discrete points along each transect (in this case, every 10 m). The data was then converted to shapefiles (points) that are attributed with wave characteristics for both current and future (5-ft SLR) scenarios.

3.1.2.5 Riverine Flood Hazard Assessment

The riverine flood hazard assessment was completed statewide so as to be available for future use and other purposes. It identifies wastewater infrastructure that are situated at ground elevations within 2- or 3- vertical feet of the existing FEMA 100-year floodplain. The assessment is based on guidance issued in Executive Order 13690 – the Federal Flood Risk Management Standard – which provides recommendations for establishing flood elevation and hazard areas that account for uncertainties associated with future climate changes. The new standard amends the definition of floodplain to include the following approaches to establish the vertical elevation and corresponding horizontal extent of flooding for federally funded projects:

1. Use data and methods informed by best-available, actionable climate science;
2. Build two feet above the 100-year (1%-annual-chance) flood elevation for standard projects, and three feet above for critical buildings like hospitals and evacuation centers; or
3. Build to the 500-year (0.2%-annual-chance) flood elevation.

The analysis described here corresponds with option 2, and was intended to complement recent hydrologic modeling conducted for the Rhode Island Department of Health SafeWater RI study (RIDOH, 2012). SafeWater RI developed estimates of future floodplains in the Pawtuxet River Basin using downscaled climate models; the results were then extrapolated to other watersheds in the state (option 1). By contrast, this approach used a consistent, map-based calculation, to delineate floodplains based on FEMA's Base Flood Elevation (BFE) and the underlying topography. The mapping also extended to Special Flood Hazard Areas designated by FEMA as Zone A – areas subject to inundation by the 1-percent-annual-chance flood event that are determined using approximate methodologies and do not have assigned Base Flood Elevations.

The methodology involved developing new flood areas based on higher flood elevations than those used by FEMA, and mapping the corresponding horizontal floodplain extent. The input data for the analysis were FEMA BFEs, which are provided at each riverine transect. The BFEs were taken from each county's DFIRM database, which was downloaded from the FEMA Mapping Center in August 2015[4]. The mapping relied on a single source of topography data – LiDAR – which was collected statewide in 2011. A digital elevation model derived from the statewide LiDAR at 1-meter resolution (RIGIS, 2013) was applied for this assessment[5].

The mapping was executed through a series of geoprocessing steps summarized below:

1. DFIRM data were acquired for each county in RI. Riverine transects, and flood polygons (Special Flood Hazard Areas) for each county were merged statewide. Polygons designated Zone A and Zone AE were isolated. Coastal AE zones were removed because they represent a different source of flooding.
2. Using the underlying topography, Zone A polygons were attributed with flood elevations. (Inundation extent within Zone A areas is determined by FEMA using approximate methods and therefore BFEs do not exist for these zones.)
3. Point features were generated at vertices along each riverine transects and each Zone A polygon. Two sets of points were developed and assigned an elevation (ft. NAVD88) of the 100-year flood elevation plus 2- and 3-feet, respectively.
4. An inverse distance weighted interpolation was run, statewide, for each set of elevations based on the nearest six points. The resulting interpolation surface was a raster dataset at 1 m resolution.
5. Land elevations (LiDAR) were subtracted from the interpolation surface to produce a raster dataset where positive values equal the flooding depth (all values greater than zero = inundated land). The dataset was converted to a polygon for editing.
6. A series of quality control steps were performed to identify and edit disconnected flood areas, and locations with anomalous flooding due to inaccuracies in the digitization of the original flood zone. All flooding was clipped to the state boundary and coastline. Large flood zones were qualitatively compared to LiDAR and high-resolution imagery during the editing process.
7. Separate raster surfaces were derived for each scenario (2- and 3-feet) showing the extent of flooding. A raster grid was also produced with the depth of flooding for each scenario.

The final products of this analysis are a series of GIS files (raster datasets) showing the expanded floodplain under each scenario. These files are map layers that present the area of inundation and the depth of flooding for both conditions. These GIS files have been provided in **Appendix D**. The riverine data is available at http://www.rigis.org/data/ridem_RiverineFlooding. A RIDEM Mapper is also available at http://arcg.is/2mlL2bF with simplified access to the riverine imaging that is used in this report. As a point of reference, the USGS flood gauge 01116500 on the Pawtuxet River in Cranston recorded the river elevation on March 31, 2010 as 28.79 feet NGVD29 (elevation 27.95 NAVD88). The FIRM identifies the 100-year flood at this location as elevation 23 NAVD88. Therefore, the 100-year flood plus 2 feet mapped in this exercise is approximately 3 feet lower than the flooding experienced at the peak of the March 2010 floods. The 100-year flood plus 3 feet mapped in this exercise is approximately 2 feet lower than the flooding experienced at the peak of the March 2010 floods.

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[4] During the course of the analysis, the FIRMs for Kent and Providence County were updated with new data for portions of the Narragansett Bay Watershed (including portions of the Moshassuck, Pawtuxet, Ten Mile, and Woonasquatucket Rivers). Although the updated FIRMs include changes in several parameters that were used for this assessment, a comparison of flooding elevations at WWTFs within the watershed show only minor differences (average offset in BFEs at transects surrounding the plants <1ft). The updated FIRMs became effective in October 2015.

[5] In many inland locations this data exceeds the resolution and accuracy of the topography used to develop the FIRMs, and for this reason the flooding is not always directly comparable between the two sources. For example, in some locations flooding at the 100-year plus 2-ft level actually occupies a smaller footprint than the original FEMA floodplain because the underlying ground elevation (and inundated areas) is more accurately resolved.

3.2 INITIAL ASSESSMENT RESULTS

This Section provides an overview of each of the wastewater treatment facilities based on the data provided. It summarizes information provided by the facility operators pertinent to climate change, such as storm events that caused damage to the facilities or sanitary sewer overflows (SSOs), climate change adaptation measures that they have planned or implemented, and facility components they perceive to be at risk from climate change related events. The description of the facility systems and their respective vulnerabilities reflects the extent that information was made available for this assessment, which varied. This Section also describes how the results of the state-wide modeling efforts generally apply to each of the WWTFs. As noted in Section 2, the 2011 LiDAR data was used to define the topography for the modeling analyses. Therefore, the analyses do not reflect changes in grade such as protective berms or walls that have been raised at some facilities after that date. Section 4 applies this information more specifically to the WWTFs to assess the risk of the various facility components to climate change.

Figure 3-1: RI Wastewater Treatment Facilities is a statewide map showing the locations of the WWTFs and the pump stations that were identified as being the most vulnerable. These are described with the corresponding WWTF later in this Section.

The following tables, **Table 3-2: WWTFs Predominantly Inundated, Table 3-3: WWTFs Partially Inundated,** and **Table 3-4: WWTFs Not Inundated,** summarize the relative risk from inundation of the 19 WWTFs evaluated. Because wave height is driven predominantly by the depth of coastal flooding, the relative wave damage is broadly captured by the extent of inundation, which is appropriate for this level of comparison. Seven of the WWTFs are predicted to become predominantly inundated under the conditions modeled in this study and thus have the highest likelihood of failure as a result of climate change related events. Seven are predicted to become partially inundated, and five are well protected.

Table 3-2: WWTFs Predominantly Inundated

WWTF	Risk
Bucklin Point	Coastal
East Greenwich	Coastal
East Providence	Coastal
Fields Point	Coastal
Quonset Point	Coastal
Warren	Coastal
West Warwick	Riverine

Table 3-3: WWTFs Partially Inundated

WWTF	Risk
Bristol	Coastal
Burrillville	Riverine
Cranston	Riverine and Coastal
Newport	Coastal
Smithfield	Riverine
Westerly	Coastal
Woonsocket	Riverine

Table 3-4: WWTFs Not Inundated

WWTF	Risk
Jamestown	Coastal
Narragansett *	Coastal
New Shoreham	Coastal
South Kingstown	Coastal
Warwick **	Riverine and Coastal

**Assumes proposed flood barrier is installed to elevation 20 (NAVD88)*
*** Assumes flood barrier is raised to elevation 29 (NAVD88)*

Table 3-5: Pump Stations Evaluated Most Vulnerable to Climate Change lists the pump stations shown in **Figure 3-1: RI Wastewater Treatment Facilities and Most Vulnerable Pump Stations.** The pump stations that were identified as most vulnerable are those that have experienced flooding, power failures, or exceeded capacity during severe weather events, or their operations were threatened by severe weather events warranting concern by facility operators. Other pump stations on this list were predicted to be vulnerable based on the modeling results and Woodard & Curran's institutional knowledge. The definitions of the risks noted in this table are as follows:

Access: Coastal or riverine mapping identified access to the pump station to be restricted.

Backup Power: Pump station does not have reliable or permanent back-up power

Capacity: Pump station capacity has been exceeded or threatened by severe precipitation events.

Coastal: Pump station is located within the coastal hazard/SLR impacted area.

Localized: Pump station has experienced flooding from a localized source that is not identified on the FEMA maps.

Riverine: Pump station is located within the riverine hazard impacted area.

Unmapped: The pump station has experienced flooding from precipitation event(s), however the riverine mapping exercise does not extend to the pump station location because the source of flooding identified in the FEMA flood maps is coastal.

There are additional pump stations identified in RIDEM's database that are predicted to become inundated or have accessibility restrictions during the modeled and mapped flooding events. The RIDEM Database pump stations and their apparent flood risk are listed in the table in **Appendix E**.

Of the seventy-nine most vulnerable pump stations, seven are predicted to become inundated during both coastal and riverine flooding events although three of these (Westerly's Beach Street PS, New Canal PS, and Old Canal PS) are in Coastal AE zones where the riverine flooding could not be mapped. Forty pump stations are predicted to become inundated only by coastal flooding events and three pump stations are predicted to have accessibility issues during the modeled coastal events. In addition, seventeen pump stations are predicted to become inundated only from the riverine flooding events mapped in this study and four are predicted to have accessibility issues during the mapped riverine events. One pump station (Bristol's Brook Farm PS) was identified to be at risk during riverine flooding events based on past occurrences reported by operators. Eight pump stations that are not subject to inundation were identified by operators to be at risk either because they lack backup power or because inflow during storm events jeopardized capacity.

Figure 3-1: RI Wastewater Treatment Facilities and Most Vulnerable Pump Stations

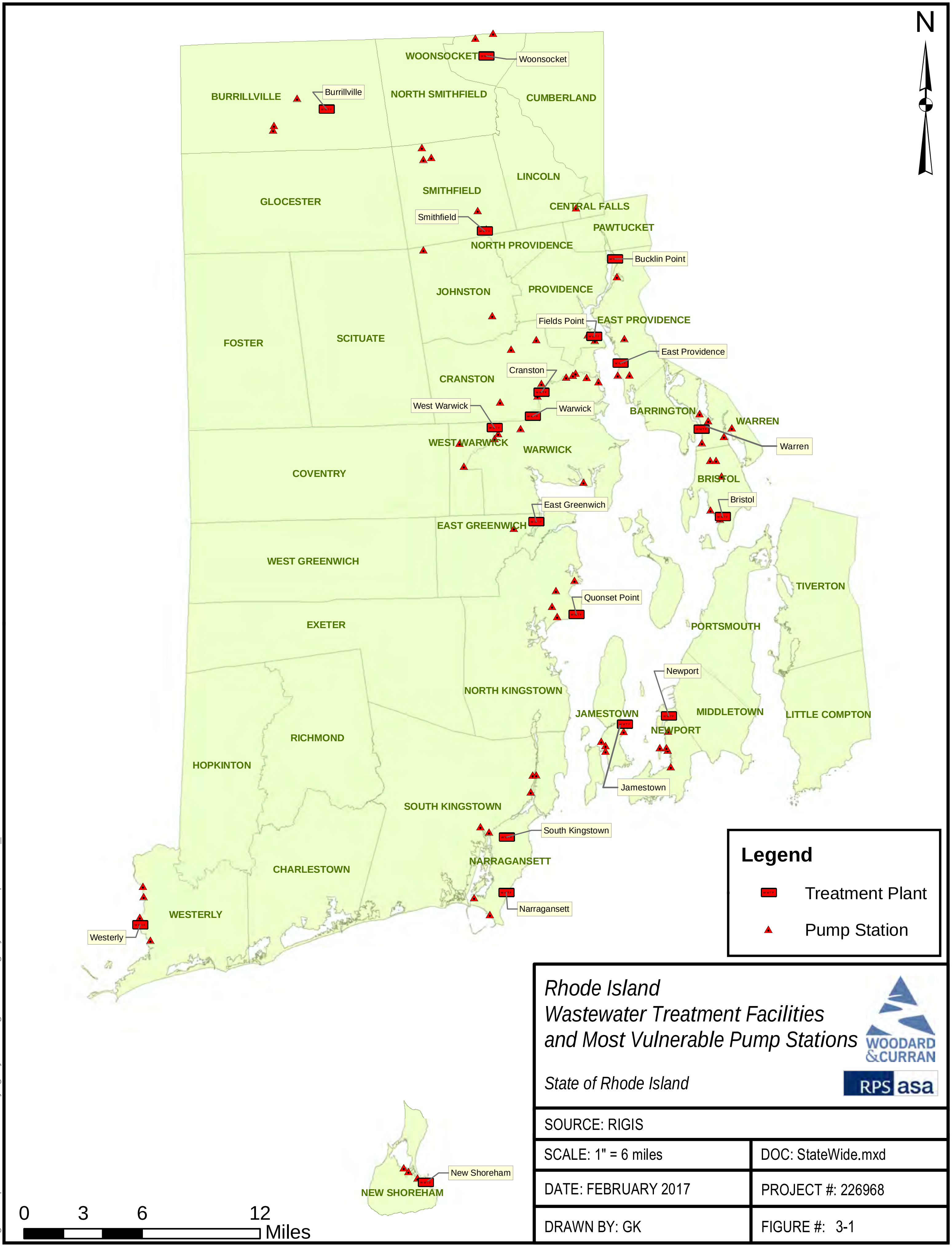

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Table 3-5: Pump Stations Evaluated Most Vulnerable to Climate Change

(See Appendix E for RIDEM Database Pump Stations Predicted to be Affected by Flooding)

WWTF	Pump Station	Risk
Bristol	Broadcommon	Backup Power
	Brook Farm PS#9	Localized; Backup Power
	Constitution PS#4	Coastal
	Main Lift PS	Coastal
	Ferry Rd. PS#3	Coastal
	Peter Rd. PS#8	Backup Power
Bucklin Point	Omega PS	Coastal; Riverine
	Saylesville PS	Riverine
Burrillville	Beach Rd. Ej. Sta.	Riverine; Backup Power
	Rock Ave. Ej. Sta.	Backup Power
	School St. Ej. Sta.	Riverine
Cranston	Allard PS	Riverine
	Burnham PS	Riverine
	Mayflower PS	Coastal; Riverine
	Pontiac PS	Riverine; Coastal (Access)
	Randall PS	Riverine
	Seaview PS	Coastal
	Worthington PS	Riverine
	Youlden PS	Coastal; Riverine
East Greenwich	Cedar Heights PS	Riverine (Access)
East Providence	Bullocks Pt. Ave. PS	Backup Power
	Merritt Rd. PS	Capacity
	Sabin Pt. PS	Coastal; Backup Power
	Silver St. PS	Coastal
Fields Point	Central Ave PS	Riverine
	Ernest St PS	Coastal
	Washington Park PS (Shipyard St)	Coastal
Jamestown	Bayview Drive PS	Coastal (Access)
	Beavertail Rd. PS	Coastal
	Maple Ave. PS	Coastal
	Narragansett Ave. PS	Coastal; Capacity
Narragansett	Galilee PS	Coastal
	Mettatuxet	Coastal
	Stanton Ave. PS	Coastal
New Shoreham	Boat Basin PS	Coastal
	Ocean Ave. PS#1	Coastal
	Ocean Ave. PS#2	Coastal
	Old Harbor PS	Coastal
	Champlin's Marina PS	Coastal

WWTF	Pump Station	Risk
Newport	Dyre St. PS	Coastal
	Goat Island PS	Coastal; Backup Power
	Long Wharf PS	Coastal
	Washington St CSO Facility	Coastal
	Wave Avenue (owned by Middletown)	Coastal
	Wellington PS & CSO Facility	Coastal
Quonset Point	Burlingham PS	Coastal
	Commerce Park PS	Coastal
	Davisville Pier PS	Coastal
	Davisville PS	Coastal
Smithfield	Burlingame Rd PS	Backup Power
	Camp St PS	Riverine
	Farnum Pike PS	Capacity
	Latham Farm Rd PS	Backup Power
	Roger Williams Dr PS	Capacity
	Whipple St PS	Riverine
South Kingstown	Middlebridge N PS	Coastal; Backup Power
	Middlebridge S PS	Coastal; Backup Power
	Salt Pond PS	Coastal
	Silver Lake PS	Coastal
Warren	Asylum Rd PS (Cole School PS)	Coastal
	Locust Ter. PS	Coastal
	North PS	Coastal
	Patterson Ave PS	Coastal
	Wood St PS (East PS)	Coastal
Warwick	Bellows St PS	Coastal (Access); Riverine (Access)
	East Natick 1	Riverine
	East Natick 2	Riverine
	Irving Rd PS	Coastal; Riverine
	Knight St PS	Riverine
	Oakland Beach PS	Coastal
West Warwick	Clyde PS	Riverine
	Sandy Bottom (Owned by Coventry)	Riverine (Access)
	Maisie Quinn PS	Riverine
Westerly	Beach St. PS	Coastal; Riverine (Unmapped)
	Margin St. PS	Coastal; Capacity
	New Canal	Coastal; Riverine (Unmapped)
	Old Canal	Coastal; Riverine (Unmapped)
Woonsocket	Privilege St PS	Riverine (Access)
	St. Louis PS	Riverine

3.2.1 Bristol

The Town of Bristol owns and operates the Bristol Wastewater Treatment Facility located on Plant Avenue in Bristol and it discharges to Bristol Harbor. Bristol is a community situated on a peninsula between Narragansett Bay and Mount Hope Bay. The facility serves the Town of Bristol (US Census population of 22,954) and an estimated 20,700 customers. The WWTF location is landlocked and 1,000 feet inland from Bristol Harbor. The Bristol WWTF operates with a design flow capacity of 3.8 MGD and it treats an average daily flow if 2.8 MGD. The facility operates a typical treatment process including rotating biological contactors. In addition to the facility's main lift station, there are ten pump stations in the community that contribute flow to the WWTF. Several of them are in a floodplain or of concern for climate change impacts.

Bristol's Hazard Mitigation Plan Update (Draft 2015) acknowledges that portions of the wastewater treatment plant are in the floodplain of Tanyard Brook, which is also in an area of poor drainage. The plan notes that if the facility becomes inoperable, there are public health issues and the potential for pollution impacts to nearby waterways.

3.2.1.1 Operator Data

There have been several occasions when access to the Bristol WWTF or specific pump stations has been limited by extreme heavy rains. The WWTF suffers from occasional flooding during significant rain events caused by surface runoff from the surrounding wetlands. The most severe flooding at the facility occurred in April 2014 when the water level in the surrounding wetlands rose above the RBC tanks (these tanks were built below grade and are uncovered), adding over 7 MGD to effluent flows. The additional flow caused tank levels to rise, placing equipment and motors at risk. Eight of the twenty-four RBC motors became fully inundated during this event. There are no parts of the facility being protected by a berm or other means to prevent floodwaters from entering.

Recent work at the facility includes the headworks which was upgraded in 2015 and the rotating biological contactor (RBC) system. RBC replacement is ongoing. Sixteen of 24 total units have been replaced to date, beginning in 2012 and the remaining eight RBCs are projected to be replaced by the end of 2018. The facility has prepared plans and submitted them to RIDEM to construct drainage infrastructure at the south side of the facility following a flooding incident in 2014. The facility operates with a maximum influent capacity of 14 MGD. This influent flow is regulated by allowing only one of two 72" 14 MGD influent screw pumps to operate at any given time; however, flooding over tank walls has raised the effluent flows to a peak of 22 MGD. Additionally, Bristol sees a high amount of I&I and the influent pump stations receives higher flows than the facility can handle leading to back-ups and SSOs throughout the Town. At the time of the assessment, this endeavor was in the design stage with on-going coordination between the State Coastal Resources Management Council. The plans include creating an easement to Fair View Avenue, which would provide a secondary access point to the plant. There is one underground diesel fuel storage tank at the WWTF which is not subject to flooding that will be removed by 2017.

In addition to the facility's main lift station, there are ten pump stations that contribute flow to the WWTF. Facility staff consider five of these to be at risk to climate change: Peter Road, Brook Farm, Broadcommon, Constitution, and Ferry Road. The Peter Road and Broadcommon pump stations have electrical services at grade and the back-up generators are stored remotely at the treatment facility. The Brook Farm Pump Station and Brook Farm Drive flooded in 2014 and 2010 and there were no means to bring a portable generator to the site in case of power loss. At the time of this assessment, the Town had been denied Hazard Mitigation Grant funding to support the installation of allocated generators at Peter Road, Broadcommon, and Brook Farm pump stations; the Town resubmitted the pump stations for consideration under a second round of selections. The Constitution Pump Station has a 30-year old generator and is located only 20± feet from the coast. The generator is elevated above the FEMA 100-year base flood elevation. A major rehabilitation is planned for Constitution Pump Station in 2017, which may include new dry-pit submersible pumps, control systems, and a new generator system in the same location as the current generator.

In general, a major concern for the Bristol WWTF is that funding availability and mitigation work is more reactive than proactive. The Emergency Response Plan for the Bristol Water Pollution Control Department (December 2007) indicates that when flooding is imminent, sandbag dikes should be constructed around electrical equipment and low-lying buildings. In the event of flooding at the treatment facility, the plan notes electric power should be disconnected and locked out of the flooded area, and if possible, equipment should be moved or secured from a flooded area. Sandbags could be placed around door openings to reduce flood water entering the facility, but this has never been implemented. The WWTF and system components are in need of additional maintenance, repair and upgrade that will help them withstand natural hazard events.

3.2.1.2 Modeling Results

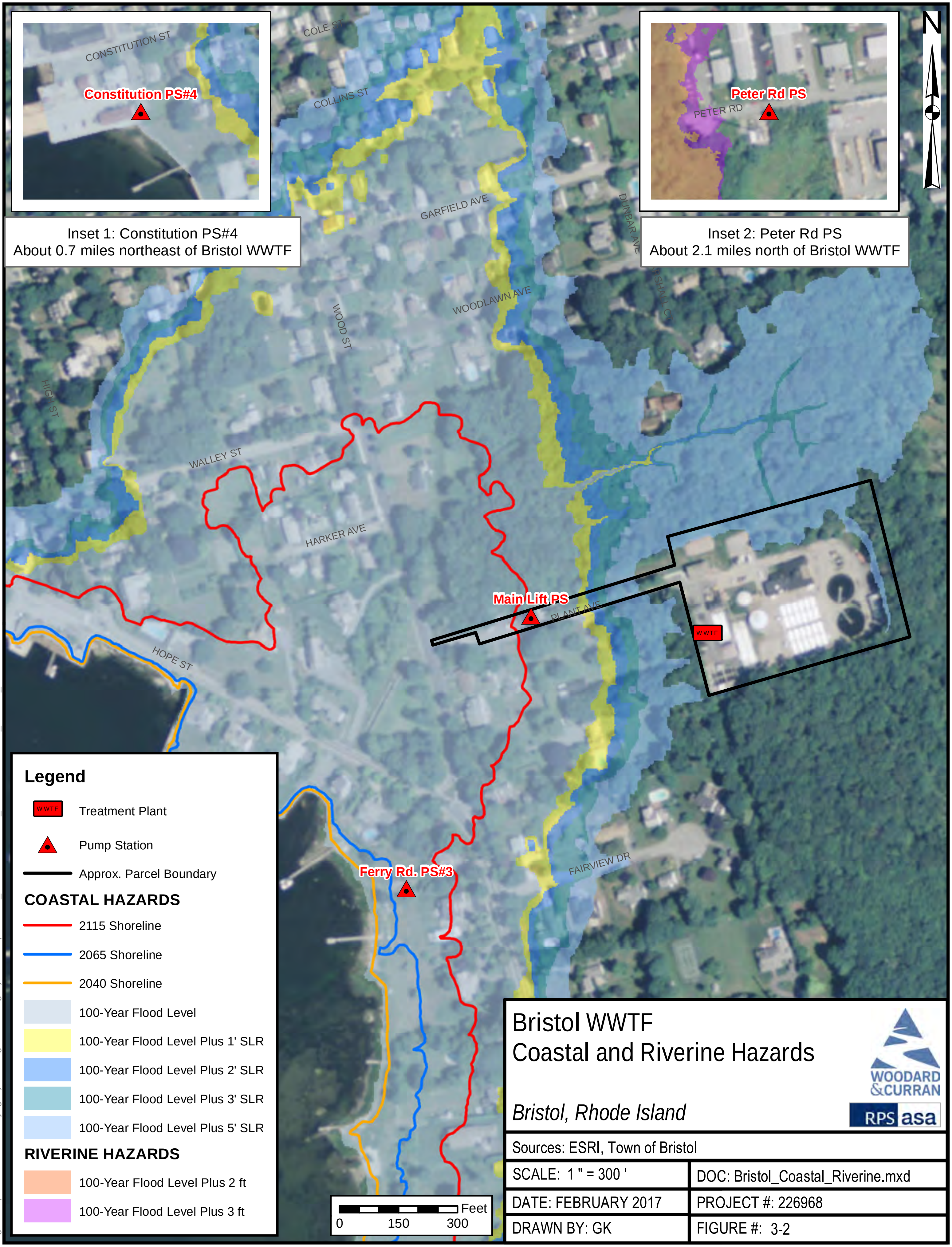
The Bristol WWTF was assessed for risk to sea level rise, coastal flood hazards, and coastal erosion (**see Figure 3-2: Bristol WWTF Coastal and Riverine Hazards**). The coastal flood hazard assessment predicted the Bristol WWTF would not be inundated by storm surge with up to 5 feet of SLR, however, the road to access the plant as well as the Constitution Street Pump Station (located 0.7 mile from the WWTF) would be inundated by a 100-year storm and access to the facility would be limited.

The Bristol facility is not predicted to be directly impacted by coastal erosion but access could be in the 100-year time frame if shoreline protection measures are not implemented. The predicted shoreline configurations shown in **Figure 3-2: Bristol WWTF Coastal and Riverine Hazards** assumes the erosion occurs without interference and includes the effects of SLR. Very little change is predicted at the 25-year and 50-year time horizons, however, the predicted 100-year shoreline would impact the access drive to the facility and collection system components.

3.2.1.3 Data Correlation Notes

Considering the past events observed and described by the WWTF operators along with the potential events identified by the state-wide modeling analysis, it appears that the immediate concern for the WWTF and the Brook Farm pump station is localized flooding, which was not evident in the state-wide mapping exercise. Recent improvements to Tanyard Brook might have improved the flooding threat along Wood Street near Plant Avenue. The coastal modeling predicted that access to the WWTF could be restricted by flooding during severe coastal storms even without SLR, although to date, the WWTF has not experienced access restrictions. These findings reinforce the importance of evaluating the facilities in both a historic and predictive manner. The operators' concerns with the resiliency of the Constitution and Peter Drive pump stations corresponds well with the modeling results, indicating that the coastal and riverine hazard assessments are a good predictive tool for flooding in future circumstances and in other locations within the community.

Figure 3-2: Bristol WWTF Coastal and Riverine Hazards



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3.2.2 Bucklin Point

The Narragansett Bay Commission owns and operates the Bucklin Point WWTF, which serves approximately 130,000 customers within the Blackstone Valley region: Pawtucket, Central Falls, Lincoln, and portions of Providence and East Providence. The WWTF is located in East Providence on Bucklin Point, a promontory on the east bank of the Seekonk River. Three sides of the facility are adjacent to this tidally influenced waterbody and protected by a berm. The plant has a design flow capacity of 46 MGD and treats an average daily flow of 23.1 MGD. This includes vortex grit removal, typical clarification and nutrient removal treatment processes, and chemical disinfection. Conditions may also require use of effluent pumping systems and influent equalization tanks (wet weather holding tanks).

3.2.2.1 Operator Data

The Bucklin Point WWTF has wet weather holding tanks with 2.4 million gallons of storage capacity. Wastewater entering the tanks receives disinfection, and is either pumped back into the treatment system when plant capacity is available or discharged to the river when the tanks and plant are at capacity. The holding tank and disinfection process is designed to treat flows up to 70 MGD in excess of design flow capacity, allowing a total wet weather plant capacity of 116 MGD. Influent flows in excess of 116 MGD will result in plant bypass.

The berm surrounding the WWTF adequately protected the facility during the March 2010 storm events, however, the berm was subsequently raised an additional 12 to 18 inches in 2014 to above the 500-year flood elevation mapped on the FIRM. This berm protection incorporates tide gates for the plant effluent and storm water from the north and south retention ponds. Although the facility's Emergency Action Plan does not address procedures for rising floodwaters, the operators close the outfall tide gates and pump the effluent out to the river when the river level exceeds 8 NAVD88. Also during storm events, operators close the tide gates on the discharge lines from the onsite stormwater collection ponds.

Two of the four effluent pumps failed during the March 2010 storms, but the remaining two were able to maintain outfall wet-well levels. Operators expressed confidence that no major weak points remained after the post-2010 upgrades.

The Narragansett Bay Commission owns and operates three pump stations within the Bucklin Point wastewater collection system. Facility staff consider the Omega Pump Station in East Providence and the Saylesville pump station in Lincoln to be at risk to climate change. There have been access issues associated with the Saylesville Pump Station during significant rain or flooding events and NBC has had to arrive at this pump station via boat on several occasions. Additional concerns raised at the site included wall discoloration indicating that wastewater has previously infiltrated the electrical system through the wet well lighting conduit during high wet well levels.

3.2.2.2 Modeling Results

Bucklin Point was assessed for risk to coastal flood hazards, sea level rise, wave hazards, and coastal erosion. **Figure 3-3** depicts the extent of inundation caused by the 100-year storm event with 0-, 1-, 2-, 3-, and 5-feet of SLR; the predicted shoreline location at time horizons of 25-, 50-, and 100-years from 2015; and the location of the two transects along which wave models were developed.

The coastal flood hazard modeling used topographic data from 2011, so it does not account for the increased height of the protective berm surrounding the facility that was constructed in 2014. The coastal flood hazard assessment predicted that all the treatment facility components situated within the promontory in the berm-protected low-lying area would be inundated by storm surge at the 100-year return period. Taking into consideration the increased berm height, the modeled 100-year storm stillwater level would overtop the berm by approximately 12 to 18 inches and the average water depth in the driveway between the wet weather tanks and the secondary treatment would be approximately 10.5 feet deep. With the addition of 1 foot of SLR, the extent of flooding during a 100-year storm would reach the centrate holding tanks located up the hill. With 5 feet of SLR, the entire centrate tank area would be inundated during a 100-year storm event.

A wave analysis was conducted at two transects through the Bucklin Point facility as shown in **Figure 3-4** and **Figure 3-5.** Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations. The analysis predicted that the significant wave height for a 100-year storm event would be approximately 5 feet as it approached the berm. Because waves are additive to the storm surge, wave action would lead to overtopping of the berm, even for storms that are less severe than the 100-year event. The berm will dampen wave action so that the significant wave height experienced at the facility components would be approximately 1-2 feet without SLR, and approximately 3-4 feet with 5 feet of SLR.

The shoreline at Bucklin Point was altered to develop the facility and erosion has been physically managed through structural protection such that the historic erosion rate at this location is zero. The predicted shoreline configurations depicted in **Figure 3-3** assume erosion occurs without interference and include the effects of SLR.

3.2.2.3 Data Correlation Notes

Past events and concerns expressed by the WWTF operators correspond well with the potential events identified by the state-wide coastal modeling analysis. Based on the March 2010 storms, the operators recognized the vulnerability of the WWTF to coastal flooding and raised the protective berm surrounding the facility. The coastal modeling exercise predicted the site would have been inundated in a 100-year storm prior to raising the berm. Reported flooding at the Saylesville Pump Station was duplicated by the riverine hazard assessment, indicating that the riverine hazard assessment is a good predictive tool for flooding in future circumstances and in other locations within the service area.

Figure 3-3: Bucklin Point WWTF – Coastal and Riverine Hazards

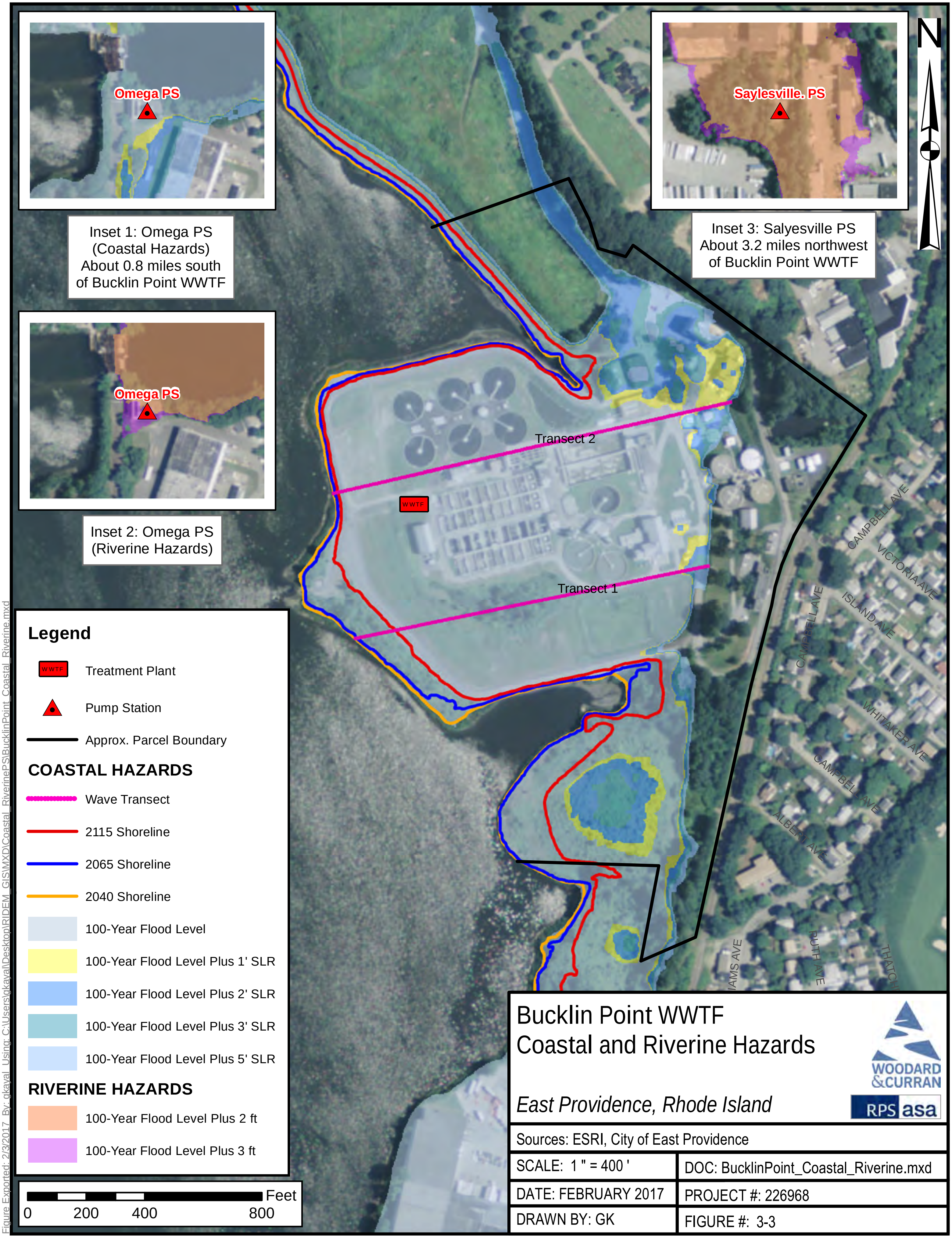

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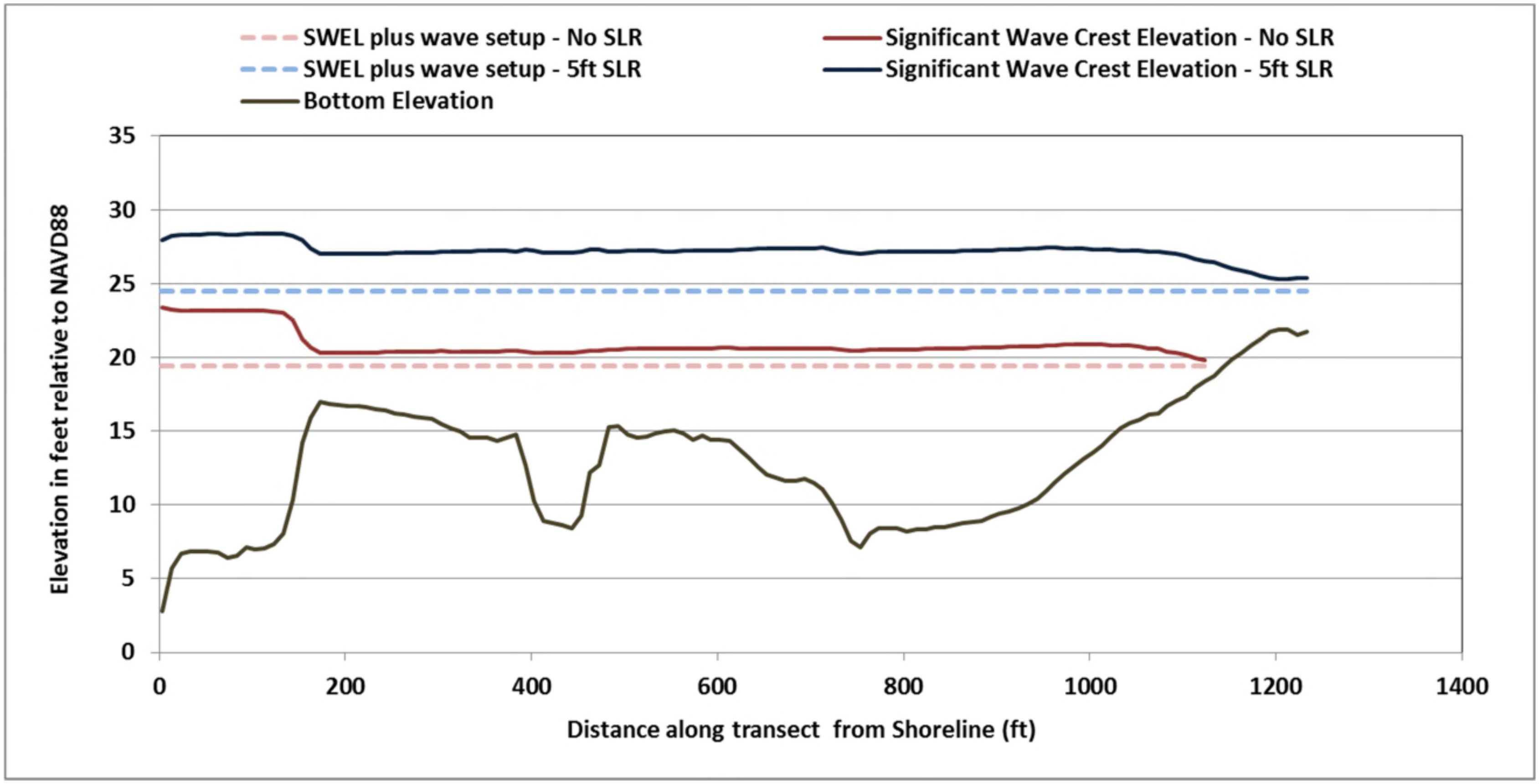
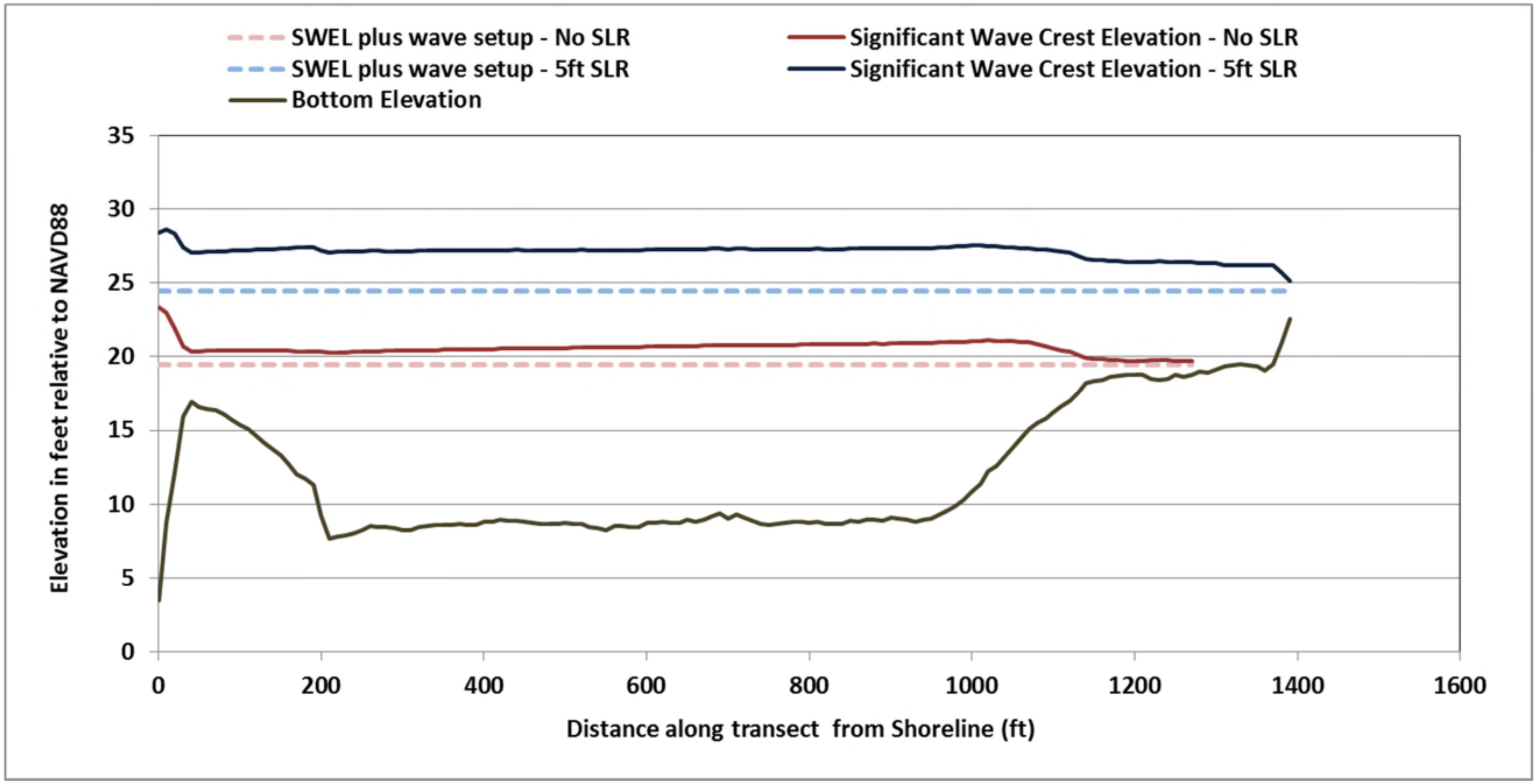
Figure 3-4: Bucklin Point Transect 1 - Wave Analysis (Elevation vs. Distance)



Source: RPS ASA

Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

Figure 3-5: Bucklin Point Transect 2 - Wave Analysis (Elevation vs. Distance)



Source: RPS ASA

Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

3.2.3 Burrillville

The Town of Burrillville owns and operates the Burrillville Wastewater Treatment Facility located at 141 Clear River Drive and it discharges to the Clear River. Burrillville is a predominantly rural area of the northwestern corner of the state with few large surface waters and extensive forested surface area. The facility serves the Town of Burrillville (US Census population of 15,955) and an estimated 9,700 customers. Constructed in 1978 (with its most recent upgrade in 1994), the Burrillville WWTF has a design capacity of 1.5 MGD, with average flows of 0.83 MGD. Pump stations range in age from 5 to 30 years old and the facility maintains a typical activated sludge treatment process with phosphorus reduction through chemical addition. There are 7 pump stations and 5 ejector stations that contribute flow to the WWTF. Burrillville's Hazard Mitigation Plan is approved and expires in 2020.

3.2.3.1 Operator Data

The Burrillville WWTF currently utilizes phosphorus-reducing treatment methods and views the new T-PO4 system and building to be most vulnerable to flooding. Chemicals stored on site in containers that might be subject to flotation or critical to maintain the various treatment processes include potassium hydroxide, ferric chloride, ferric sulfite, and disinfection chemicals. Many treatment process components were noted for potential flood vulnerability, including preliminary treatment systems located at grade, primary/secondary treatment systems located below grade, and a facility electrical transformer at grade. Primary and secondary treatment system controls and pumping equipment are protected by elevated facility entryways and sump alarms. When the facility experienced flooding in 2005, they covered and taped the contact tank mixers and motors to make them watertight, then restored them to service when the water receded. The facility has the ability to apply chlorination at the secondary clarifier launder so chlorination of secondary effluent could continue if the contact tanks were flooded.

The facility maintains 3 back-up portable generators but does not maintain back-up pumping systems. Operators noted that there are no reported cases of a pump station failing to keep up with influent flows but the Rock Ave. and Beach Road ejector stations, both of which are located adjacent to surface waters, lack permanent back-up power. Operators also noted that the School Street ejector station is prone to flooding. The generator and belly tank are elevated, but during flood conditions the pump station is not accessible due to roadway flooding. Representatives from the Burrillville WWTF provided additional information on December 5, 2016 that might warrant further evaluation by RIDEM.

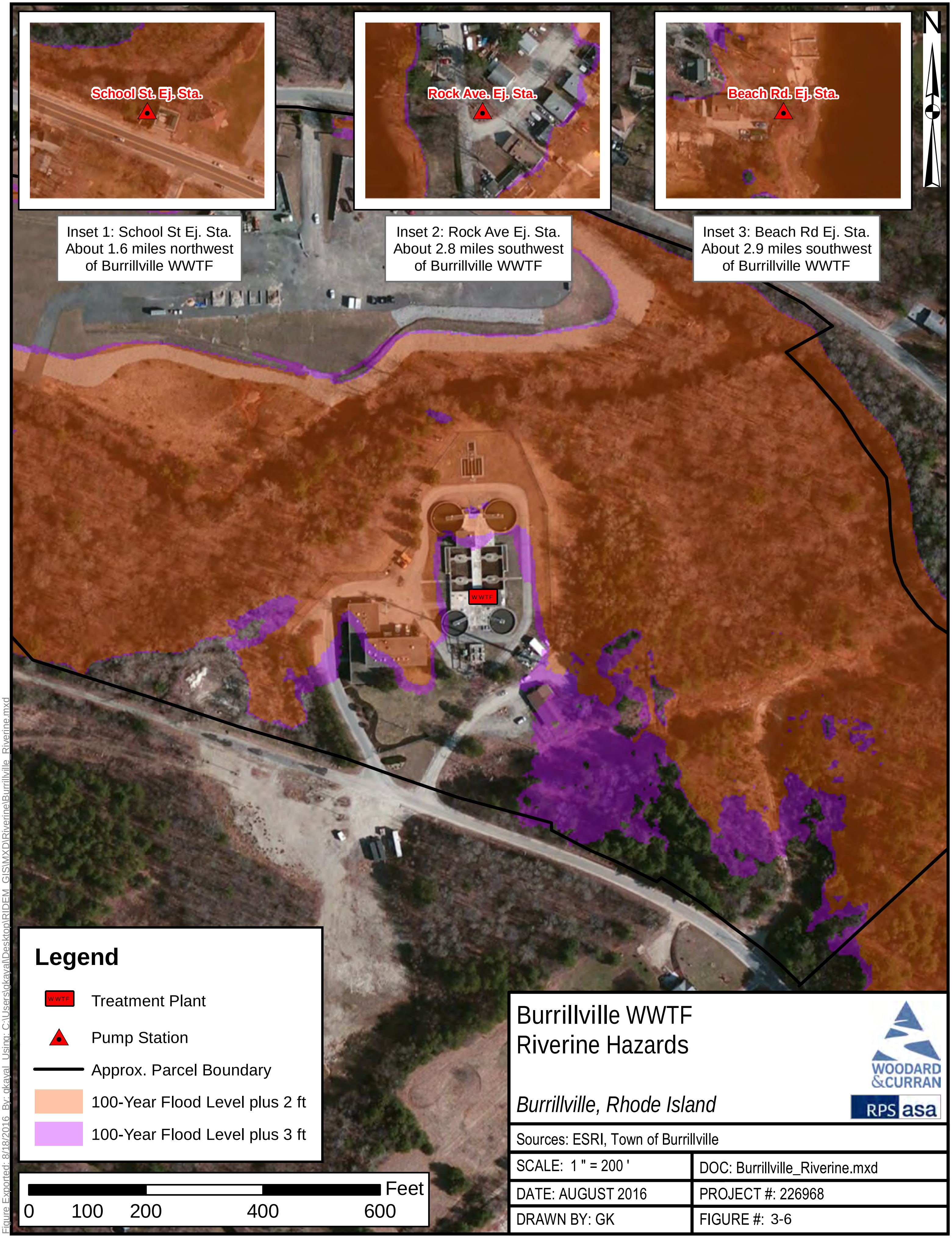
3.2.3.2 Modeling Results

The Burrillville WWTF was assessed for risk to riverine hazards. The riverine flood hazard assessment predicted that parts of the Burrillville WWTF would be inundated at the 100-year flood level plus 2 feet and the 100-year flood level plus 3 feet. During those situations, staff would likely be able to get to the WWTF but access to portions of the property would be limited. The water depth in the access road between the chlorine contact tanks and the secondary clarifiers would be just over 1-foot deep during the 100-year flood level plus 2 feet scenario. The School Street Ejector Station would also be impacted by these two flood level events. Components of the Burrillville WWTF that will be specifically impacted include the secondary clarifiers and the chlorine contact tanks.

3.2.3.3 Data Correlation Notes

Past hazard events and concerns expressed by the WWTF operators correspond well with the potential events identified by the state-wide riverine hazard assessment. The potential for inland flooding at the WWTF was noted by the operators and predicted by the riverine hazard assessment. Also, the operators' reports of the School Street pump station access road flooding were replicated by the riverine hazard assessment. This correlation indicates that the riverine hazard assessment is a good predictive tool for flooding in future circumstances and in other locations within the community.

Figure 3-6: Burrillville WWTF – Riverine Hazards



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3.2.4 Cranston

The Cranston WWTF, located at 140 Pettaconsett Avenue, is operated by Veolia Water and it discharges to the Pawtuxet River. Cranston is nearly landlocked with approximately 2 miles of its east edge resting on the Providence River, and the west edge stretching just short of the Scituate Reservoir. The facility serves Cranston (2010 US Census population of 80,387) and an estimated 73,200 customers. The Cranston WWTF operates with a design capacity of 20.2 MGD, and receives average flows of 13.2 MGD. The facility resides adjacent to the Pawtuxet River, which increases its susceptibility to river flooding. The major components of the facility were constructed in the 1980s however, the facility has undergone numerous upgrades since that time and was undergoing additional upgrades (including improvements to phosphorous removal) during this assessment. Current treatment includes typical processes under contract operation by Veolia, however this site is unusual because of its extensive underground pipe gallery system as well as an on-site incinerator system capable of processing up to 66 dry tons of sludge per day.

Cranston's Hazard Mitigation Plan (2021 expiration date) identified the Cranston WWTF and 14 pump stations as at risk from flooding or natural hazard events. The plan notes that these assets are at high risk because large amounts of stormwater infiltrating the piping system can overwhelm the pump stations, short circuit the pumping equipment, and create the potential for sewer backups. The plan specifically notes that the Allard Pumping Station and the Randall Street Pumping Station have flooded in the past and the Seaview Avenue Pumping Station is in a velocity zone.

3.2.4.1 Operator Data

Previous flood events have impacted the Cranston WWTF and inundated treatment processes, including the chlorine contact tanks. High flows have exceeded the hydraulic capacity of the system causing overflows. Operators believe the hydraulic capacity limitations may be addressed with the scheduled replacement of the current venturi flow meter with a mag meter. Uncapped pipes and conduits in the pipe galleries showed signs of previous water infiltration, representing a possible risk to that portion of the facility, and back-up power systems mounted at grade may be vulnerable as well. Equipment and parts line many of the large corridors although some equipment previously stored in the flood-vulnerable basements and pipe galleries of the facility have been moved to higher points within the facility's pipe galleries as a result of previous flood events. Cranston was able to install a permanent emergency generator at the end of 2014 for the aeration blowers.

The Cranston WWTF does have some vulnerabilities, but the vast majority of operator concern with this system lies in the collection system. During the March 2010 flooding, the Pontiac Avenue PS, Worthington PS and Youlden PS became inaccessible. The Pontiac Avenue PS has a generator mounted at grade and may become inaccessible through flood waters emanating from an adjacent stream. This pump station showed evidence of flood water leaks into the drywell through conduit, and the on-site generator is mounted at grade. The Mayflower PS may share similar access issues due to the adjacent river, and has experienced similar water infiltration problems. The Burnham Avenue Pump Station shares similar access issues during flood events, but lacks the flood risk to the pump station's functionality. Cranston oversees numerous pump stations with significant resiliency and vulnerability concerns, which could not be covered in adequate detail under this broad system overview; a more detailed assessment of the Cranston collection system may be beneficial.

According to Operators, one major issue the facility is facing is equipment related. Having been impacted by storm events in the past (most recently, March 2010), there is a need for additional portable rental pumps to handle high flows at the Pontiac Pump Station in the event of a loss of pumping ability. While this pump station is much less prone to flood damage, two additional pumps would be required to handle 25-30 MGD (likely this would only be during intense rain events or severe flooding).

The Cranston Hazard Mitigation Plan (Draft 2014) indicates that some mitigation actions have taken place since the March 2010 flood, including flood proofing all the pump stations and their respective generators located within the floodplain.

3.2.4.2 Modeling Results

The Cranston WWTF was assessed for risk to riverine hazards **(Figure 3-7)**, coastal flood hazards, and sea level rise **(Figure 3-8: Cranston WWTF – Coastal Hazards)** The riverine flood hazard assessment predicted that parts of the Cranston WWTF would be inundated at the 100-year flood level plus 2 feet and the 100-year flood level plus 3 feet, however, most of the inundation would be on the south side of the property where the former primary and secondary treatment systems were located. The only current operations effected would be the chlorine contact tanks at the 100-year plus 2' event and the disinfection and sludge thickening buildings at the 100-year plus 3' event. The pipe galleries and tunnels connecting the former treatment structures with the active systems have been sealed to be watertight. Six pump stations (Allard, Burnham, Mayflower, Pontiac, Randall, and Youlden) would also be impacted by these two flood level events.

The coastal hazard assessment predicted that floodwaters would enter the property during a 100-year coastal event, but would not reach the WWTF systems and equipment during a 100-year event, even with 5 feet of SLR. The Seaview and Youlden pump stations would be inundated by a 100-year coastal event, and the Mayflower pump station would be inundated by a 100-year event with 1 foot of SLR.

3.2.4.3 Data Correlation Notes

Past events and concerns expressed by the WWTF operators correspond well with the potential events identified by the state-wide riverine hazard assessment, which predicted a greater potential for flooding than the coastal hazard assessment. An aerial photograph of the Cranston WWTF taken during the March 2010 storms generally corresponds with the Riverine Hazards figure **(Figure 3-7)**. Also, multiple pump stations recorded flooding conditions resulting from the March 2010 storms that correspond with the riverine hazard assessment. This correlation indicates that the riverine hazard assessment is a good predictive tool for flooding in future circumstances and in other locations within the community.


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Figure 3-7: Cranston WWTF – Riverine Hazards

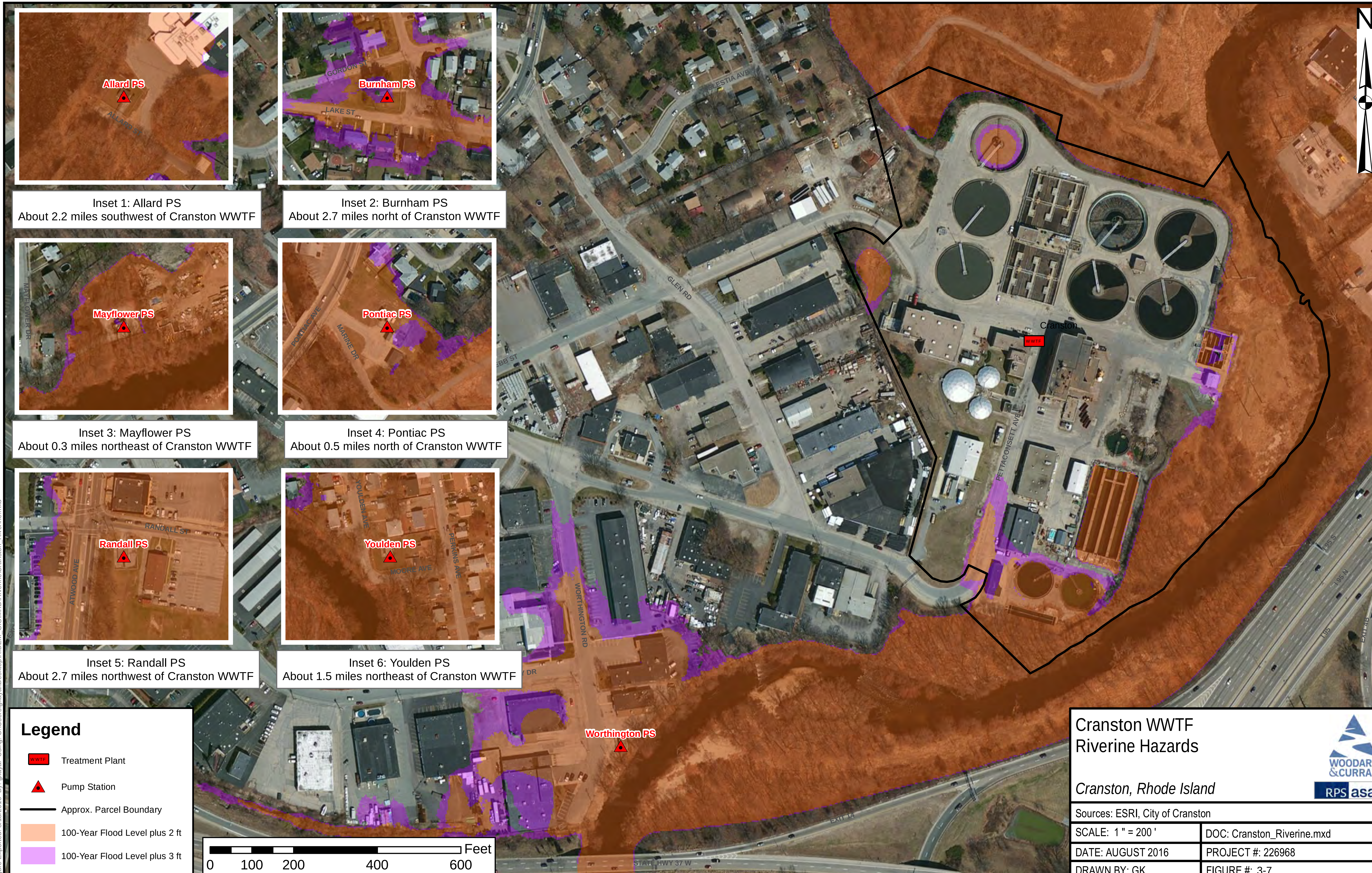


Figure Exported: 8/18/2016 By: gkayal Using: C:\Users\gkayal\Desktop\RIDEM_GIS\MXD\Riverine\Cranston_Riverine.mxd

Figure 3-8: Cranston WWTF – Coastal Hazards

Figure Exported: 1/18/2017 By: gkayal Using: C:\Users\gkayal\Desktop\RIDEM_GIS\MXD\Coastal\Cranston_CoastalHazards.mxd

3.2.5 East Greenwich

The Town of East Greenwich owns and operates the East Greenwich Wastewater Treatment Facility (WWTF) located on Crompton Avenue in East Greenwich and it discharges to Greenwich Cove, a tidally influenced stretch of coastline. The facility serves the Town of East Greenwich (US Census population just over 13,000 people) and an estimated 6,000 customers. The town is nearly landlocked with a mere 1-mile stretch of the town's perimeter along Greenwich Cove, which is an offshoot of Narragansett Bay. The East Greenwich WWTF operates with a 1.7 MGD design capacity and average flows of 0.8 MGD. The original East Greenwich WWTF was constructed in the 1920s, however, all of the remote pump stations (exclusive of the influent pump station at the treatment facility) are less than 10 years old and nearly identical in design. The East Greenwich WWTF operates atypical tertiary treatments systems, including biological aerated filters and denitrifying filters, to meet nitrogen discharge limits. East Greenwich has an approved Hazard Mitigation Plan that expires in 2020.

3.2.5.1 Operator Data

The East Greenwich WWTF utilizes atypical treatment chemicals including magnesium hydroxide and methanol to support the various components of the treatment system, including tertiary treatment. During the site visit at this facility, several secondary process components were non-functional, leaving redundant systems unavailable for backup operation, but critical and primary treatment components were functional. Follow-up discussions indicated that the previously offline systems have been returned to service.

The facility is unusual in that the access roads surrounding the facility are at a relatively low elevation, but many of the process components are operated from elevated locations within a main building on the site, protecting them from flood hazards. Many system components, including the recently upgraded influent pump station and tertiary treatment systems, are operating with dry-mounted submersible pumps. Some electrical system components, however, are in locations that may prevent them from functioning during a flood event.

The facility's three remote pump stations are nearly identical in design and were installed at approximately the same time. The Cedar Heights pump station was the only one that showed notable flood risk. The Cedar Heights pump station is adjacent to a small stream, which could potentially hinder access to the site during significant rain events, due to the lack of a paved access road and the low access bridge crossing the stream. Operators noted that access to the facility and pumping stations has never been restricted during storm events due to flooding and they were not aware of any process constraints that have been worsened by natural events, including increased precipitation or drought conditions. All three pump stations have the capacity to operate on propane-fueled automatic back-up generators.

Operators indicated that the biggest issue currently being faced is the age of the facility. To date, they have been addressing this concern through a capital improvement program for facility equipment upgrades. In addition to the capital improvement plan, operators identified a need for a new generator to improve standby power capabilities at the plant and pump stations. An expenditure of $6M has been approved for upgrades to the preliminary, primary and secondary treatment systems which are currently in design. As a component of this upgrade, the four new RBC gear systems that were installed immediately following the site visit, will be stored as back-up drive components for use as spares following the upgrade. The critical systems excluded from this upgrade include the influent pump station, tertiary nutrient removal processes, and UV disinfection, which were installed between 2004 and 2014. At the time of this assessment, the facility stored a single portable pumping system capable of handling half of the influent flow into the treatment facility, along with several smaller portable generators and pumps. The main facility and pump stations have permanent pumping redundancy and back-up power systems so the primary function of the portable pump is to support pump station maintenance.

3.2.5.2 Modeling Results

The East Greenwich WWTF was assessed for risk to coastal flood hazards, sea level rise, wave hazards, and coastal erosion. **Figure 3-9** depicts the extent of inundation caused by the 100-year storm event with 0-, 1-, 2-, 3-, and 5-feet of SLR; the predicted shoreline location at time horizons of 25-, 50-, and 100-years from 2015; and the location of the three transects along which wave models were developed. Cedar Heights Pump Station was assessed for risk to riverine hazards and the riverine flood hazard assessment predicted that while the actual pump station would not be directly impacted, the area surrounding it would be inundated at the 100-year flood level plus 2 feet and the 100-year flood level plus 3 feet, preventing access to it.

The coastal flood hazard assessment predicted that most of the facility components would be inundated by storm surge at the 100-year return period. The driveway areas within the site sit at a low elevation and the water depth would range between 6-8 feet in the areas closest to Greenwich Cove and then be between 2-4 feet closer to the facility entryway adjacent to Crompton Avenue. Access to the site could be limited and challenging if it were to become inundated with flood waters. The only treatment component that would be completely inundated is the effluent UV disinfection where the depth of water is estimated to be approximately 2.5 feet. The well-maintained influent pump station located west of the effluent UV disinfection has a doorway at grade and all of the interior equipment is below grade, which could become inundated by water depths of approximately one foot.

A wave analysis was conducted at three transects through the East Greenwich facility as shown in **Figure 3-10**, **Figure 3-11: East Greenwich Transect 2 – Wave Analysis (Elevation vs. Distance**, and **Figure 3-12**. **Transect 1** and **Transect 2** are situated through the main facility systems. The analysis for these Transects predict that the significant wave height for a 100-year storm event at the facility would be approximately 5 feet at the shoreline but then drop to 1 to 2 feet moving inland. With 5 feet of SLR and the 100-year storm event, the significant wave height experienced at the facility would be just over 5 feet up until about 70 feet from shore and then drop to 3.5 to 4 feet moving inland. The topography along **Transect 3** remains lower such that the water depth during a 100-year event is sufficient to maintain a 5' significant wave height for approximately 170' before decreasing. With 5 feet of SLR, the significant wave heights followed the same trajectory and drop off pattern at 170 feet from shoreline.

The shoreline at the East Greenwich WWTF was historically filled and hardened, so the erosion rate used for the shoreline analysis was set to zero. The predicted shoreline configurations depicted in **Figure 3-9** therefore, solely reflect the effects of SLR and the topography of the site.

3.2.5.3 Data Correlation Notes

Although operators did not report experiencing coastal flooding at the WWTF, several flood resistant features were incorporated into the design and construction of the facility. The operators' concerns with the access to the Cedar Heights pump station matched the riverine hazard assessment, indicating that the riverine hazard assessment is a good predictive tool for flooding in future circumstances and in other locations within the community.

Figure 3-9: East Greenwich WWTF – Coastal and Riverine Hazards

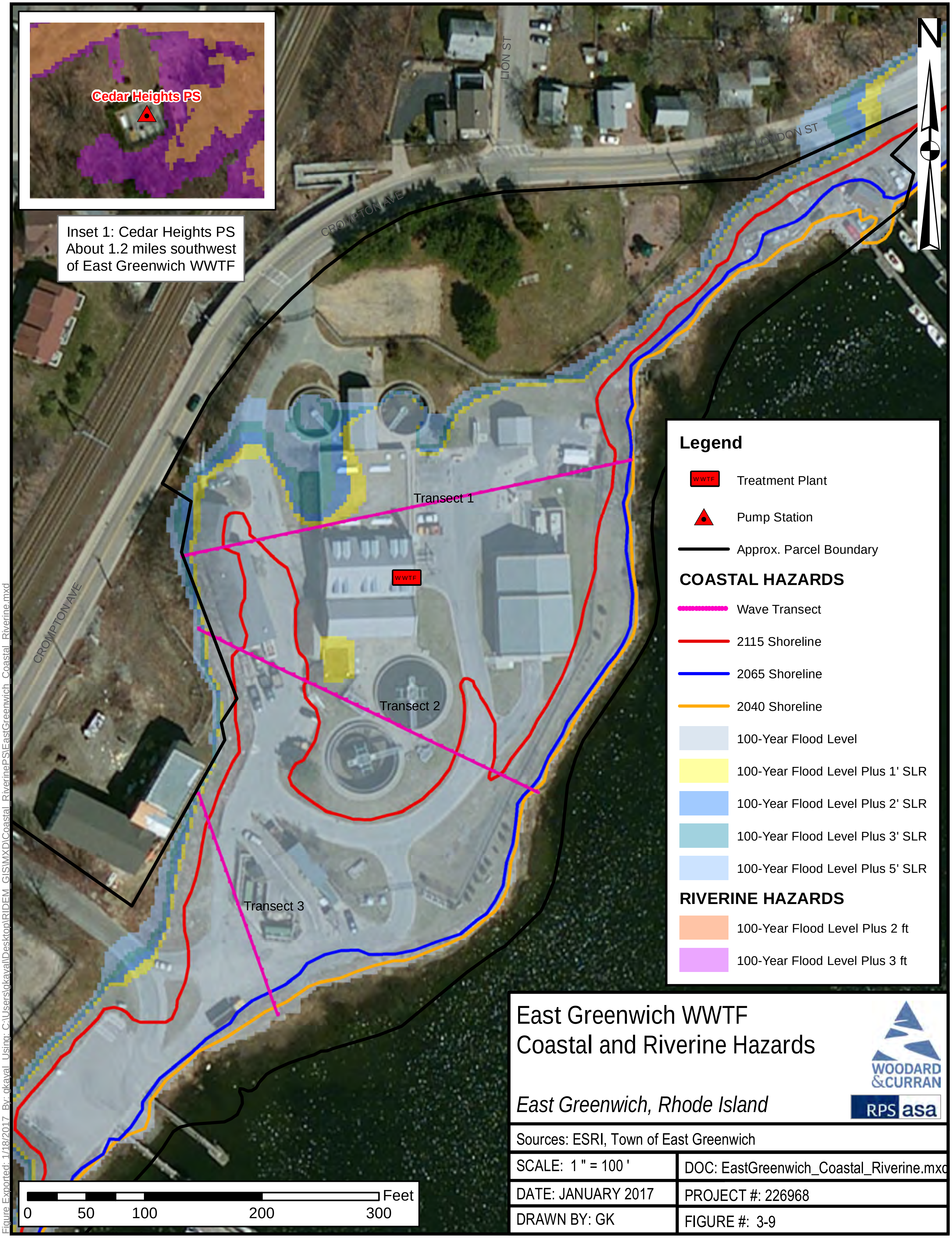
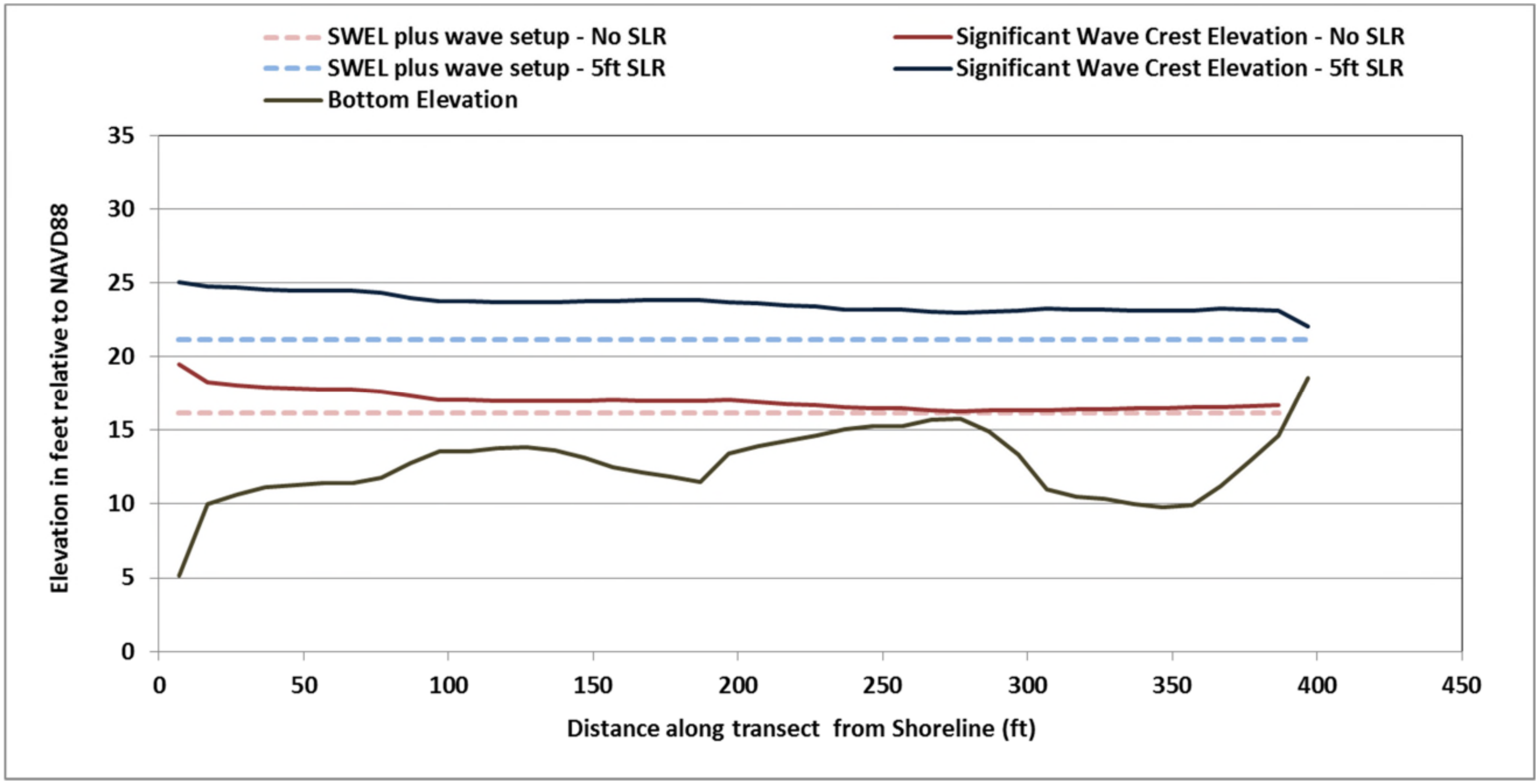

Cedar Heights PS
Inset 1: Cedar Heights PS
About 1.2 miles southwest
of East Greenwich WWTF
N
LION ST
LONDON ST
CROMPTON AVE
CROMPTON AVE
Transect 1
Transect 2
Transect 3
WWTF
Legend
Treatment Plant
Pump Station
Approx. Parcel Boundary
COASTAL HAZARDS
Wave Transect
2115 Shoreline
2065 Shoreline
2040 Shoreline
100-Year Flood Level
100-Year Flood Level Plus 1' SLR
100-Year Flood Level Plus 2' SLR
100-Year Flood Level Plus 3' SLR
100-Year Flood Level Plus 5' SLR
RIVERINE HAZARDS
100-Year Flood Level Plus 2 ft
100-Year Flood Level Plus 3 ft
Feet
0 50 100 200 300
East Greenwich WWTF
Coastal and Riverine Hazards
East Greenwich, Rhode Island
WOODARD &CURRAN
RPS asa
Sources: ESRI, Town of East Greenwich
SCALE: 1 " = 100 '
DOC: EastGreenwich_Coastal_Riverine.mxd
DATE: JANUARY 2017
PROJECT #: 226968
DRAWN BY: GK
FIGURE #: 3-9
Figure Exported: 1/18/2017 By: gkaval Using: C:\Users\gkaval\Desktop\RIDEM_GIS\MXD\Coastal_Riverine\PS\EastGreenwich_Coastal_Riverine.mxd

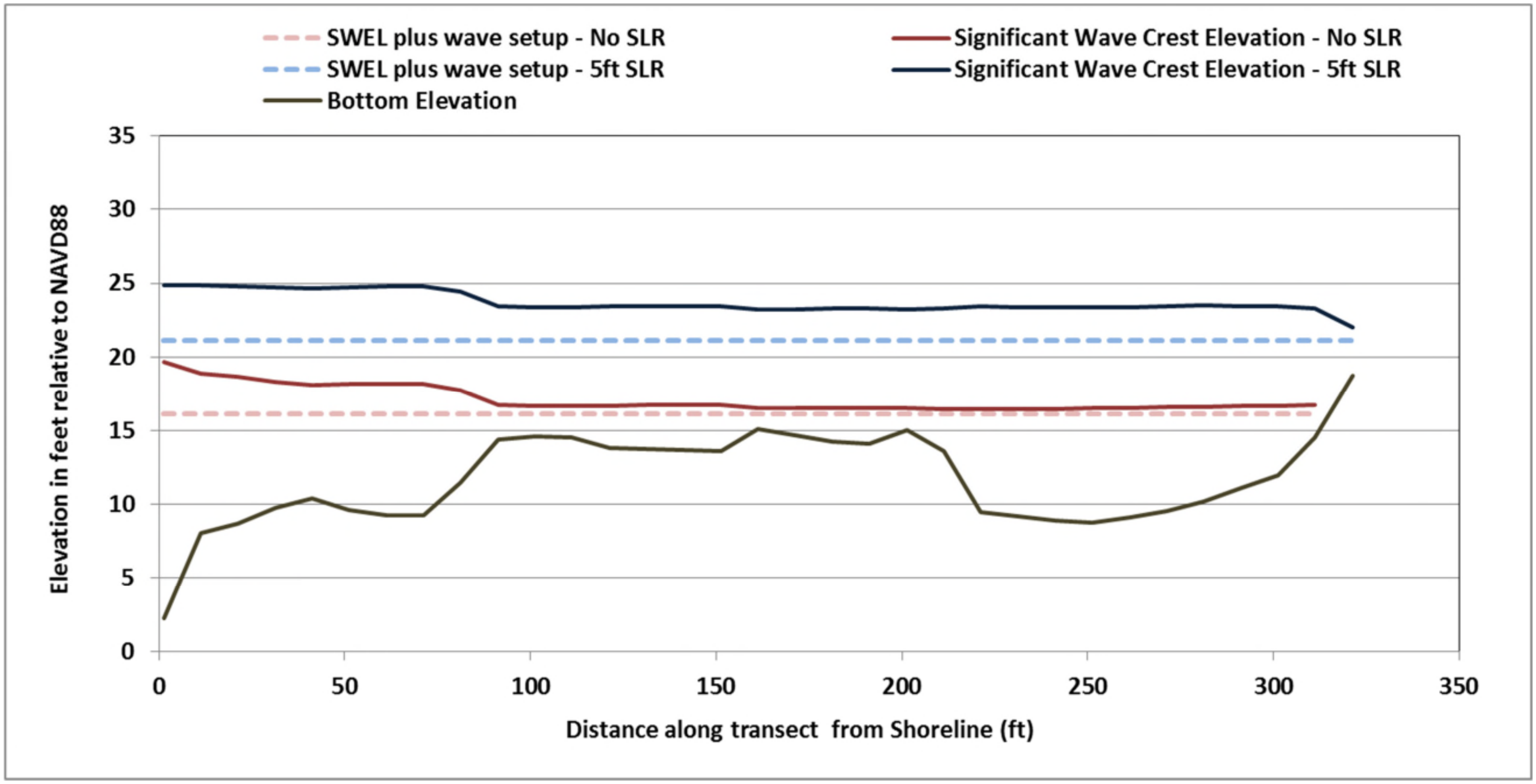
Figure 3-10: East Greenwich Transect 1 - Wave Analysis (Elevation vs. Distance)



Source: RPS ASA

Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

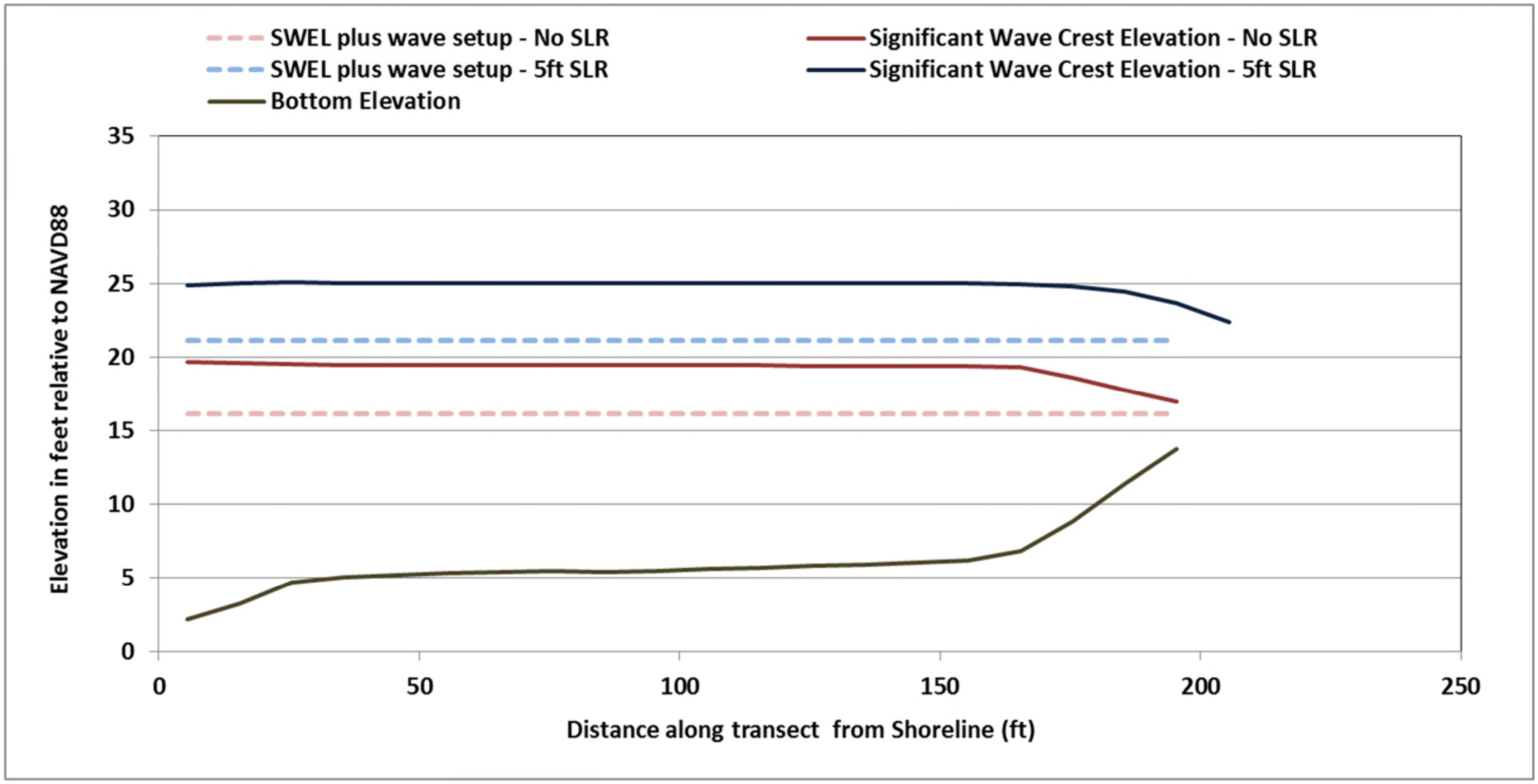
Figure 3-11: East Greenwich Transect 2 - Wave Analysis (Elevation vs. Distance)



Source: RPS ASA

Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

Figure 3-12: East Greenwich Transect 3 - Wave Analysis (Elevation vs. Distance)



Source: RPS ASA

Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

3.2.6 East Providence

The East Providence WWTF serves East Providence (US Census 2010 population of 47,037) and Barrington (US Census 2010 population of 16,300) with an estimated 46,100 customers in these communities. The WWTF is located on Crest Avenue in East Providence and resides along a tidally-influenced stretch of the Providence River. The facility is owned by East Providence and operated by Suez with a design capacity of 14.2 MGD and average flows of 6.7 MGD. United Water entered into a 10-year, design-build-operate (DBO) contract for the City's 103-mile collection system in 2010. The East Providence WWTF received a $52M upgrade in 2012 including a new odor control system, conversion to biological nutrient removal (BNR) process, and new Fournier Rotary Presses for sludge dewatering. The facility operates typical activated sludge and clarifier treatment processes with BNR. Almost half of the supporting pump stations are less than 10 years old.

The East Providence facility and pump stations are identified in the East Providence Hazard Mitigation Plan (expired 2016) as high and medium risk categories in terms of their vulnerability to natural hazard weather events. The plan indicated that the risk ranking was based on potential for damage and that there have not been impacts to the facility or pump stations in the past.

3.2.6.1 Operator Data

According to the Operators, East Providence has extensive infiltration and inflow issues, which are currently being addressed by a variety of means including raising manhole covers and epoxy lining the collection system piping. This is an on-going process of evaluation, execution and re-evaluation as funding becomes available and work is prioritized. In October 2010, the facility experienced a peak flow of approximately 33 MGD of influent flow, significantly exceeding plant capacity, and overflowing the aeration tanks and contact tanks.

Multiple generators on site, excluding the primary generator, have been recently upgraded and are elevated to safe levels on belly tanks.

East Providence has 13 pump stations. Nearly all pump stations with permanent back-up power generation have older power generation equipment. The exceptions are Boyden Boulevard PS and Watchemoket PS. Sabin Point PS and Bullocks Point Avenue PS function from at-grade electrical equipment and lack permanent back-up power. Operators noted that Merritt Road PS, a pump station that otherwise would present no resiliency concerns, may be unable to meet wet-weather influent flows requiring augmented capacity from portable pump systems.

Operators noted several recent improvements and remaining concerns regarding flood mitigation for the facility and pump stations. The new Watchemoket Pump Station was constructed above the FEMA designated 100-year floodplain and its capacity was increased to 10 MGD to prevent SSOs. The Boyden Boulevard Station was replaced and the design flow was increased to 5 MGD. Three smaller stations were also added (Industrial Way, Fuller and Stonegate) to remove a bottle neck in the gravity line to the treatment plant. The Silver Street pump station has hurricane doors installed, but this location also has an underground storage tank that could be subject to flooding.

Operators reported a concern that should a hurricane or other severe storm hit the bay directly, the hurricane barriers at Fox Point will be closed, which might pose a flooding concern to those south of the barrier, including the East Providence facility. The Fox Point Hurricane Protection Barrier is approximately one-mile south of downtown Providence and three plus miles north of the East Providence WWTF. There was no indication that the facility has been impacted when the Fox Point barriers have been closed in the past.

3.2.6.2 Modeling Results

East Providence was assessed for risk to coastal flood hazards, sea level rise, wave hazards and coastal erosion. **Figure 3-13** shows the extent of inundation caused by the 100-year storm event with 0-, 1-, 2-, 3-, and 5-feet of SLR; the predicted shoreline location at time horizons of 25-, 50-, and 100-years from 2015; and the location of the two transects along which wave models were developed.

The coastal flood hazard analysis predicted that most of the facility would be inundated by a 100-year storm surge, including the four aeration tanks, the three secondary clarifiers, and two chlorine contact tanks, however, many of these process stages are protected by high tank walls. The primary clarifier and many of the operations buildings, are outside of the area of inundation. Portions of the system which may remain vulnerable include supporting systems for the aeration tanks and clarifiers due to at-grade entryways and glass enclosures. Many process components at the treatment facility utilize elevated air tanks, which would help maintain functionality during flood conditions.

The hazard assessment predicted that the water depth between the aeration tanks and secondary clarifiers would be between 5-6 feet during a 100-year storm event. With the addition of 2 feet of SLR, the extent of flooding during a 100-year storm would reach the main facility building. Crest Avenue, the access road to the site, would not be impacted so operators could access the WWTF during a storm event.

The inset on **Figure 3-13** also shows the extent of inundation caused by the 100-year coastal storm event at the Sabin Point pump station. The average still water depth at this pump station during a 100-year storm event would range from 9 to11 feet.

A wave analysis was conducted at two transects through the East Providence facility as shown in **Figure 3-14** and **Figure 3-15**. The analysis predicted that at Transect 1, the significant wave height for a 100-year storm event would be approximately 5 to 6 feet as it approached the shore and then would drop off completely approximately 50 feet inland. With 5 feet of SLR, the significant wave height would be reduced to approximately 2 feet up to 250 feet inland. Transect 2 traverses the center of the facility. The significant wave height along this alignment would be consistent at 4 to 5 feet for a 100-year storm event up to approximately 500 feet inland. With 5 feet of SLR, it would remain consistent at approximately 5 feet.

The shoreline at the East Providence WWTF was historically filled and hardened, so the erosion rate used for the shoreline analysis was set to zero. The predicted shoreline configurations depicted in **Figure 3-13** therefore, solely reflect the effects of SLR and the topography of the site.

3.2.6.3 Data Correlation Notes

Information provided by the East Providence Hazard Mitigation Plan and the WWTF operators agreed that the East Providence WWTF and pump stations have not suffered damage from past hazard events, however, the potential exists for coastal flooding of some of these facilities. The coastal hazard modeling provides a basis for the City to plan for future coastal hazards. The operators' concern for the vulnerability of Silver Street pump station is supported by the coastal hazard modeling results.

Figure 3-13: East Providence WWTF – Coastal Hazards

East Providence WWTF Coastal Hazards

East Providence, Rhode Island

WOODARD & CURRAN
RPS asa

Sources: ESRI, City of East Providence	
SCALE: 1 " = 200 '	DOC: EastProvidence_CoastalHazards.mxd
DATE: JANUARY 2017	PROJECT #: 226968
DRAWN BY: GK	FIGURE # 3-13

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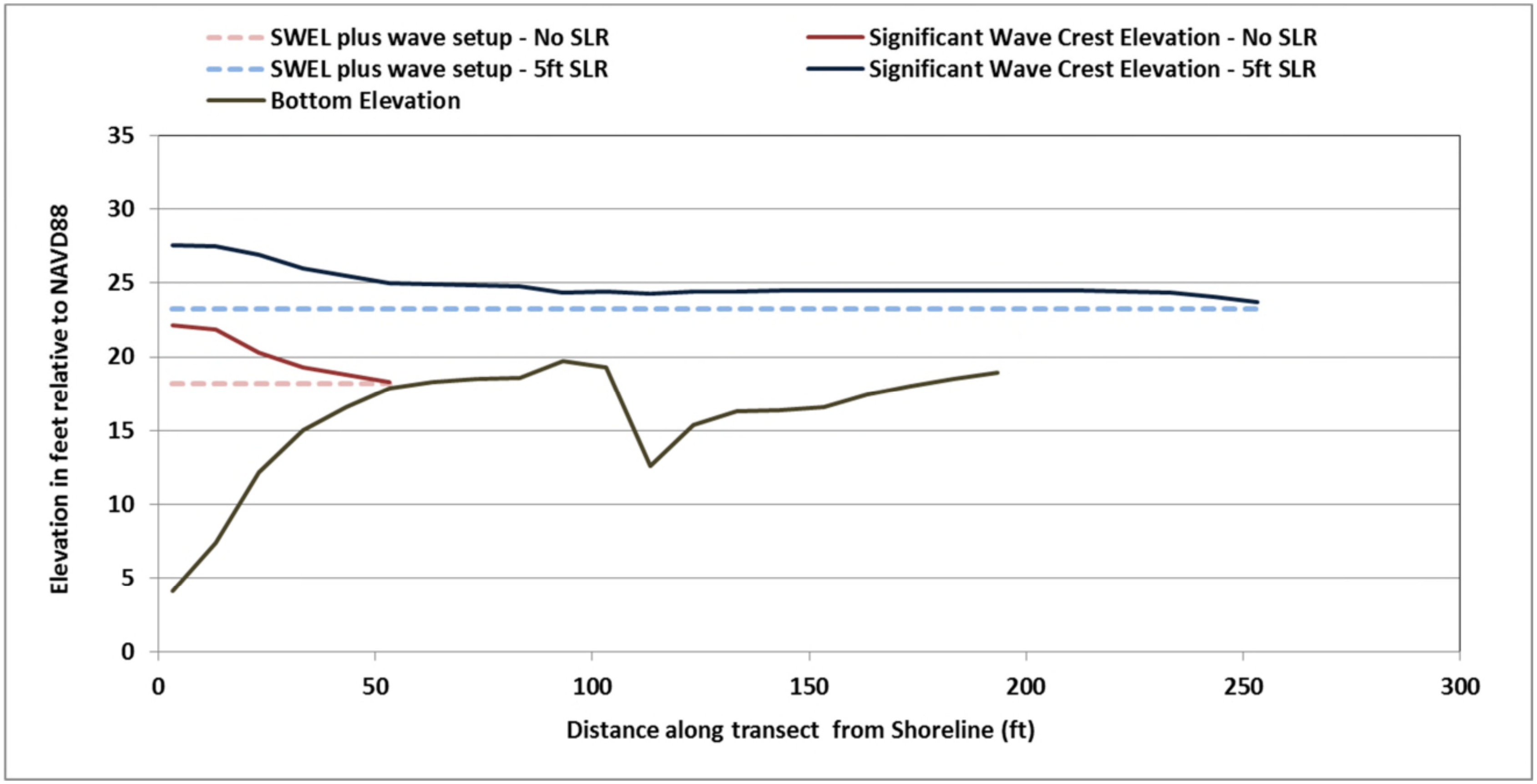
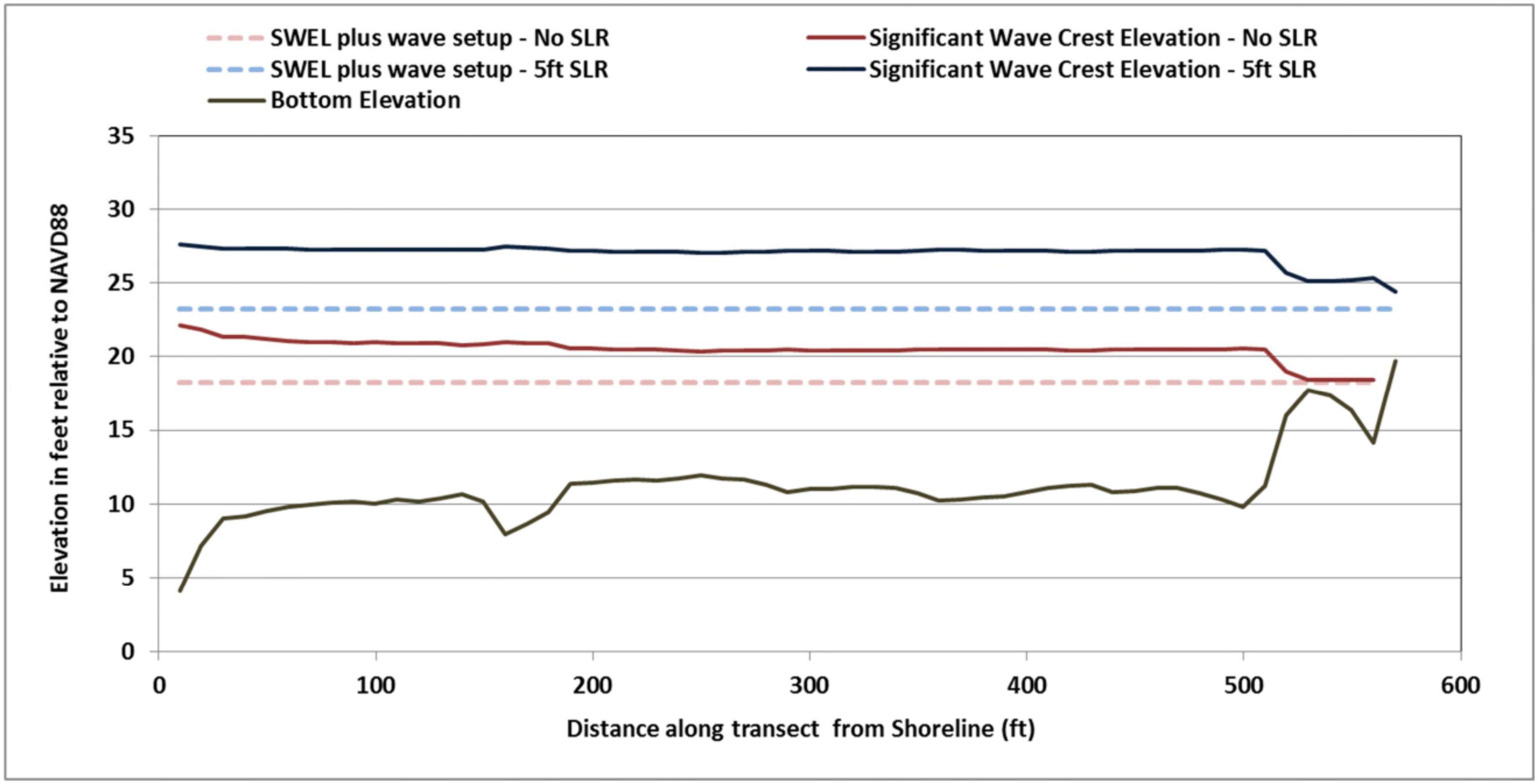
Figure 3-14: East Providence Transect 1 - Wave Analysis (Elevation vs. Distance)



Source: RPS ASA

Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

Figure 3-15: East Providence Transect 2 - Wave Analysis (Elevation vs. Distance)



Source: RPS ASA

Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

3.2.7 Fields Point

The Narragansett Bay Commission (NBC) owns and operates the Fields Point WWTF located on Ernest Street in Providence and it discharges to the Providence River. The Fields Point WWTF is Rhode Island's largest facility and has an estimated 226,000 customers from portions of Johnston, North Providence, Providence, and Cranston. The only barrier between the facility and the Providence River is a strip of flat terrain less than 400 feet wide. Originally constructed in 1901, the WWTF is home to three historic buildings, which remain in use as the influent pump station, maintenance building, and disinfection building. The treatment facility has a design capacity of 65 MGD with average flows of 45.5 MGD; however, during wet weather conditions, the facility can reach secondary-level treatment for up to 77 MGD and route additional flows through primary treatment and disinfection up to 123 MGD. The total treatment capacity at the Fields Points WWTF is 200 MGD and influent flows in excess of 200 MGD are discharged directly to the Providence River. To equalize high wet weather influent flows, the facility operates off a main interceptor carrying roughly 3 MG of capacity and a "deep rock tunnel" designed to hold 65 MG of excess influent making its collection system unusual and complex. Additional unusual characteristics of the site include three wind turbines generating up to 1.5 MW each; these turbines can generate up to 40% of the power necessary to operate the facility but have created some bird-related environmental issues.

Three outlying pump stations in the Fields Point service area are also owned, operated and maintained by the NBC. The Washington Park and Reservoir Avenue Pump Stations are located within the City of Providence, and the Central Avenue Pump Station is in Johnston. The Ernest Street Pump Station is located adjacent to the Fields Point WWTF and handles 98% of the flow into the WWTF. The NBC also maintains six permanent flow metering stations and is responsible for 38 Combined Sewer Overflows, 32 tide gates, and 80 miles of interceptors in the Fields Point service area.

3.2.7.1 Operator Data

The facility has implemented an IFAS treatment process to improve nitrification and denitrification within the existing WWTF footprint because the surrounding development prohibits expanding the site.

Many facility systems are operated below grade, and buildings on site appear to be constructed predominately with entrances at grade, offering little protection. These include the influent pump station, primary clarifier systems for wet weather equalization, aeration tank systems, secondary clarifier systems, and disinfection controls. Some buildings, such as the influent pump station, have stop-logs installed for increased flood protection, while other buildings remain unprotected, such as the wet weather pump building with ventilation louvers at grade. The treatment systems are capable of operation on generators located on site and portable stand-by generators are available for augmentation. Process components that are not on permanent generators include the return activated sludge (RAS) pumps and one primary effluent screw pump, however, a portable generator can be hardwired into the RAS pumps if necessary. In the event that electrical service to the facility is lost, the generators will be the sole source of electrical power. As a safety feature, the wind turbines will automatically shut down in the event of an electrical service outage to prevent the turbines from energizing failed electrical systems that are being repaired. Additionally, in the event that process components are functional but unsafe to operate locally, critical systems are capable of operation from Bucklin Point, or from a remote location with access to the virtual private network (VPN).

NBC has a combined system with multiple relief points, however rising sea levels could have a significant impact on capacity if the receiving waters enter the sewage collection system. Tide gates are installed at the CSO discharge points, but they can easily fail with debris becoming lodged in the gates.

NBC acknowledges that more intense rain storms are difficult for the system to handle and, during extreme high tides and associated flood conditions, flow leaving the Fields Point chlorine contact tank may be impeded by high water levels in the Providence River. Flow has never backed up into the chlorine contact tank, but it has backed up into the discharge conduit area of the chlorine contact tank.

All of the tanks at Fields Point have concrete walls that rise above the roadway level. The WWTF was designed to operate through the 25-year storm and protect against the 100-year storm. Access to Fields Point during severe weather has not been an issue in the past. The Central Avenue Pump Station in Johnston is also of concern and the generator, wet well hatchway, and pump station entrance are all located at grade. The Ernest Street Pump Station is in a low lying area with some entryways elevated and doors that can be reinforced with stop logs for added protection, but this has not been done in the recent past. Similarly, the tunnel access points adjacent to the Ernest Street Pump Station, have elevated walls and covers to prevent intrusion of rain or inflow of flood waters. According to operators, after the 2010 storms, there were no mitigation projects completed associated with the pump stations. NBC has been eliminating or elevating tide gates and their relevant weir heights to account for surcharged conditions but no site mitigation projects have been conducted.

3.2.7.2 Modeling Results

Fields Point was assessed for risk to coastal flood hazards, sea level rise, wave hazards and coastal erosion. **Figure 3-16** highlights the extent of inundation caused by the 100-year storm event with 0-, 1-, 2-, 3-, and 5-feet of SLR; the predicted shoreline location at time horizons of 25-, 50-, and 100-years from 2015; and the location of the three transects along which wave models were developed.

The coastal flood hazard modeling predicted that the majority of the facility would be inundated by storm surge at the 100-year return period including nine secondary clarifiers, the chlorine contact tank, the aeration tank, four primary clarifiers and four former primary clarifiers that are now wet weather tanks. In addition, the Ernest Street Pump Station (the facility's main pump station) would be inundated along with the area surrounding the wet weather tunnel entryway. The tunnel entrance is covered and raised above grade, protecting it from entering floodwaters. Access from Ernest Street would still be possible but Fields Point Drive will be inundated. The water depth on site would vary up to 7 feet. With the addition of 2 feet of SLR, the extent of flooding during a 100-year storm would reach the maintenance building and preliminary treatment area, which though slightly elevated, will also be inundated along with equipment that is stored below ground.

A wave analysis was conducted at two transects through the Fields Point facility as shown in **Figure 3-17: Fields Point Transect 1 – Wave Analysis (Elevation vs. Distance)** and **Figure 3-18**. The analysis for **Transect 1** predicted that the significant wave height for a 100-year storm event would be approximately 5 feet at the shoreline and then drop gradually to 2 feet approximately 1,000 feet inland as the grade gradually rises. With 5 feet of SLR and the 100-year storm event, the significant wave height experienced at the facility would be approximately 5 feet and gradually drop to 4' approximately 1,350 feet inland. The analysis for **Transect 2** showed different results because of the steep rise in grade approximately 350 feet from shore. Here, the significant wave height for a 100-year storm event would be approximately 5 feet up until about 350 feet from shore where it drops to about one foot moving inland until approximately 750 feet from shore. With 5 feet of SLR, the significant wave height is approximately 6 feet at the shoreline and follows the same trajectory and drop off pattern until approximately 350 feet from the shoreline to approximately 750 from shore where a one-foot wave height would be experienced to approximately 1,100 feet from shore.

The shoreline at the Fields Points WWTF was historically filled and hardened, so the erosion rate used for the shoreline analysis was set to zero. The predicted shoreline configurations depicted in **Figure 3-16** therefore, solely reflect the effects of SLR and the topography of the site.

3.2.7.3 Data Correlation Notes

According to the Fields Point WWTF operators, the facility's design addresses protection from coastal storms and they have not witnessed severe flooding at the facility. Their primary concern is overcoming greater head pressure to discharge flow from the WWTF and CSOs during extreme high tides, which they recognize will become more critical as sea level rises. The riverine hazard analysis corresponds with operators' concerns regarding the Central Avenue pump station, and the coastal modeling results corresponds with concerns regarding Ernest Street pump station indicating that the hazard assessments are a good predictive tool for flooding in future circumstances and in other locations.

Figure 3-16: Fields Point WWTF – Coastal and Riverine Hazards

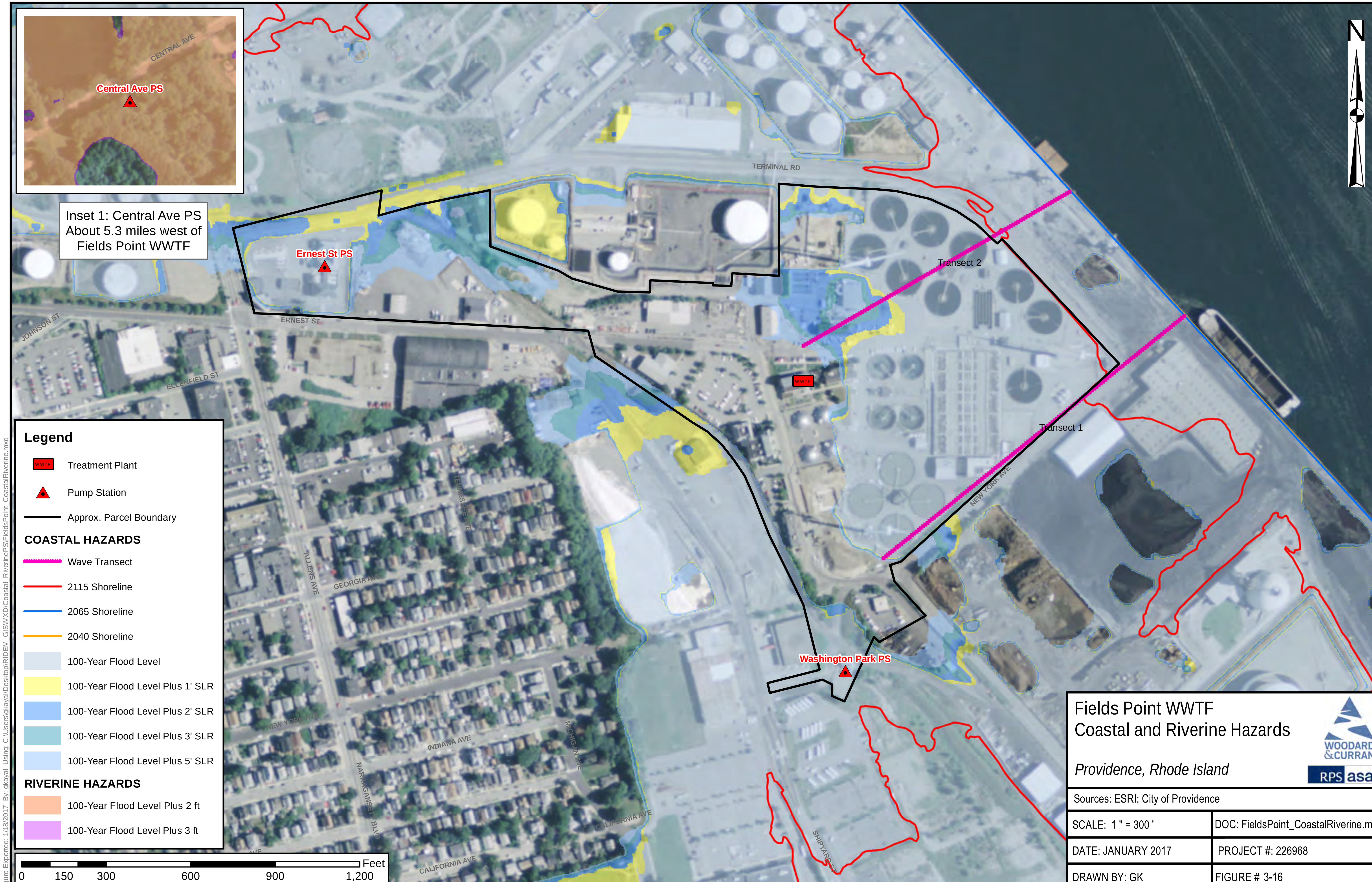


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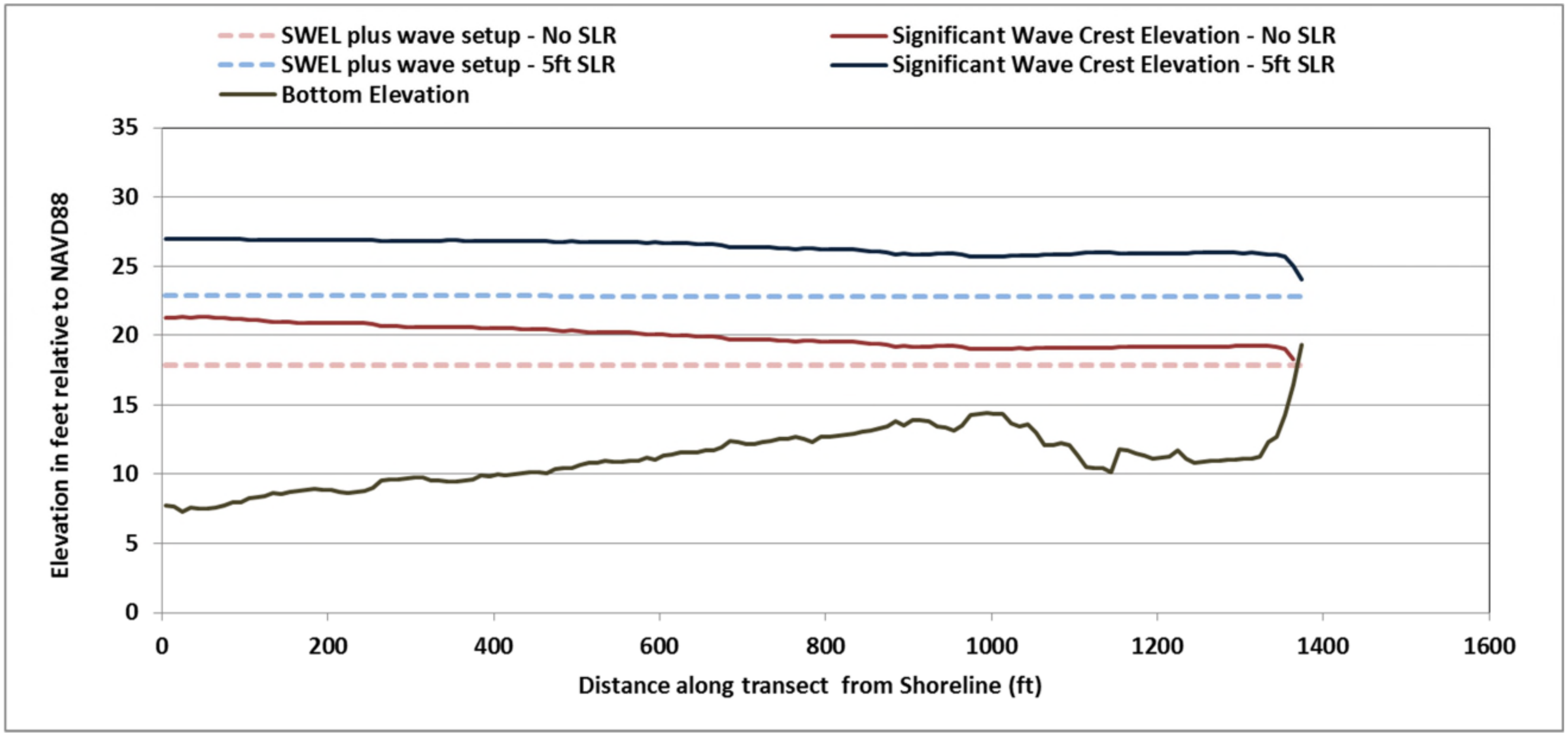
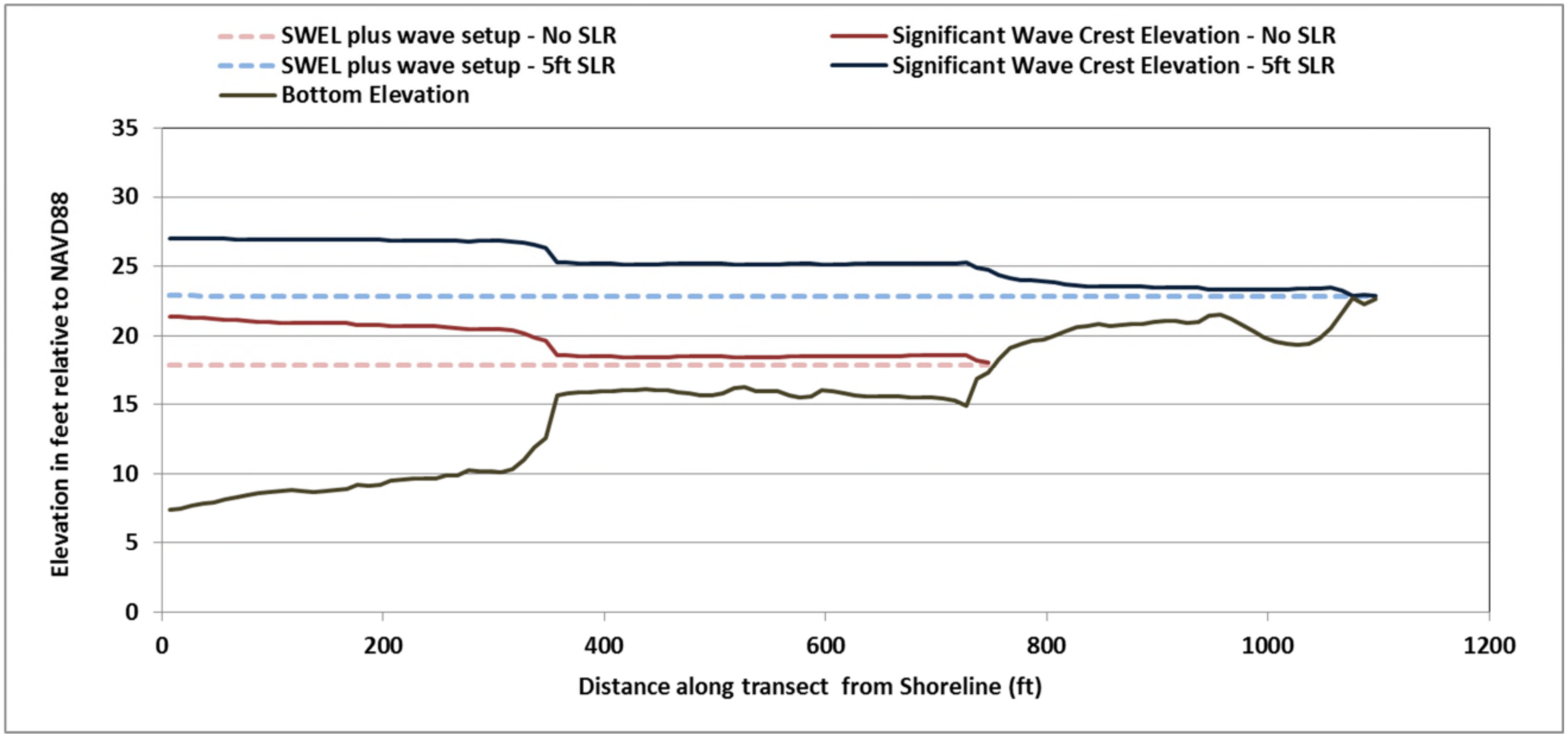
Figure 3-17: Fields Point Transect 1 - Wave Analysis (Elevation vs. Distance)



Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

Figure 3-18: Fields Point Transect 2 - Wave Analysis (Elevation vs. Distance)



Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

3.2.8 Jamestown

The Jamestown WWTF serves the Town of Jamestown (US Census 2010 population of 5,405) with an estimated population served of 1,280. The WWTF is located on a 7-acre parcel on Freebody Drive in Jamestown and it sits elevated above rocky cliffs and beaches on the east edge of the island. The original Jamestown WWTF and supporting pump stations were constructed in the late 1970s but all of the aforementioned facilities have undergone major upgrades in the last 10 years. The facility's four pump stations are located throughout Town, primarily within the village area. The Jamestown WWTF operates as a typical treatment process with preliminary screening, extended aeration, secondary clarification and chemical disinfection. The Jamestown WWTF has a design capacity of 0.73 MGD, with average flows of 0.30 MGD.

In 2010, the EPA awarded the Jamestown WWTF staff for their work in managing the complex operations and maintenance of the facility during upgrade construction. Jamestown is one of only two plants in Rhode Island that recycles a portion of its treated effluent for reuse at the plant. The Jamestown WWTF is identified in the Jamestown Hazard Mitigation Plan (2014) as a critical facility for the community.

3.2.8.1 Operator Data

Most of Jamestown's WWTF critical components are protected by the site's elevated location and elevated components on the aeration tanks and dry-pit submersibles supporting the secondary clarifiers (excluding unprotected below-grade electrical systems).

Jamestown has four pump stations. Each station is equipped with two pumps and has a spare third pump that is stored at the WWTF for use as back up in case the primary pumps fail. All four pump stations were inundated by influent flow or floodwaters during the March 2010 storm events. The Narragansett Avenue Pump Station more frequently requires augmentation with a portable pump during wet weather. Portions of the collection system were in the process of being rehabilitated through slip lining during this assessment, which will address some infiltration and capacity concerns. This rehabilitation focuses on the Bayview Pump Station collection system area; which was determined to be a higher priority to address the potential failure of aging asbestos cement pipe. With Bayview Pump Station selected as the highest priority, Narragansett Pump Station was excluded from the plans for rehabilitation, and at the time of this assessment no firm plans had been established to address I&I in the collection system for the Narragansett Avenue Pump Station.

Bayview Drive PS and Beavertail Road PS are similarly designed with dry-pit submersible pumps, which will survive flood inundation but may not function during a flood event due to electrical system vulnerabilities. The Maple Avenue Pump Station is the primary concern regarding resiliency. This station and the access road are located in a low marshy area with no permanent standby power, thus increasing the likelihood of a loss of functionality during a flood event. The Maple Avenue PS is constructed on a manmade mound, and a steel enclosure protects pump drives and electronics from floodwaters.

Operators reported that both high precipitation and drought pose operational challenges at the Jamestown facility. High flows from heavy rains (I&I) overwhelm the process units and limit detention times. Extended droughts cause the town to implement water-conservation efforts, which combined with wastewater exfiltration in aging sections of the collection system, leads to substantially reduced influent flows and excessive detention times.

The Emergency Response Plan (ERP) for the Jamestown Water Pollution Control System includes a vulnerability assessment of each wastewater system component to identify weaknesses or deficiencies that may make them more susceptible to damage or failure during an emergency. Information in the report relevant to this study includes:

- **Collection System** – There are approximately 80,000 feet of pipelines of which about 70% is VC pipe. Approximately 60% of the VC pipe has been lined with cured-in-place pipe. The remaining 30% is PVC pipe and overall, the collection system is in fair condition. The vulnerability of the collection system is I&I and some generators are located outside.

- **Sewage Pumping** –The vulnerability in addition to potential inundation is that two of the pump stations have outdoor generators that are accessible to vandals.
- **Treatment Plant** – The vulnerability of the treatment plant is that the treatment process can be compromised during elevated flows by I & I as a result of heavy rains or excessive snow melt and the entry system is outdated.
- **Effluent Disposal** - The vulnerability noted in the ERP relates to the part-time facility staffing. Because it is manned only eight hours per day, it is possible for vandals to enter the grounds of the facility and interfere with the effluent disposal.
- **Computer and Telemetry System** - There is one stand-alone computer used primarily for data entry and accomplishing reports. There is a dialer equipped telemetry system for all pump stations and plant alarms. The vulnerability is that the plant computer is outdated. Data can be compromised as some of the data is only recorded on the computer. Weather is a factor because the telemetering lines run on telephone poles and in the event of downed trees communication with the stations could be lost.

The data provided by operators indicate that funding is a major concern for the Jamestown WWTF.

3.2.8.2 Modeling Results

The Jamestown WWTF was assessed for risk to coastal flood hazards, sea level rise and coastal erosion. **Figure 3-19** depicts the inundation caused by the 100-year storm event with 0-, 1-, 2-, 3-, and 5-feet of SLR and the predicted shoreline location at time horizons of 25-, 50-, and 100-years from 2015.

The coastal flood hazard assessment predicted that the facility would not be inundated by storm surge at the 100-year return period, however the entire portion of the island south of the Route 138 tollbooth interchange (including the WWTF and several pump stations) would be isolated without access from the mainland. In addition to becoming inaccessible from the mainland during a 100-year coastal storm event, three pump stations (Narragansett Avenue, Maple Avenue, and Beavertail Road) would all be at risk to coastal flooding and sea level rise. The water depth at the Maple Avenue Pump Station during a 100-year event is predicted to range between 1-3 feet. The Narragansett Avenue Pump Station and Beavertail Pump Stations will be inundated by storm surge at 3 feet of SLR and the 100-year return period.

The shoreline at Jamestown has seen a historic erosion rate of approximately 1 foot per year on average. The predicted shoreline configuration depicted in **Figure 3-19** assumes erosion occurs without interference and includes the effect of SLR. Very little change is predicted at the 25-year time horizon, however, the predicted 50-year shoreline would impact the main access road to the facility.

3.2.8.3 Data Correlation Notes

Consistent with operators' records, the coastal hazard assessment revealed that the elevation of the Jamestown WWTF protects it from coastal flooding. The operators' main concern for inundation is the Maple Avenue pump station, which is consistent with the coastal hazard assessment that predicted inundation during a 100-year coastal event.

Figure 3-19: Jamestown WWTF – Coastal Hazards

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3.2.9 Narragansett

The Town of Narragansett owns and operates the Scarborough Wastewater Treatment Facility (WWTF) located on Ocean Road in Narragansett and it discharges to Rhode Island Sound. The facility serves the southern portion of the Town of Narragansett (US Census 2010 population of 15,868) with an estimated population served of 7,300. The WWTFs location is on a sandy low-slope beach immediately south of Scarborough State Beach and is highly susceptible to wind, high tides, sea level rise and storm surge. The facility has a design capacity of 1.4 MGD, with average flows of 0.6 MGD and was constructed over 50 years prior to this assessment. The facility has undergone several upgrades and construction of a flood mitigation barrier is planned in the near future. The Narragansett WWTF operates a typical small treatment process with preliminary treatment, secondary treatment, disinfection and sludge dewatering with an influent pump station conveying preliminary effluent to secondary treatment. The Narragansett Wastewater Division is responsible for the operation and maintenance of the wastewater conveyance treatment system including 19 pumping stations and the WWTF.

Narragansett's WWTF and pumping stations are listed in the Narragansett Hazard Mitigation Plan (2018 expiration date) as vulnerable areas. The plan notes that retrofits to the facility are needed to better protect it from storm events. Other work may include flood proofing sanitary sewer pump stations. The Facilities Plan identifies pumping to the South Kingstown WWTF as a long term option

3.2.9.1 Operator Data

According to Operators, the major issue the facing the Scarborough WWTF is its location on the southeastern shoreline of Narragansett, which makes it susceptible to storm surge and other severe weather impacts. The WWTF is currently planning to construct a flood-proofing barrier comprised of driven steel sheet piles and a cast-in-place concrete wall. The top of the barrier will be constructed to elevation 20.0 (NAVD88), which will provide about 4 feet of freeboard above the BFE of 16.0 and about 2.8 feet of freeboard above the wave run-up of 17.2 that was calculated as part of the barrier design process. The intent of this ongoing flood-proofing project is for protection from the potential loss of the influent pump station due to storm surge, which almost occurred during Superstorm Sandy. At the time of this assessment, this project had been approved by the state Coastal Resources Management Council (CRMC) and construction completion was anticipated for early Spring 2017.

The proposed flood-proofing project is designed to protect various components of the process, including the facility's aging generator, which is mounted at a relatively low elevation and currently relies on city water for engine cooling. Back-up power generation has been previously augmented with support from adjacent treatment facilities. The various process components are relatively protected with tank walls extending above grade however, bulk chemical storage for disinfection is mounted at grade, similar to the generator.

Three pump stations were noted as having some resiliency concerns, specifically regarding roadway access. Stanton Avenue PS, Galilee PS, and Mettatuxet PS all have access roads at low elevations, which may prevent access during flood events. The Stanton Avenue PS is of particular concern because it is isolated and floods regularly because of its location adjacent to a salt-water marsh. In the past, access to the WWTF during a storm event has not been an issue, but access to the Stanton Avenue PS has been restricted during seasonal high tides and heavy rainfalls. A generator was added to the Stanton Avenue PS in 2015 to help augment its operation during an emergency.

The Scarborough WWTF maintains a stock of some spare parts, generators and other equipment for use during emergency situations. Spare motors are available for the Stanton Avenue, Mettatuxet, Winterberry, and Industrial pump stations. Two trailer mounted pumps and a third 3,200 GPM trailer mounted pump were delivered to the facility in April 2015. In the past, the Scarborough WWTF has borrowed a portable generator to power the facility. They also have access to a portable generator that can handle the Circuit, Baneberry and Congdon pump stations.

Photo: *Stanton Avenue Pump Station Generator*

3.2.9.2 Modeling Results

The Scarborough WWTF was assessed for risk to coastal flood hazards, sea level rise, wave hazards, and coastal erosion. **Figure 3-20** depicts the extent of inundation caused by the 100-year storm event with 0-, 1-, 2-, 3-, and 5-feet of SLR; the predicted shoreline location at time horizons of 25-, 50-, and 100-years from 2015; and the location of the transect along which a wave model was developed.

The coastal flood hazard assessment was based on 2011 topographic conditions, prior to the construction of the flood mitigation barrier. It predicted that none of the facility components located at Ocean Avenue would be inundated by storm surge at the 100-year return period. With the addition of 2 and 3 feet of SLR, the extent of flooding during a 100-year storm would reach the sludge handling and bulk chemical storage buildings, and the preliminary treatment system. With 5 feet of SLR, these assets would be further inundated during a 100-year storm event. The assessment did predict that the Galilee PS and Stanton Avenue PS would be inundated by storm surge at the 100-year return period. The average water depths at these pump stations would be 2.5 feet and 5 feet respectively.

A wave analysis was conducted at one transect through the Narragansett facility as shown in **Figure 3-21.** The analysis predicted that the significant wave height for a 100-year storm event at the facility would be approximately 5 feet at the shoreline but then drop to 1 foot within 50 feet of shore. With 5 feet of SLR and the 100-year storm event, the significant wave height experienced at the facility would be approximately 7 feet at the shoreline, dropping sharply for the next 50 feet to approximately 4 feet high, then gradually dropping to about 1-foot high until about 350 feet from the shoreline.

The predicted shoreline change for this facility is reflective of the 2011 topography of the site. Very little change is predicted at the 25-year and 50-year time horizons, however, the predicted 100-year shoreline would be approaching portions of the site. The predicted shoreline configuration depicted in **Figure 3-20** assumes erosion occurs without interference and includes the effect of SLR, which is based on an erosion rate of 0.6 feet on average per year.

The proposed flood mitigation barrier at the WWTF will impede shoreline erosion and dampen the effects of wave action on the facility. Assuming that the barrier is constructed to the proposed elevation of 20 feet (NAVD88), flood inundation would also be mitigated. However, as sea level rises over time, flooding is expected to circumvent the barrier and enter the site from the adjacent properties if those adjacent shorelines are not maintained or hardened.

3.2.9.3 Data Correlation Notes

Historical flooding events and concerns expressed by the WWTF operators correspond well with the potential events identified by the statewide coastal hazard assessment. Frequent flooding of the Stanton Avenue pump station and concerns with flooding at the Mettatuxet and Galilee pump station are consistent with the coastal hazard assessment. Likewise, consistent with the modeling efforts conducted by this study, operators recognize the threat of storm surge, wave action, and erosion on the WWTF, which prompted the construction of a protective seawall.

Figure 3-20: Narragansett WWTF – Coastal Hazards

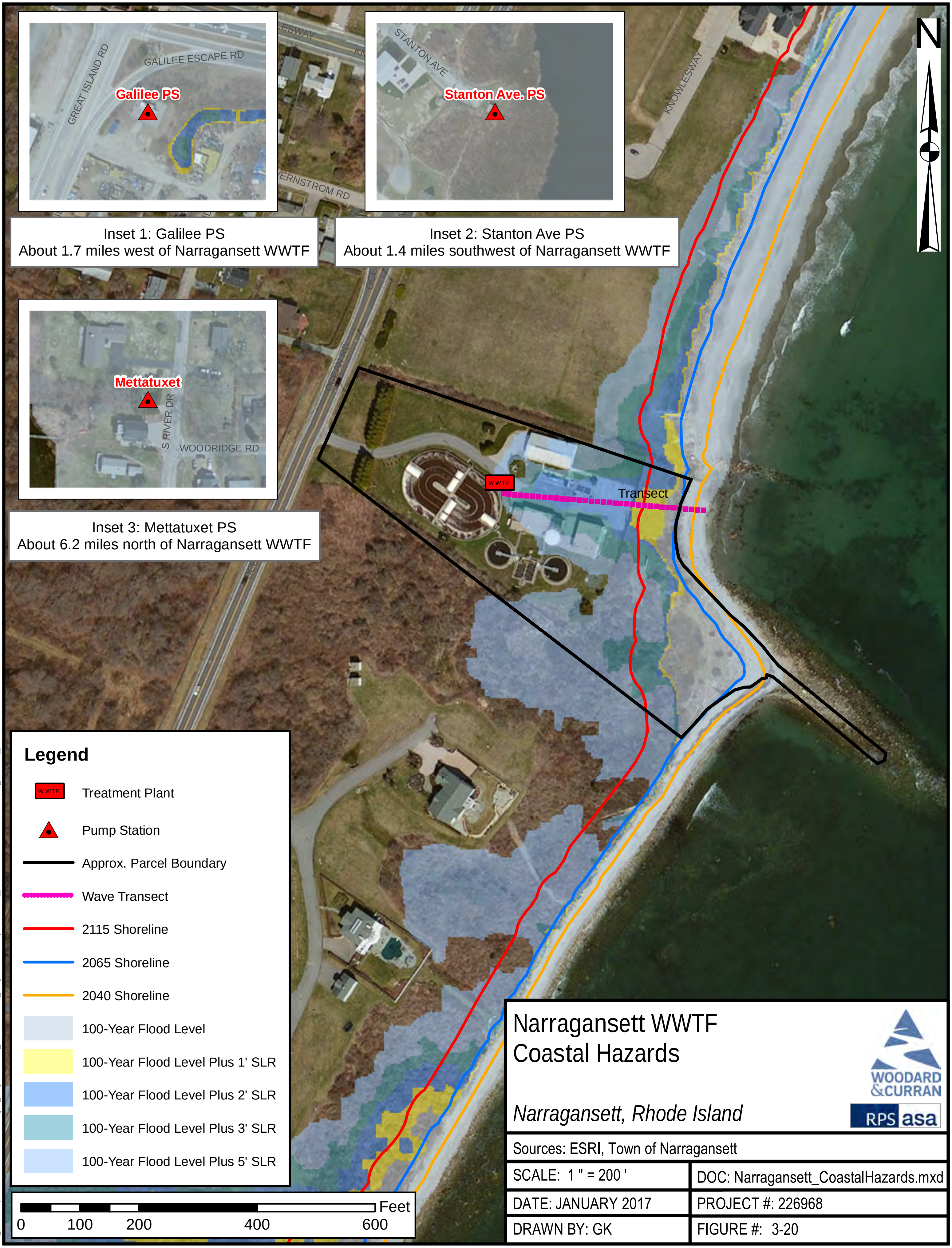

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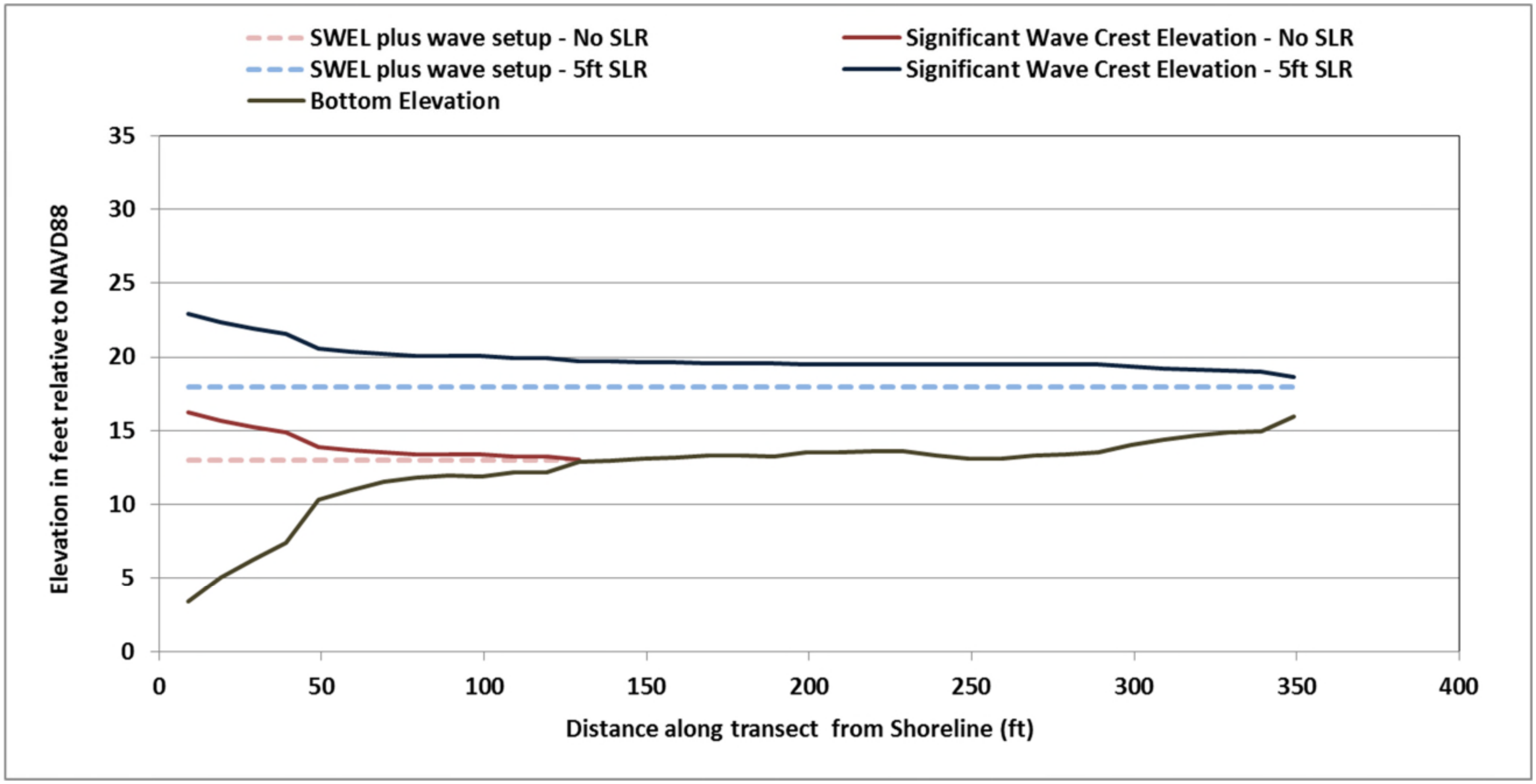
Figure 3-21: Narragansett Transect 1 - Wave Analysis (Elevation vs. Distance)



Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

3.2.10 New Shoreham

The Town of New Shoreham owns and operates the New Shoreham Wastewater Treatment Facility (WWTF) located at 252 Spring Street in New Shoreham, RI. It discharges the plant effluent to Rhode Island Sound. New Shoreham (Block Island), an island between Block Island Sound and the Atlantic Ocean, is primarily accessed from the mainland by ferries operating out of Point Judith and Newport, Rhode Island and New London, Connecticut. The New Shoreham WWTF has a design capacity of 0.3 MGD with average flows of between 0.2 to 0.25 MGD in the summer season and approximately 50,000 GPD in the winter season. The New Shoreham WWTF is located on a coastal bluff on the eastern side of Block Island making it vulnerable to storm damage typical of coastal areas.

The treatment facility operates an extended aeration treatment system with BNR as well as an estimated half-mile effluent force main system. The main source of power for the WWTF is through two generators located at the plant – one that operates as the prime source, and the second generator as a backup. In recent years, the plant has gone off generator power in October when the load would not affect the power company and the costs are lower.

The facility serves the Town of New Shoreham (US Census 2010 population of 1,010) and an estimated 300-700 customers in the winter and 4,000 customers in the summer. The New Shoreham facility must cope with significant seasonal flow fluctuations, resulting from the island having a summertime population of approximately 10,000 residents, with only an estimated 1,000 residents remaining through the winter. Unusual to New Shoreham is the driving force for wastewater management, which is to protect the current quality of the Island drinking water supplies and other surface waters and wetlands. These resources include federally designated sole source aquifers, 300 fresh water ponds, over 17 miles of coastal beach, and a large salt pond with a recreational boating harbor which also supports shellfishing, fishing, swimming. The town has a history of pro-active effort to preserve the Island's environmental resources as these are inextricably linked to quality of life and Island economy. New Shoreham's Hazard Mitigation Plan expired in 2011.

3.2.10.1 Operator Data

In addition to the main facility, there are five pump stations servicing New Shoreham. The Old Harbor (Main) Pump Station pumps all wastewater flows collected in the sewer system to the WWTF. It is powered by the wastewater treatment facility and its standby generators. Operators noted that the collection system in the vicinity of the Old Harbor Pump Station is subject to inundation from coastal flooding events.

There are two pump stations on Ocean Avenue that operate year-round. The Boat Basin (Block Island Marina) and Champlin's Marina Pump Stations operate only in the summer season. If the marinas are off-line for any reason, including extreme storm events, these pump stations would not experience sewerage flow and can remain off-line.

The New Shoreham WWTF handles numerous aspects of resiliency that are atypical of wastewater treatment facilities due to its coastal location and isolation. New Shoreham can become very isolated during the winter and during storm events. Transportation vessels servicing the island terminate operation approximately 72 hours prior to major storm events. The facility isolates itself electrically when winds reach 45 mph and electrical power is cut by the servicing utilities when wind speeds reach 75 mph. Two old rectangular clarifiers are used to hold press filtrate, but in the winter these tanks can hold up to 2 days' worth of influent flow in case of system failure, and the generator can hold up to 30 days' worth of fuel. The facility stores chlorinating/dechlorinating chemicals and sodium hydroxide for alkalinity adjustment on-site, and maintains a stock of lime for back-up alkalinity adjustment.

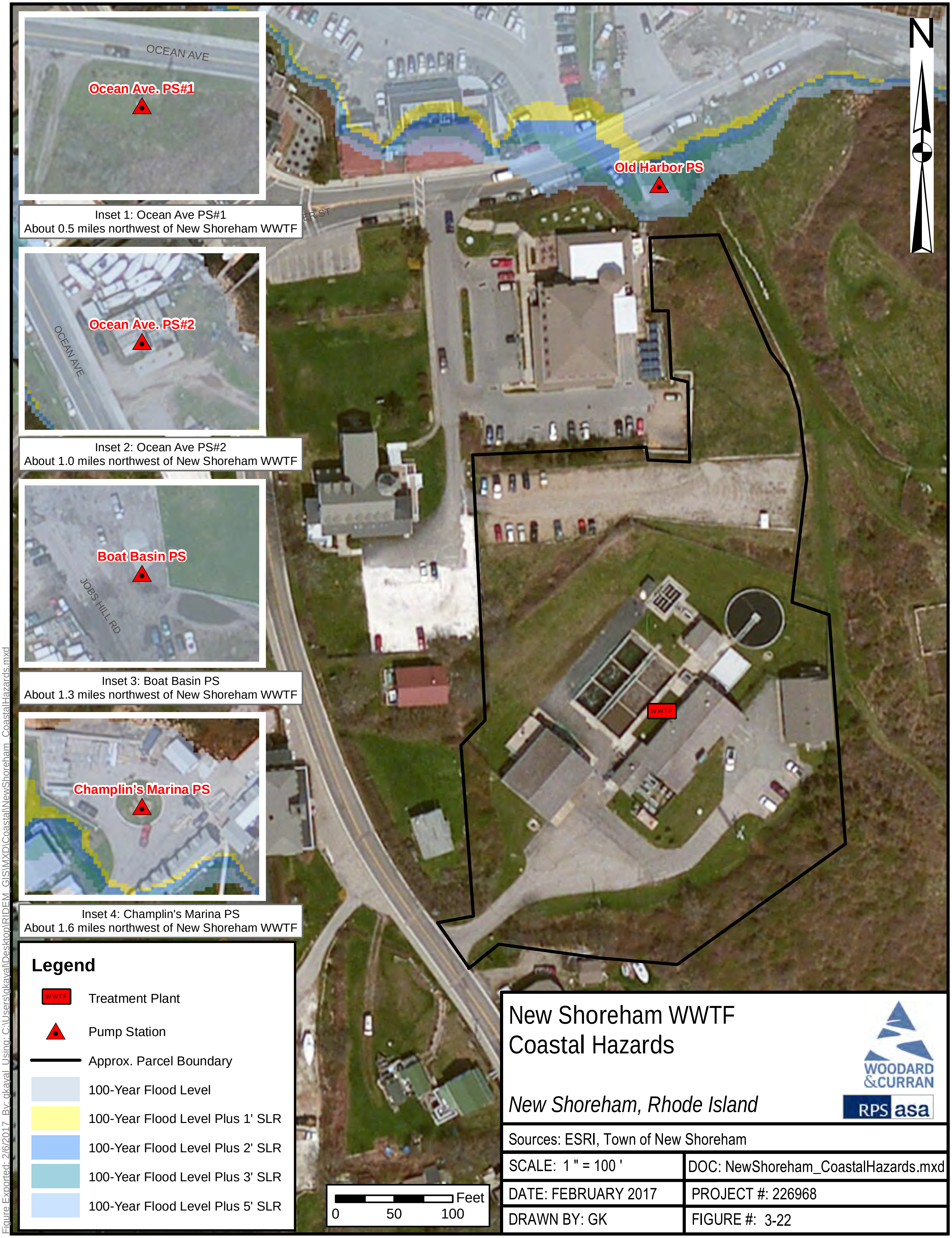
3.2.10.2 Modeling Results

New Shoreham was assessed for risk to coastal flood hazards and sea level rise. **Figure 3-22: New Shoreham WWTF – Coastal Hazards** depicts the extent of inundation caused by the 100-year storm event with 0-, 1-, 2-, 3-, and 5-feet of SLR. The coastal flood hazard assessment predicted that the treatment facility components would not be inundated by storm surge at the 100-year return period or with the addition of SLR. However, the coastal assessment indicated that the Old Harbor (Main) pump station is at risk for inundation during a 100-year coastal storm event with one foot of SLR. The other four pump stations are at risk for inundation during a 100-year coastal storm event.

3.2.10.3 Data Correlation Notes

The coastal modeling results matched with the operators' information for the New Shoreham WWTF in that it is not at risk to inundation. Also, the coastal modeling results showed that the collection system in the vicinity of the Old Harbor (Main) Pump Station is clearly vulnerable to inundation at the 100-year flood level.

Figure 3-22: New Shoreham WWTF – Coastal Hazards



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3.2.11 Newport

The Newport WWTF serves Newport (US Census 2010 population of 26,475), Middletown (US Census 2010 population of 17,334) and U.S. Naval Station Newport with an estimated total population served of 41,600. The WWTF is located on J.T. Connell Highway and discharges to Narragansett Bay's East Passage. The facility has a design capacity of 10.7 MGD with average flows of 8.4 MGD. The permit provides for an average monthly flow of 16 MGD and a maximum daily flow of 19.7 MGD. The WWTF resides over 800 feet inland of Coasters Harbor offering the facility some protection from coastal-related hazards. In addition to 97 miles of gravity and force main sewer collection pipes, the system also consists of 15 sanitary pump stations and two Combined Sewer Overflow (CSO) facilities. The sanitary sewer collection system and wastewater treatment facility are operated and maintained in accordance with a service contract with Newport Water Services LLC.

The original Newport WWTF was constructed in the 1950s however, the treatment facility and the 5 largest pump stations have all been upgraded in the last 12 years. The Newport WWTF operates typical treatment processes however, the facility also operates an extensive odor control system and an effluent pumping system during high surface water conditions at the outfall (operators estimated 1 effluent pumping event per month). Components of the facility include multiple buildings, six primary settling tanks, four aeration tanks, four secondary clarifiers, a chlorine contact chamber, grit chamber, and a septage receiving station.

The Newport facility and pump stations are identified in the Newport Hazard Mitigation Plan (approved, appending adoption) as critical facilities for the community. One specific recommended action of the plan related to the wastewater system infrastructure is to reduce its vulnerability by separating the remaining combined sewer and stormwater drainage systems. The plan notes that sections of the sewer system are overwhelmed during flooding events and they discharge effluent into the bay. To date, 80% of the system has been separated and Newport is working with RIDEM and the EPA to develop a System Master Plan to establish control and regulation of the combined sewer overflows.

3.2.11.1 Operator Data

The City of Newport entered into a Consent Decree (CD) with EPA in 2011 regarding working towards compliance with the CWA and the EPA's CSO Policy. A requirement of the CD was the development of a system master plan (SMP) for long term CSO control. The CD was modified in 2015 to incorporate the approved SMP that includes a June 2033 end date. The SMP's approach to CSO control incorporated improvements to the collection system, catch basin separation, improvements to the CSO treatment facilities, and increasing the capacity at the wastewater plant for wet weather flows. The improvements to the plant include increasing max day flow capacity from 19.7 to 30 MGD by June 28, 2019. The City awarded a new DBO contract in May 2016 to achieve the plant improvements which include significant upgrades to all the treatment processes in order to meet the new max day flow capacity.

The facility's collection system includes several pump stations and two CSO treatment facilities that are adjacent to surface waters or marshes. Long Wharf PS, Dyre Street PS, and Goat Island PS all operate on either submersible pumps or pumps with motors elevated above the dry-pit, but all share similar vulnerabilities to their electrical system. Additionally, Goat Island PS lacks a permanent back-up electrical power supply. Both the Washington St. CSO facility Wellington Avenue PS/CSO treatment facility have been recently upgraded as part of the SMP for CSO control. The City has identified evaluated potential impacts of climate change to key components of its sanitary sewer and storm drainage systems. The evaluation includes an update of information on current base flood elevations as shown on FEMA Flood Insurance Maps(FIRMs) and accounting for sea level rise. A preliminary list of vulnerabilities and potential adaptive and/or remedial measures were identified to improve resiliency for the 100-year flood over the next 25 years at the following facilities: Wastewater Treatment plant; Wellington Ave. Pump Station/CSO Treatment Facility; Washington St. CSO Treatment Facility; and the Long Wharf Pump Station. The City is incorporating the flood protection measures into capital projects to its wastewater facilities. To date flood protection measures have been included with the recently completed improvements at the Wellington Ave. and Washington St. facilities and are included in the current improvements proposed for the wastewater treatment plant.

3.2.11.2 Modeling Results

Newport was assessed for risk to coastal flood hazards, sea level rise and coastal erosion. **Figure 3-23** shows the extent of inundation caused by the 100-year storm event with 0-, 1-, 2-, 3-, and 5-feet of SLR and the predicted shoreline location at time horizons of 25-, 50-, and 100-years from 2015.

The coastal flood hazard assessment predicted that some of the treatment facility components would be inundated by storm surge at the 100-year return period including the storage garage and portions of the gravity thickener, chemical storage, and sludge dewatering. With the addition of 2, 3 and 5 feet of SLR, the extent of flooding during a 100-year storm would impact the main administration building, driveway access, preliminary treatment, the chlorine contact tank, effluent pumping, the septage receiving building, rectangular primary clarifiers and some of the secondary clarifiers. The main power disconnect is currently at grade and will be impacted at 2 to 3 feet of SLR. The sludge pump room is below ground and would be impacted by 5 feet of SLR. One concern with the sludge pump room is that there is no alarm system currently to indicate when and if flood waters are entering this area.

The insets on **Figure 3-23** indicate the extent of inundation cause by the 100-year storm event at Dyre Street Pump Station, Goat Island Pump Station, Washington CSO Facility, Long Wharf Pump Station and Wellington Pump Station.

Table 3-6: Newport Pump Stations Inundated by the 100-Year Storm Event lists the average water depth for a 100-year storm event at each of these facilities.

Table 3-6: Newport Pump Stations Inundated by the 100-Year Storm Event

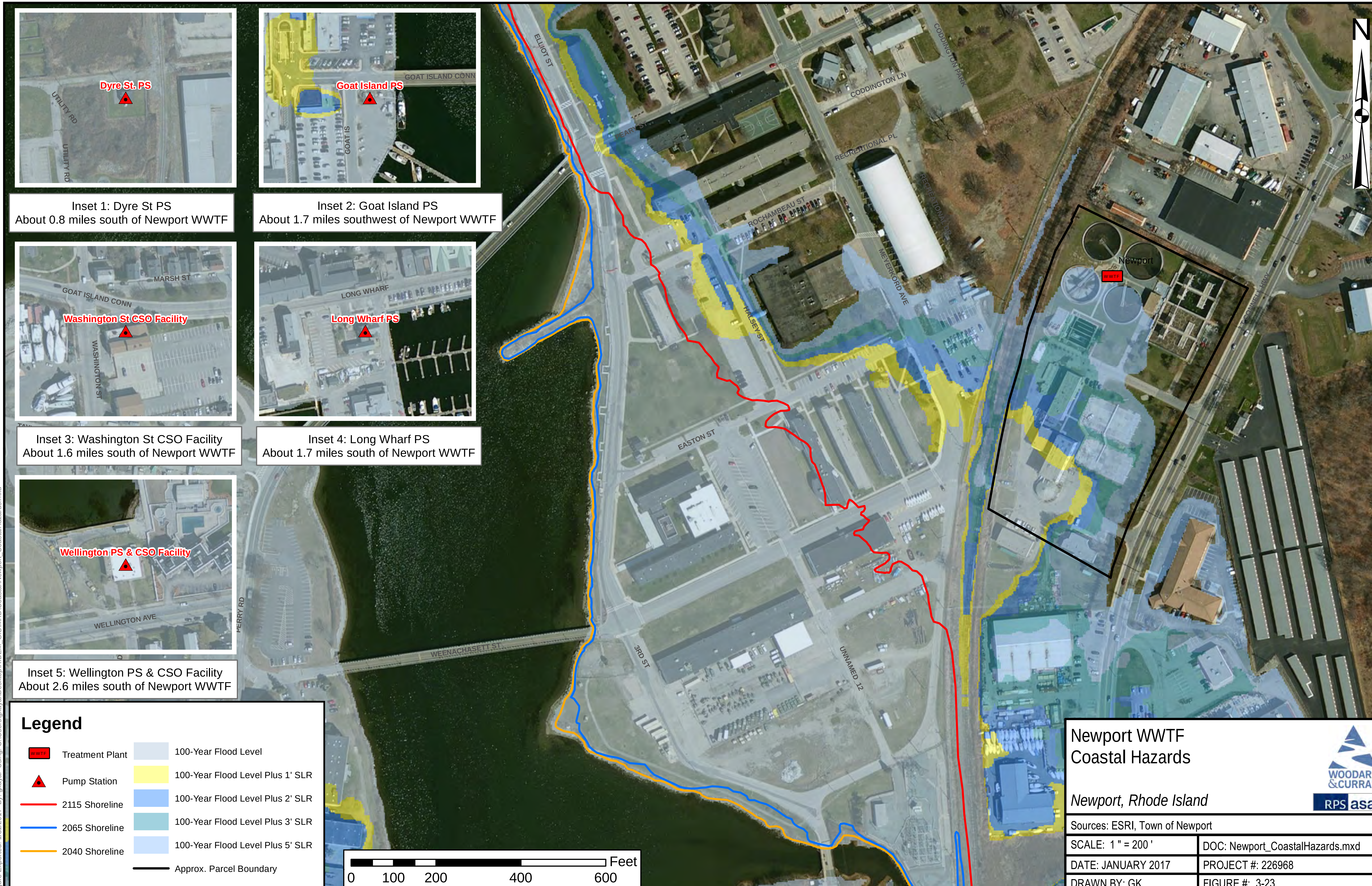
Pump Station	Average Water Depth for a 100-Year Storm Event
Dyre Street Pump Station	4 to 5 feet
Goat Island Pump Station	3 to 4 feet
Washington CSO Facility	3 to 4 feet at the facility and 6-7 feet around access areas to CSO
Wellington Pump Station	1 to 3 feet at the PS and 5-7 feet around access areas to PS
Long Wharf Pump Station	5 to 7 feet at the PS and surrounding area

The Newport WWTF is not directly adjacent to the shoreline. The shoreline in the vicinity of the Newport WWTF was historically filled and hardened, so the erosion rate used for the shoreline analysis was set to zero. The predicted shoreline configurations depicted in **Figure 3-23** therefore, solely reflect the effects of SLR and the topography of the site assuming no shoreline protection mechanisms are implemented. Under this scenario, very little change is predicted at the 25-year and 50-year time horizons. While the predicted 100-year shoreline would significantly impact land to the west of the facility and the adjacent rail line, the WWTF itself would remain 300+ feet shoreward of the coast.

3.2.11.3 Data Correlation Notes

Operators concerns with inundation of several pump stations and two CSO facilities were corroborated by the coastal hazard mapping indicating that the coastal hazard assessment is a good predictive tool for flooding in future circumstances and in other locations within the community. The Newport WWTF itself is further inland, and while the coastal hazard assessment identified it as being at some risk to inundation, it has not experienced an event of the magnitude that would impact it.

Figure 3-23: Newport WWTF – Coastal Hazards



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3.2.12 Quonset Point

The Quonset Development Corporation owns and operates the Quonset Point WWTF located at 150 Zarbo Avenue in North Kingstown, RI. The facility specifically serves and supports the adjacent Quonset Business Park (QBP). It has a design capacity of 1.78 MGD with average flows of 0.49 MGD and discharges to a tidally-influenced stretch of Narragansett Bay's West Passage. Quonset Point is a commercially developed peninsula with industrial tenants. The area also serves as a major shipping and transportation port through the Port of Davisville (ferry and cargo), Seaview Transportation Company (railroad) and Quonset State Airport (civil-military). New collection system connections were on-going at the time of the assessment in North Kingstown, which have produced an estimated 20,000 gpd increase in influent flow. New connections are expected to contribute up 200,000 gpd over the following 5 years. The facility operates a typical treatment system with rotating biological contactors and has the capacity to support future expansion of wastewater collection and treatment to both QBP and the Town of North Kingstown.

The North Kingstown Hazard Mitigation Plan identifies Quonset Point as a vulnerable facility located in an area prone to flooding and wave action. The plan notes that installing temporary mitigation measures at the facility may be necessary if damage is anticipated during a specific type of storm, and options to consider for additional protection include using a portable dike with pumping equipment. The plan also notes that relocating the facility should be considered if it is damaged or destroyed.

3.2.12.1 Operator Data

The Quonset Point WWTF is located in an area that is exceptionally flat, making flood waters especially hazardous when wave action is present. This facility has numerous flood mitigation efforts in place, and may successfully function during a natural hazard event, however it would likely be unsafe for personnel to be onsite during such conditions. All sections of the facility were built to withstand 100-year peak flood levels at elevation +17.5 ft.

Many of the treatment process components around the site are protected by elevated tank walls, from the influent pumping system to the secondary clarification. These gradually decrease in height through the process from approximately 10ft above grade at preliminary and primary treatment, 6ft above grade at the RBCs, and 3ft above grade at the secondary clarifiers. In addition, many of the facility entryways around the site are elevated several feet above the ground and the sludge pump building has a stop-log system installed for a higher level of protection. Pumping systems around the site are located below grade and would be vulnerable if water were to pass through the entryways, but all of the lower facilities on site have sump alarms to alert personnel of flood water intrusion. The louvers supporting the aging generator system are elevated to similar heights but are on the bayside of the building and may be vulnerable to wave action or run-up during a major storm event. In the event that back-up power generation or pumping capacity is required, spare pumps and generators are stored on-site, and additional stand-by equipment is available through other QDC departments.

The QDC maintains four pump stations at Quonset Point of varying designs, and vulnerability, ranging in age from 5 to 70 years old at the time of the assessment. All of the pump stations have sump alarm systems with radio communications back to the treatment facility. Davisville PS includes preliminary treatment with entryways and electrical systems at grade, however pump motors are elevated approximately 6 feet above the floor. Commerce Park PS has power generation systems and supporting louvers at grade but pump motors are elevated slightly above floor level. Davisville Pier PS and Burlingham PS both have elevated tank walls and Burlingham is additionally protected from flood waters with submersible pumps and a dedicated on-site generator. Davisville Pier PS is supported by back-up power generation but the power is supplied remotely and is shared with port operations. Representatives from the Quonset Development Corporation provided additional information on December 9, 2016 that might warrant further evaluation by RIDEM.

3.2.12.2 Modeling Results

Quonset Point was assessed for risk to coastal flood hazards, sea level rise, wave hazards and coastal erosion. **Figure 3-24** depicts the extent of inundation caused by the 100-year storm event with 0-, 1-, 2-, 3-, and 5-feet of SLR; the predicted shoreline location at time horizons of 25-, 50-, and 100-years from 2015; and the location of the two transects along which wave models were developed.

The coastal flood hazard assessment predicted that the entire facility and surrounding area would be fully inundated by storm surge at the 100-year return period. The site of the Quonset Point WWTF is extremely flat and there are no obstructions or barriers to mitigate storm impacts and the water depth would be 1-5 feet throughout the site. The Davisville Pier and Burlingham Pump Stations would also be inundated by storm surge at the 100-year return period and water depths at these pump stations would be 3-4 feet and 2-3 feet respectively. Davisville PS would also be inundated by storm surge at the 100-year return period. The Commerce Park Pump Station would be inundated with 5 feet of SLR.

A wave analysis was conducted at two transects through the Quonset Point Facility as shown in **Figure 3-25: Quonset Point Transect 1 – Wave Analysis (Elevation vs. Distance)** and **Figure 3-26**. The analysis for **Transect 1** predicted that the significant wave height for a 100-year storm event would be approximately 5 feet at the shoreline and drop to 3 feet approximately 30 feet inland. The wave height would then drop to 1-2 feet at approximately 400 feet inland. With 5 feet of SLR and the 100-year storm event, the significant wave height experienced at the facility would be approximately 6 feet up until 400 feet from shore where it would drop to 4 feet moving inland. The analysis for **Transect 2** predicted that the significant wave height would be approximately 5 feet at the shoreline and gradually drop to 3 feet by the time it reached 800 feet from shore. At 5 feet of SLR, the wave height would start at approximately 6 feet and follow the same trajectory and drop off pattern, dropping to 5 feet at 800 feet from shore.

The shoreline at Quonset Point was historically filled and hardened, so the erosion rate used for the shoreline analysis was set to zero. The predicted shoreline configurations depicted in **Figure 3-24** therefore, solely reflect the effects of SLR. The analysis revealed that the existing hardened shoreline would exhibit very little change at the 25-year and 50-year time horizons, however, the effect of SLR at the 100-year time horizon would result in the shoreline receding landward well past the WWTF if no mitigations measures are implemented.

3.2.12.3 Data Correlation Notes

The potential for coastal storm damage was clearly a factor addressed in the design and construction of the Quonset WWTF and pump stations. While operators did not report that wastewater treatment process has been impacted by coastal storms, the North Kingstown Hazard Mitigation Plan recognizes the vulnerability of the facility. This document along with the protective measures in place correlates with the coastal hazard and wave assessments.

Figure 3-24: Quonset Point WWTF – Coastal Hazards

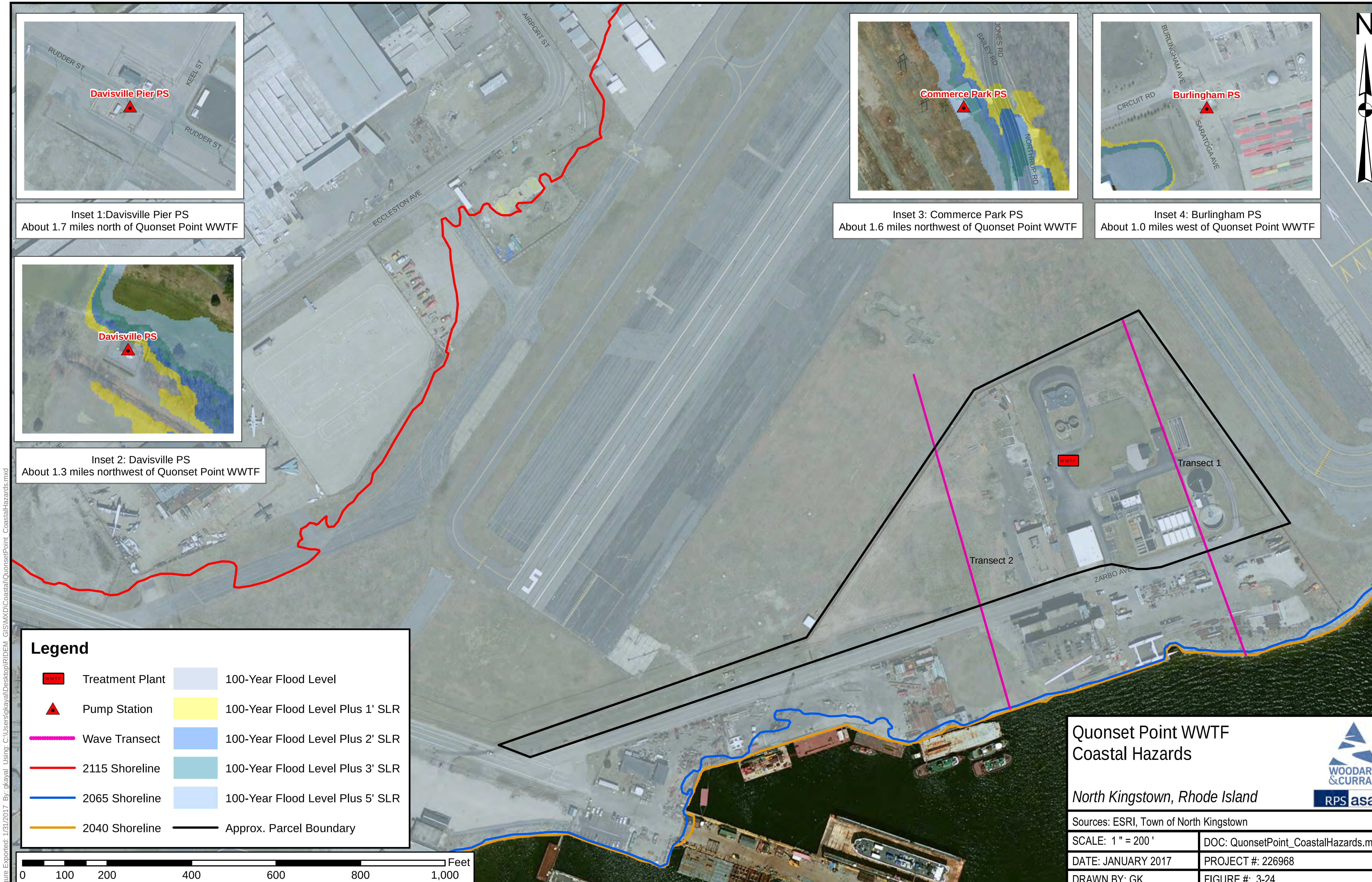

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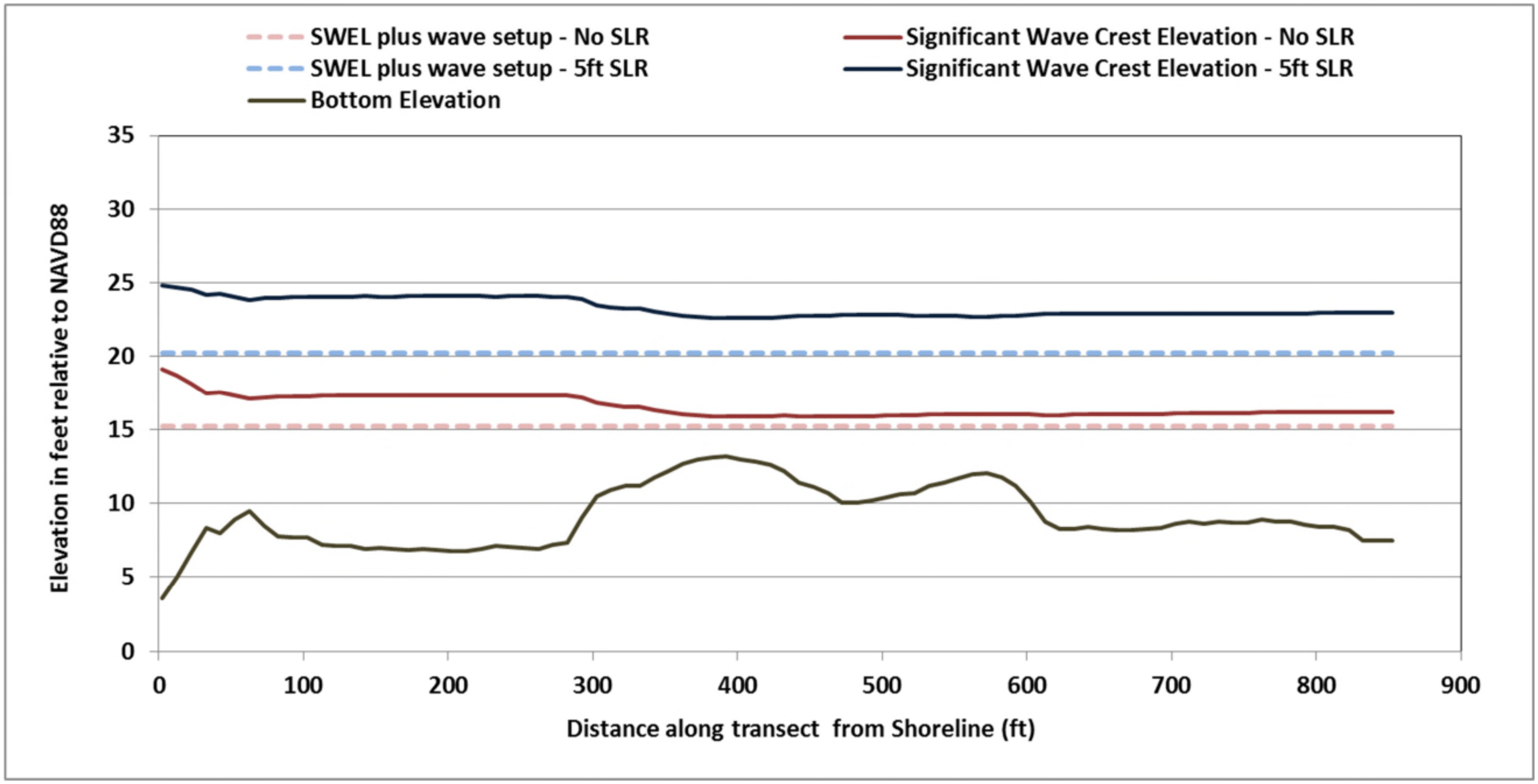
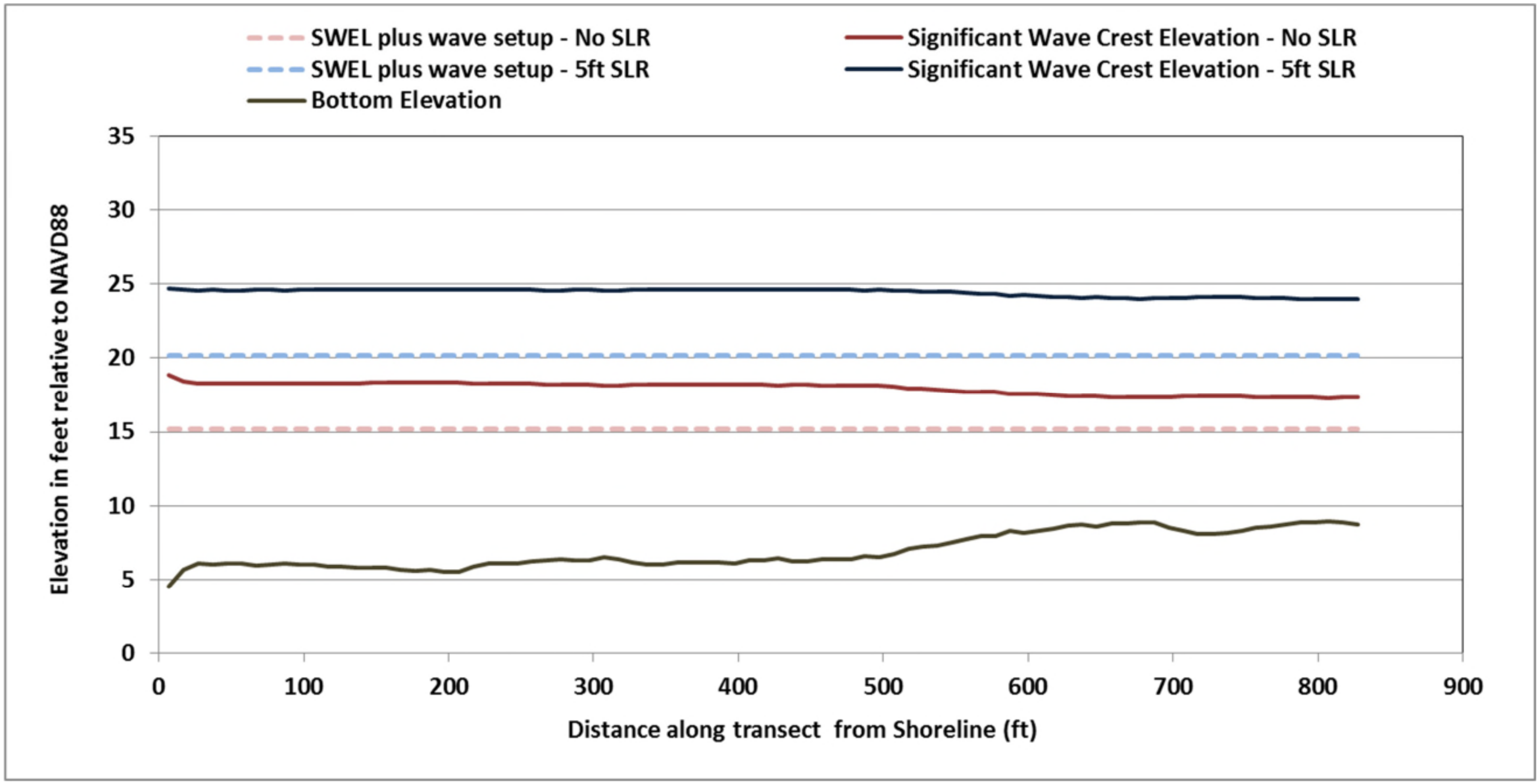
Figure 3-25: Quonset Point Transect 1 - Wave Analysis (Elevation vs. Distance)



Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

Figure 3-26: Quonset Point Transect 2 - Wave Analysis (Elevation vs. Distance)



Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

3.2.13 Smithfield

The Smithfield WWTF serves the Town of Smithfield (US Census 2010 population of 21,430) and an estimated population of 14,000 served by sewer service. Smithfield is located inland and is a predominantly rural area in the northern part of Rhode Island that consists of heavily forested areas and a large reservoir. The facility discharges to the Woonasquatucket River and is located at 20 Esmond Mill Drive. Veolia Water operates the facility with a design capacity of 3.5 MGD and average flows of 1.4 MGD. The facility was originally constructed in 1978 and its most recent major upgrade was in 2014. The pump stations that make up the collection system range in age from 10 to over 40 years old, with nine of the twelve stations being constructed in 1974. The facility operates a typical activated sludge treatment process however; the effluent is also routed through tertiary treatment (ACTIFLOW®) for phosphorus and zinc removal, prior to disinfection. Several atypical chemicals are stored on-site to support the treatment systems including lime (alkalinity adjustment), ferric chloride (ACTIFLOW® coagulant), polymer (ACTIFLOW® flocculent), and sand (ACTIFLOW® ballast) which is in addition to disinfection and odor control chemicals. Future permit changes are anticipated to include harsher phosphorus and zinc discharge limits. The Town of Smithfield does not have a Hazard Mitigation Plan.

3.2.13.1 Operator Data

The Smithfield WWTF is located in an area with minimal apparent flood risk, however, various access roads leading to the facility are lower in elevation and are at higher risk of flooding. Operators reported that the March 2010 major storm event impacted the facility and pump stations in several ways including:

- Whipple Avenue Pump Station was shut down when the pump station dry well was inundated with floodwaters from the Woonasquatucket River. The Camp Street Pump Station dry well was also inundated with river floodwaters.
- Roger Williams Drive Pump Station and Farnum Pike Pump Station were unable to keep up with influent flows so capacity was augmented with vacuum trucks.
- Treatment processes were overwhelmed and heavy solids in the primary clarifiers had to be pumped out by septage haulers.
- The treatment facility was inaccessible through the main access road during the event, with the only remaining site access being a property easement. Disinfection systems, as well as the four above listed pump stations were lost to flood water inundation.
- Restricted facility access may prohibit chemical deliveries required for the ACTIFLOW® system.

The facility has one large permanent generator mounted slightly above grade, and one transformer for the operation building mounted at grade adjacent to the river. Preliminary treatment is located at grade but primary and secondary treatment tanks have elevated tank walls. Primary and secondary treatment controls are located below grade but entryways are elevated and sumps are alarmed. The facility maintains one back-up portable generator and one portable trash pump to support failed pump stations. No pump station generators are elevated, and Burlingame Road PS and Latham Farm Road PS lack permanent generators. Operators reported that they would like to install permanent generators at these two pump stations.

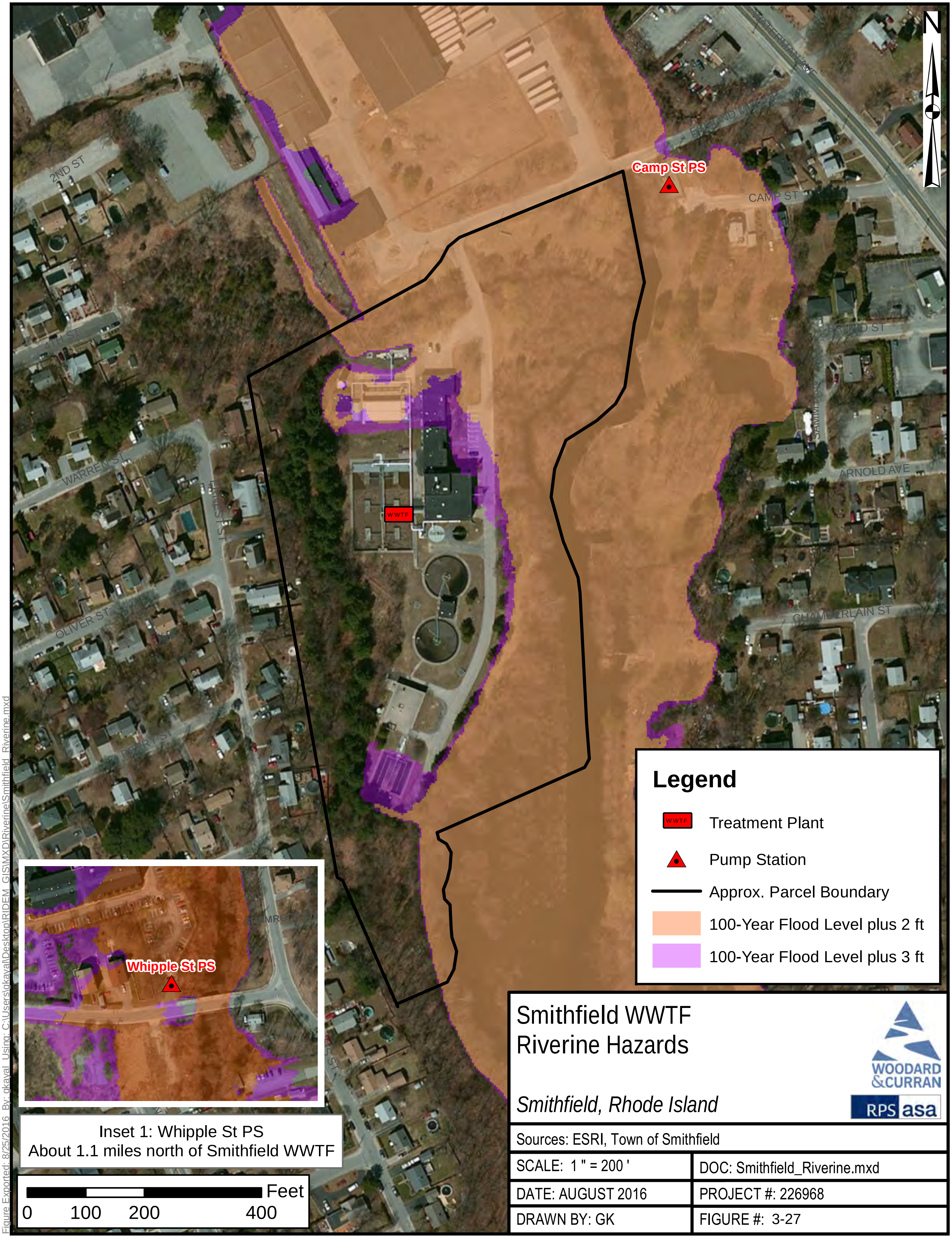
3.2.13.2 Modeling Results

The Smithfield WWTF was assessed for risk to riverine flood hazards **(Figure 3-27)**. The riverine flood hazard assessment predicted that parts of the Smithfield WWTF would be inundated at the 100-year flood level plus 2 feet and the 100-year flood level plus 3 feet. The depth of the water at the entrance road to the facility would approach five feet during the100-year flood level plus 2 feet. In addition to the access road, components of the Smithfield WWTF that will be specifically impacted include the primary clarifiers and the administration building at the 100-year flood level plus 2 feet event and the chlorine contact tanks at the 100-year flood level plus 3 feet. The Whipple Street and Camp Street pump stations were also predicted to become inundated at the 100-year flood level plus 2 feet.

3.2.13.3 Data Correlation Notes

The flooding experienced during the March 2010 storms corresponds well with the statewide riverine hazard assessment, which predicted the flood-prone portions of the WWTF to be the access road, administration building, and disinfection system. Also recorded flooding conditions at the Whipple Avenue and Camp Street pump stations correspond with the riverine hazard assessment. This correlation indicates that the riverine hazard assessment is a good predictive tool for flooding in future circumstances and in other locations.

Figure 3-27: Smithfield WWTF – Riverine Hazards



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3.2.14 South Kingstown

The Town of South Kingstown owns and operates the South Kingstown Wastewater Treatment facility located at 275 Westmoreland Street in Narragansett, RI and it discharges to Rhode Island Sound. South Kingstown is a community bordered by Block Island Sound to the south and Point Judith Pond and the Narrow River to the east. The WWTF location is inland, roughly one mile from any surface waters and it receives flows from portions of South Kingstown (9,800 customers served), the Town of Narragansett (13,000 customers served), and the University of Rhode Island (6,600 customers serves) with a design capacity of 5.0 MGD and average flows of 2.4 MGD. The original treatment facility, and many of its supporting pump stations, were constructed in 1978, however many of the facilities have seen recent upgrades. The South Kingstown WWTF operates typical treatment processes. There are twelve pump stations associated with the wastewater system.

South Kingstown's Multi-Hazard Mitigation Strategy Plan (2017 expiration date) notes that there is one specific area where sewer lines are vulnerable to natural hazard events in Middlebridge, where the sewer lines span the Narrow River under the Middlebridge Bridge. The plan also notes a concern for contamination from individual septic discharge systems in flood prone areas which can cause potential pollution and related health problems.

3.2.14.1 Operator Data

The WWTF is outside of the established flood zones and appears well protected from storm events with elevated treatment systems and back-up equipment. According to operators, the majority of the treatment facility's storm related weaknesses lie in inflow and infiltration, much of which they believe originates from the University of Rhode Island because high flows are observed coming from the Kingston Pump Station during rain events.

Operators reported that during long periods of low precipitation, the plant concentrations coming in are high and make processing difficult. When flow levels are high following precipitation events, the oxygen levels are too high and processing is again, challenging.

Silver Lake Pump Station is a large 5.0 MGD pump station located adjacent to a stream, with motors and generators mounted at grade. Salt Pond Pump Station is located adjacent to a coastal cove with pumping systems located far below grade. The dry-pit shows signs of groundwater infiltration. Middlebridge North PS and Middlebridge South PS are identical pump station designs, adjacent to surface waters. These pump stations have no back-up power generation, but operate on suction lift pumps with back-up combustion engines. These stations have no floor alarms and pump systems are mounted at grade.

Operators indicated that standby power capabilities at several pump stations needs improvement. The generator at Silver Lake Pump Station was replaced in 2013 and the Kingston Pump Station will also be updated. The Salt and Hospital Pump Stations are scheduled for generator replacement as well. They anticipate the generator for the WWTF will be replaced in 2016 or 2017.

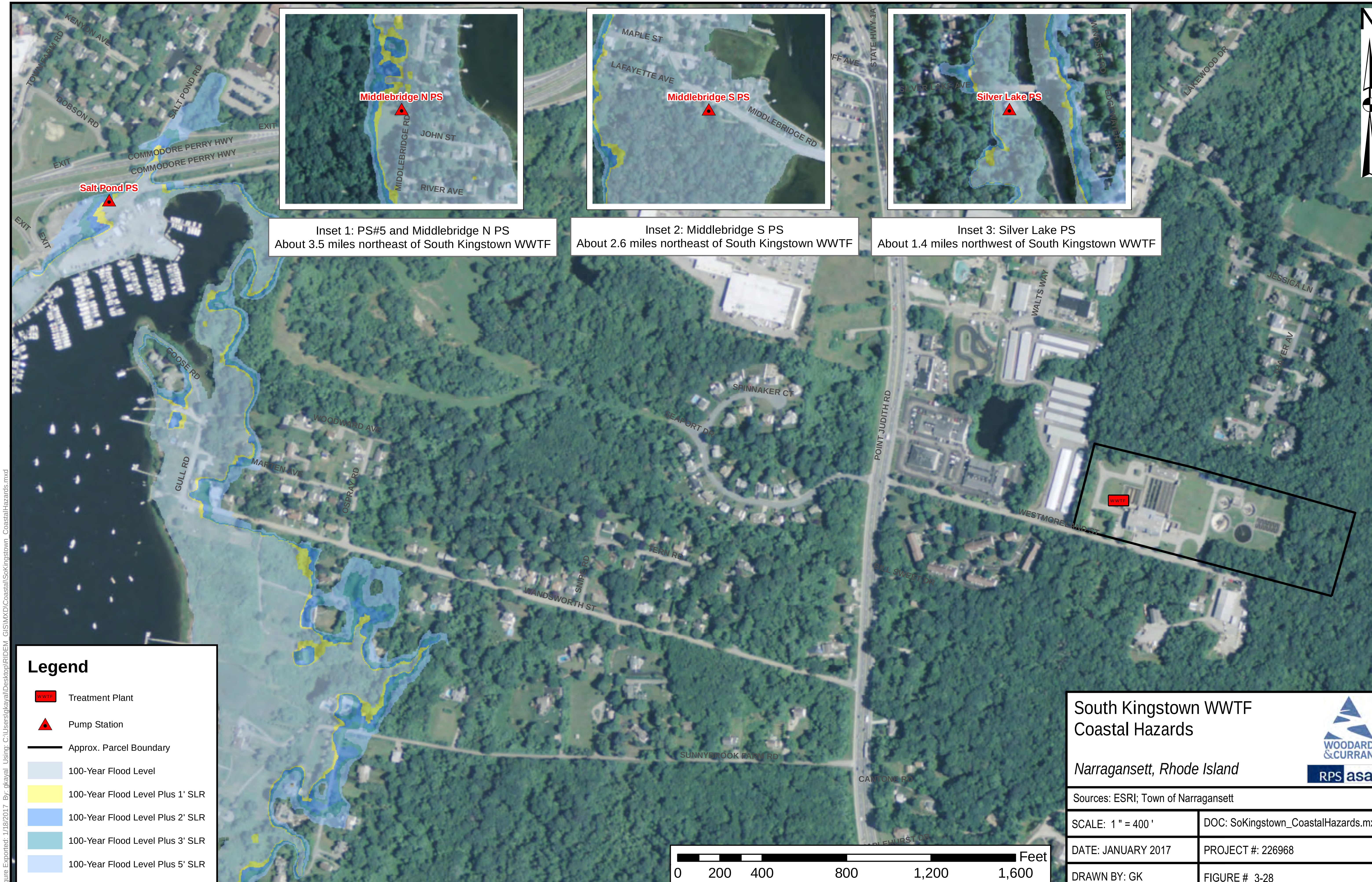
3.2.14.2 Modeling Results

The South Kingstown WWTF was assessed for risk to sea level rise and coastal flood hazards (see **Figure 3-28**). The coastal flood hazard assessment predicted the South Kingstown WWTF would not be inundated by storm surge with up to 5 feet of SLR and access to the plant would not be impacted. Four pump stations associated with the facility would be impacted by storm surge from a 100-year storm including Middlebridge North Pump Station, Middlebridge South Pump Station, Salt Pond Pump Station and Silver Lake Pump Station.

3.2.14.3 Data Correlation Notes

Information provided by operators regarding the WWTF and the pump stations at risk to inundation corresponds to the coastal hazard mapping effort. The WWTF was not considered by the operators or by the modeling exercises to be in a flood hazard prone area. The four pump stations located near coastal waters were mapped within the 100-year event.

Figure 3-28: South Kingstown WWTF – Coastal Hazards



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3.2.15 Warren

The Town of Warren is on a peninsula between the Warren River to the west and Mount Hope Bay to the east, both of which are tidally influenced surface waters connected to Narragansett Bay. The town has a combination of urban, suburban and rural levels of development. The WWTF is located on the east bank of the Warren River where a seawall defines the river's edge. Suez operates the facility, which has a design capacity of 2.01 MGD and average flows of 1.80 MGD. The facility was originally constructed in the 1940s but much of the plant as it appears now was constructed in 1981. At the time of the assessment, the pump stations supporting the facility ranged in age from less than 1 year to over 40 years old. The facility provides a conventional activated sludge treatment process. A somewhat unusual aspect of the plant is the intermediate pumping system supporting a significant increase in water surface elevation between primary and secondary treatment. Warren has an approved Hazard Mitigation Plan that expires in 2020.

3.2.15.1 Operator Data

Previous reports on the facility indicate that much of the facility's equipment is nearing the end of its useful life, and the facility itself may have inadequate capacity for future flows and loads. In addition, the Town is under a Consent Agreement with DEM to upgrade the facility to remove nitrogen. A major upgrade to the WWTF is currently being designed to address these deficiencies. In addition to increasing resilience to some of the flood vulnerability, the upgrade incorporates the following improvements:

- New screening equipment at the headworks.
- Replacement of existing primary sludge and scum pumping and collection equipment.
- New pumps at the intermediate pump station to increase the capacity to a peak hourly flow of 9 MGD.
- Construction of new reactor tanks, equipment and modifications to the existing secondary reactor tanks to provide biological nitrogen removal (BNR).
- Replacement of existing secondary sludge and scum pumping and collection equipment.
- A new sludge handling facility for thickening and storage of sludge.
- Architectural and structural rehabilitation of existing structures and buildings throughout the facility.
- Replacement of existing heating, ventilation, air conditioning and plumbing.
- New electrical service, transformer, emergency generator, switch gear and motor control centers.
- Upgrades and expansion of the instrumentation and control systems.

Preliminary and primary treatment occur below grade, but all of the site's critical system components are elevated above grade or are protected by above-grade entryways. The generator, although elevated, is aged and a new generator is proposed as part of the on-going facility upgrade, along with a new electrical service. The intermediate pumping system transferring primary effluent to secondary treatment is a hydraulic limitation in the system. This led to designing the current upgrade for the intermediate pump station to increase its capacity.

The facility is supported by several vulnerable pump stations of various ages and designs. Wood Street PS, Locust Terrace PS and North PS vary in design but all operate on a tidally influenced river and are supported by aging generator systems. Patterson Avenue Pump Station is also located on the tidally influenced Kickemuit River, but upgrades to the facility were completed during this assessment. All of the aforementioned stations either have flood proof or elevated entryways to protect against floodwaters. Asylum Pump Station was also assessed for potential vulnerabilities, which include a generator at grade and close proximity to a small stream, but it was also noted that this station operates on dry-pit submersible pumps.

3.2.15.2 Modeling Results

The Warren WWTF was assessed for risk to coastal flood hazards, sea level rise, wave hazards, and coastal erosion. **Figure 3-29** depicts the extent of inundation caused by the 100-year storm event with 0-, 1-, 2-, 3-, and 5-feet of SLR; the predicted shoreline location at time horizons of 25-, 50-, and 100-years from 2015; and the location of the two transects along which wave models were developed. Note the proposed WWTF upgrades have been designed based on flood projections and modelling performed by the US Army Corp of Engineers as part of their North Atlantic Coastal Comprehensive Study (NACCS).

The coastal flood hazard assessment predicted that the entire treatment facility would be inundated by storm surge at the 100-year return period. Under this condition, the still water depth of flooding would be approximately 7 feet in the parking lot, which is one of the highest ground elevations on the property. 100-year return period floodwaters would extend approximately 800 feet inland, well past Water Street such that vehicular access to the plant entrance would not be possible. Adding five feet of SLR to the 100-year event, flooding from the Palmer and Kickemuit Rivers to the north and south would converge with the Warren River, effectively cutting off vehicular access to the entire peninsula.

The coastal flood analysis also predicted that five wastewater pump stations in Warren would be inundated during a 100-year storm event. Floodwaters from the many tidal waterways adjacent to the town would inundate the North, East (A.K.A. Wood Street), Cole School (A.K.A. Asylum Street), Patterson Avenue, and Locust Terrace pump stations. The North, East, and Locust Terrace pump stations would particularly inaccessible, with dry land quite distant from these locations.

A wave analysis was conducted at two transects through the Warren WWTF. Graphs depicting the wave heights along these transects are presented in **Figure 3-30: Warren Transect 1 – Wave Analysis (Elevation vs. Distance)** and **Figure 3-31**. The analysis predicted that the significant wave height experienced at the facility during a 100-year storm event would be approximately 5 feet along flow paths that are uninterrupted by structures. The significant wave height would increase to approximately 6 feet with 5 feet of SLR. Adding wave action to the stillwater elevation, the depth of water across the facility would approach 15 feet deep and overtop all the major facility components, including the elevated secondary treatment.

The shoreline at the Warren WWTF was historically filled and hardened, so the erosion rate used for the shoreline analysis was set to zero. The predicted shoreline configurations depicted in **Figure 3-29** therefore, solely reflect the effects of SLR and the topography of the site.

3.2.15.3 Data Correlation Notes

The potential for coastal storm damage is being addressed in the design of a major upgrade to the Warren WWTF based on NACCS flood projections. The pump stations identified as at-risk correspond to those that were modeled by the coastal hazard assessment as within the 100-year inundation event.

Figure 3-29: Warren WWTF – Coastal Hazards

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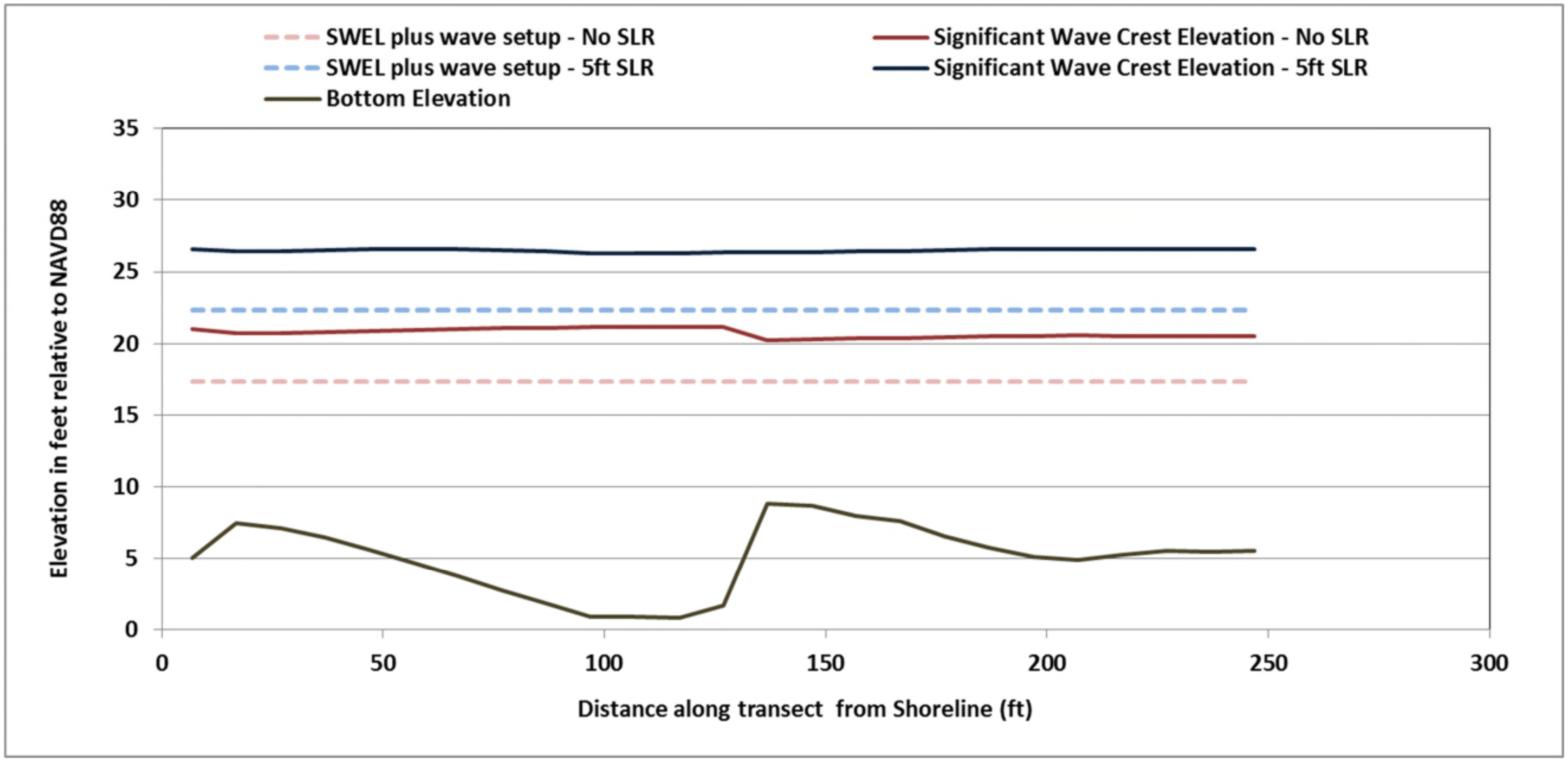
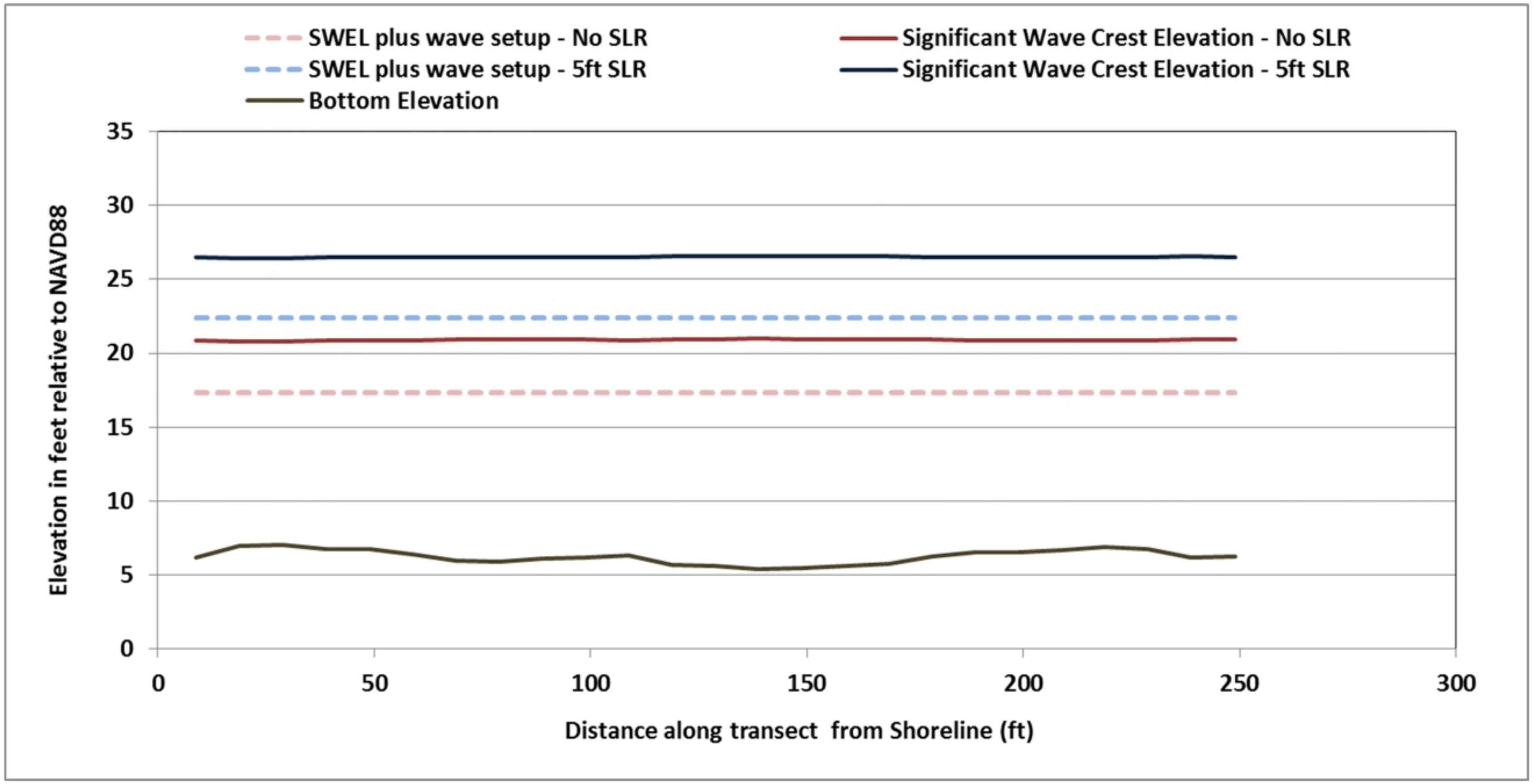
Figure 3-30: Warren Transect 1 - Wave Analysis (Elevation vs. Distance)



Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

Figure 3-31: Warren Transect 2 - Wave Analysis (Elevation vs. Distance)



Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

3.2.16 Warwick

The City of Warwick owns the Warwick Wastewater Treatment Facility located at 125 Arthur W. Devine Boulevard in Warwick and it discharges to the Pawtuxet River. The Warwick Sewer Authority (WSA) operates the facility and collection system. Warwick is a heavily-developed community south of Providence with an extensive portion of its perimeter abutting Narragansett Bay. The facility serves the City of Warwick (US Census 2010 population of 82,672) and an estimated 60,200 customers. The Warwick WWTF resides on the inside of an oxbow on the Pawtuxet River, with the north, west and south perimeter abutting the river. This location makes the facility especially vulnerable to high river level and water velocity, and the long-term impacts of those river characteristics. The facility has a design capacity of 7.7 MGD with average flows of 4.5 MGD. The original facility was constructed over 50 years prior to this assessment but the treatment facility and its supporting pump stations have undergone numerous upgrades between 2010 and 2015 with some upgrades still on-going. There are 48 pump stations associated with the Warwick sewer system. The facility operates a typical treatment process with a PAC-based phosphorus removal system that was under construction at the time of this assessment.

Warwick's Hazard Mitigation Plan (2017 expiration date) identifies the facility and all pump stations as critical facilities for the community.

3.2.16.1 Operator Data

Recognizing that the Warwick WWTF location makes it vulnerable to flooding, the Warwick Sewer Authority constructed a levee 17 feet above grade in the mid-1980s to provide protection against the 100-year flood. However, the March 2010 floods overtopped the levee, flooding the plant, and sending untreated sewage into the river and Narragansett Bay. The Warwick Sewer Authority then initiated a project to raise the levee from the 100-year level to the 500-year flood protection level by installing floodwalls to reinforce the existing 2,300-foot long, earthen levee. Construction began in 2014, however it halted when boulders were encountered within the earthen levee structure and the project was redesigned to raise the levee five and a half feet using more earth. This construction was completed in 2017.

Many of the process components on the WWTF site were installed at or below grade as necessary for gravity settling operations. The WWTF has an effluent pumping system that operates approximately four to six weeks per year and the entire facility became nonfunctional and inaccessible during the March 2010 flood event. The location of the facility and the geography of the surrounding land make it unlikely that this plant would be capable of continuous operation during a flood event even with resilient process components. The treatment facility maintains an abundance of back-up pumping and power generation equipment.

Warwick's Knight Street PS can function continuously when completely inundated by rising levels of the Pawtuxet River and remains accessible through a roof hatch. This pump station became inoperable during the March 2010 flood. East Natick 1 PS and East Natick 2 PS are suction-lift pump stations located adjacent to the river in areas prone to flooding. East Natick 1 PS has a permanent generator mounted at grade but the East Natick 2 PS relies on a back-up generator stored at the treatment facility. Alteri Way PS is a small submersible pump station with generator air intakes close to grade. Kilvert Street PS is also of concern.

Access to pump stations along the Pawtuxet River, including Knight Street, Irving Road, East Natick I (Riverdale), East Natick II (Ballfield) and Bellows Street was restricted during the March 2010 floods. Several of the newer pump stations were intentionally designed to be above the current 100-year flood elevation standards and the new Bellows Street pump station was recently constructed and elevated to protect it from the 500-year flood, however access would remain a problem during flood conditions. Additional flood hardening projects are in the planning stages and they include hardening at Oakland Beach, East Natick I (Riverdale) and Irving Road Pump Stations as well as elevating the roof at the Knight Street station to prevent water from the Pawtuxet River from entering through roof penetrations. Improving standby power capabilities is also a work in progress and replacing emergency generators at Oakland Beach and

Warwick Avenue pump stations is taking place. The WSA has purchased many new generators for pump stations where there were none and only nine pump stations are now without generators. The WSA has also purchased two additional portable emergency generators (>150 kW) units to support back up power capabilities and purchased portable air compressors for air lift stations at five of the nine remaining stations without backup power.

Operators reported that some of the major issues facing the Warwick WWTF and system components are aging infrastructure and the lack of capital and human resources to maintain and rehabilitate it properly. There are 80 miles of force main with older sections constructed of pre-stressed concrete cylinder pipe and the main 48-inch influent pipe that runs under I-95 was slip lined in 2015 to address signs of deterioration.

3.2.16.2 Modeling Results

The Warwick WWTF was assessed for risk from riverine hazards **(Figure 3-32: Warwick WWTF – Riverine Hazards)**, coastal flood hazards, and sea level rise **(Figure 3-33: Warwick WWTF – Coastal Hazards)**. The riverine flood hazard assessment predicted (and was confirmed in 2010) that the majority of the WWTF inundated at the 100-year flood level plus 2 feet and the 100-year flood level plus 3 feet. The coastal flood hazard assessment predicted that most of the facility processes would be inundated during a 100-year event with 5 feet of SLR. Assuming the levee around the facility was raised to the design elevation of 33.66 feet (NAVD88), it is likely that no part of the Warwick WWTF will be affected by the coastal or riverine hazards evaluated by this study.

The University of Rhode Island (URI) Pawtuxet River modeling team also prepared flood maps for the vicinity of the Warwick WWTF to reflect flood conditions after construction of the raised levee (**Figures 3-34 and 3-35)**. URI use historic data from the USGS Pawtuxet River water level gauge at Cranston to calibrate a precipitation-driven model used to develop water elevations and flood extent within the entire watershed. The results revealed that the 2010 flood elevation was equivalent to the 500 year modeled flood elevation as determined from extremal analysis of multiple events.

The East Natick Pump Station 1, East Natick Pump Station 2, Knight Street Pump Station, and Irving Road Pump Station are all predicted to be inundated by riverine flooding at the 100-year flood level plus 2 feet (which was confirmed in 2010). The Bellows Street Pump Station is predicted to be surrounded by floodwaters and inaccessible under riverine flooding conditions at the 100-year flood level plus 2 feet event and under coastal hazard conditions at the 100-year flood level. Neither Alteri Way or Kilvert Street pump stations are predicted to be inundated under the modeled conditions.

Data Correlation Notes

The flooding experienced during the March 2010 event corresponds to the statewide riverine hazard assessment. An aerial photograph of the Warwick WWTF taken during the March 2010 storm generally corresponds with the Riverine Hazards figure (**Figure 3-32**). Also, recorded flooding conditions at multiple pump stations correspond with the riverine hazard assessment. This correlation indicates that the riverine hazard assessment is a good predictive tool for flooding in future circumstances and in other locations

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Figure 3-32: Warwick WWTF – Riverine Hazards

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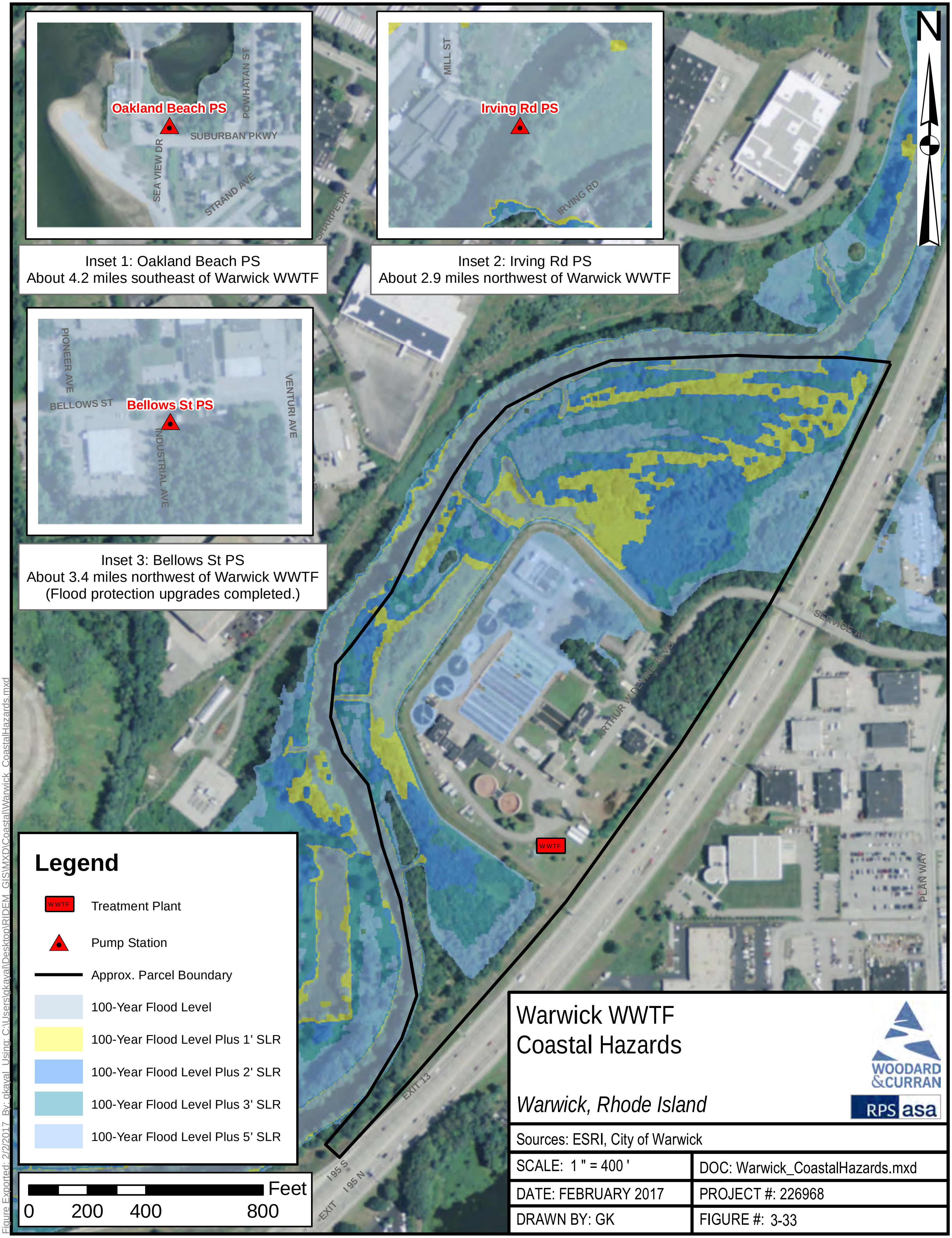
Figure 3-33: Warwick WWTF – Coastal Hazards



Oakland Beach PS
POWHATAN ST
SUBURBAN PKWY
SEA VIEW DR
STRAND AVE
Inset 1: Oakland Beach PS
About 4.2 miles southeast of Warwick WWTF
MILL ST
Irving Rd PS
IRVING RD
Inset 2: Irving Rd PS
About 2.9 miles northwest of Warwick WWTF
SHARPE DR
PIONEER AVE
BELLOWS ST
Bellows St PS
INDUSTRIAL AVE
VENTURI AVE
Inset 3: Bellows St PS
About 3.4 miles northwest of Warwick WWTF
(Flood protection upgrades completed.)
N
SERVICE AVE
ARTHUR W DEVINE BLVD
WWTF
PLAN WAY
EXIT 13
I 95 S
I 95 N
EXIT
Legend
WWTF Treatment Plant
Pump Station
Approx. Parcel Boundary
100-Year Flood Level
100-Year Flood Level Plus 1' SLR
100-Year Flood Level Plus 2' SLR
100-Year Flood Level Plus 3' SLR
100-Year Flood Level Plus 5' SLR
0 200 400 800 Feet
Warwick WWTF
Coastal Hazards
Warwick, Rhode Island
WOODARD &CURRAN
RPS asa
Sources: ESRI, City of Warwick
SCALE: 1 " = 400 '
DOC: Warwick_CoastalHazards.mxd
DATE: FEBRUARY 2017
PROJECT #: 226968
DRAWN BY: GK
FIGURE #: 3-33
Figure Exported: 2/2/2017 By: gkayal Using: C:\Users\gkayal\Desktop\RIDEM_GIS\MXD\Coastal\Warwick_CoastalHazards.mxd

Figure 3-34: Warwick WWTF – Raised Levee (100 Year Flood)


N
Warwick Sewer Authority:
Modeling of 100-year flood inundation in relation to the facility's new elevated berm design, which is currently under construction
0
0.05
0.1
0.2
Miles
Source: University of Rhode Island

Figure 3-35: Warwick WWTF – Raised Levee (500 Year Flood)

Warwick Sewer Authority:

Modeling of 500-year flood inundation in relation to the facility's new elevated berm design, which is currently under construction

3.2.17 West Warwick

The Town of West Warwick owns and operates the West Warwick Wastewater Treatment Facility located at 1 Pontiac Avenue, West Warwick and it discharges to the Pawtuxet River. The facility serves portions of the Towns of Coventry, Cranston, East Greenwich, Warwick and West Greenwich with an estimated 31,600 customers. West Warwick is landlocked with the only major surface water passing through it being the Pawtuxet River. The West Warwick WWTF resides in a small wetland on the bank of the Pawtuxet River and this location makes it exceptionally vulnerable to flooding during high river levels. The facility has a design capacity of 11 MGD with average flows of 5.2 MGD and a peak capacity of 25 MGD. The West Warwick WWTF includes process components constructed over 40 years prior to this assessment; however, the main treatment facility and the three largest pump stations received major upgrades following the storm events of March 2010. The facility operates a diverse treatment system including rotary drum screening, biological aerated filters (BAF), denitrifying filters (DNF), phosphorus removal, extensive odor control and effluent pumping. Representatives from the West Warwick WWTF provided additional information on January 9, 2017 that may warrant further evaluation by RIDEM.

West Warwick's Hazard Mitigation Plan (2017 expiration date) identifies the entire sewer system as critical facilities and vulnerable to natural hazards.

3.2.17.1 Operator Data

Numerous process components throughout the treatment facility were replaced following the flooding experienced in March 2010, however very few were able to incorporate flood mitigation efforts to protect the new equipment. According to the U.S. Fish & Wildlife Service National Wetlands Inventory, approximately two-thirds of the perimeter of the facility abuts wetlands of various classifications, potentially complicating site-wide flood mitigation efforts. The West Warwick Wastewater Treatment Facility is currently evaluating the containment around the entire treatment facility and also examining options to protect individual unit processes from catastrophic flooding similar to what occurred in 2010. Each of the unit processes and buildings have been designed to operate during the 25-year storm event and to protect all of the equipment during the 100-year flooding event (Elevation 38). The option to pump wastewater to Cranston was evaluated in the 1980 and 1987 Facilities Plans and dismissed in favor of implementing the upgrades described above.

There are numerous atypical chemicals stored on site that could be subject to flotation or inaccessibility during a flood event. These include methanol for carbon addition, various polymers, and sodium hypochlorite and potassium permanganate for odor control. During the assessment, expansion of the facility was completed to incorporate phosphorus removal into the treatment processes which requires the use of Alum. Additionally, new solids handling equipment, including thickeners and centrifuges, was integrated into the process during this assessment.

The WWTF resides low in the wetlands adjacent to the river, with the site's access road sitting slightly higher along the wetland perimeter. The only treatment systems elevated substantially above grade are the BAF/DNF systems. The facility was designed to meet the 100-year storm event. It was protected from the initial March 15, 2010 storm event but the generator and blower systems were inundated during the subsequent March 30, 2010 storm. Replacements were made with like equipment. The generator was raised, however code requirements prohibited elevating other equipment such that most were reinstalled in the same location. Although the primary and secondary clarifier systems are elevated, the below grade pumps and associated electrical systems are vulnerable to flooding.

The facility receives wastewater from several vulnerable pump stations of various sizes, designs and flows. Clyde PS is adjacent to the Pawtuxet River with the generator louver close to grade. Flood waters were observed flowing into Clyde PS through the generator louver during previous flood events, but the station maintained functionality. Maisie Quinn PS and Brookfield Hills PS share similar levels of vulnerability due to their vicinity to surface waters, but their elevations may provide protection from flooding. Operators noted that the March 2010 flood waters approached, but did not inundate, the Brookfield Hills PS. Residences adjacent to the Brookfield Hills PS have been protected with earthen berms since that event.

3.2.17.2 Modeling Results

The West Warwick WWTF was assessed for risk to riverine hazards **(Figure 3-36)**. The riverine flood hazard assessment predicted that the vast majority of the WWTF would be inundated at the 100-year flood level plus 2 feet. The water depth just south of the solids processing building would be approximately 4.6 feet under this scenario. The Clyde Pump Station would also be inundated at the 100-year flood level plus 2 feet. The Maisie Quinn Pump Station would be inundated at the 100-year flood level plus 3 feet but the Brookfield Hills Pump Station would not.

3.2.17.3 Data Correlation Notes

The flooding experienced during the March 2010 event corresponds to the statewide riverine hazard assessment. An aerial photograph of the West Warwick WWTF taken during the March 2010 storms generally corresponds with the Riverine Hazards figure (**Figure 3-36**). Recorded flooding conditions at the Clyde PS corresponds with the riverine hazard assessment. The riverine hazard assessment also appears consistent with the operators' comments regarding the vulnerability of the Maisie Quinn PS. This correlation indicates that the riverine hazard assessment is a good predictive tool for flooding in future circumstances and in other locations, although the reported flooding in the area around Brookfield Hills PS appears to be caused by a localized source that was not captured in the riverine hazard assessment.

Figure 3-36: West Warwick – Riverine Hazards

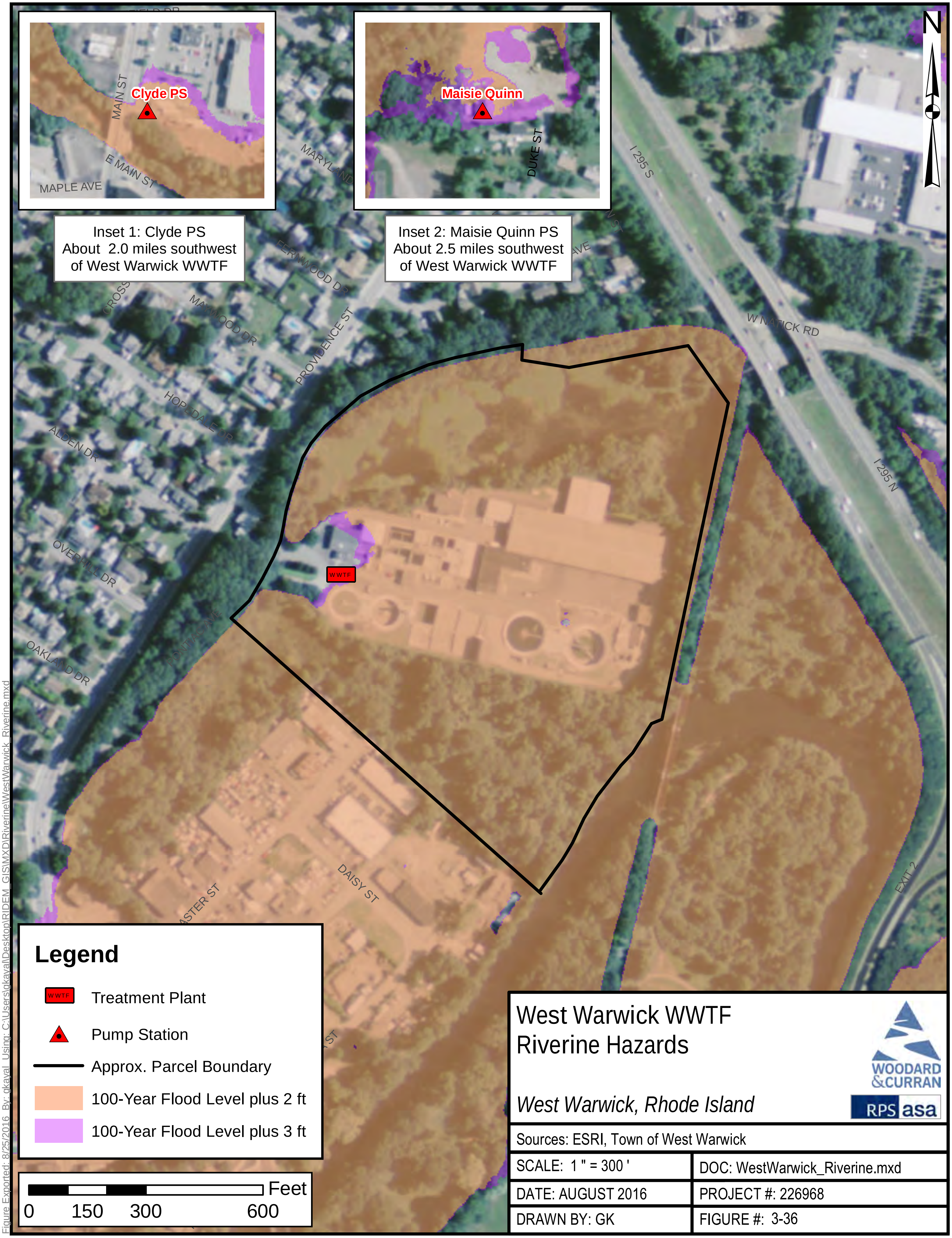


Figure Exported: 8/25/2016 By: gkaval Using: C:\Users\gkaval\Desktop\RIDEM_GIS\MXD\Riverine\WestWarwick_Riverine.mxd

3.2.18 Westerly

The Town of Westerly owns the Westerly Wastewater Treatment Facility located at 87 Margin Street in Westerly. Westerly is a community situated in the southwestern most corner of Rhode Island on Block Island Sound. The facility and pump stations are operated by Suez and they serve the Town of Westerly (US Census 2010 population of 22,787) with an estimated 16,500 customers. The Westerly WWTF is adjacent to and discharges to the tidally influenced Pawcatuck River. The facility operates typical treatment processes with a design capacity of 3.5 MGD and average flows of 2.5 MGD. The treatment facility has experienced atypical drops in influent flow rates caused by the loss of industrial influent sources. The wastewater treatment plant was built in 1920 and was modified and upgraded in the late 1950's, 1979, 1986 and 1992. There was also a major upgrade in 2003 for biological nutrient removal and replacement of 1970s era equipment. The remote pump stations range in age from 4 years to over 40 years old. There are nine active wastewater pumping stations in the town. All four major sewer pump stations have been rebuilt since 2003 and they are located at Beach Street, Margin Street, Old Canal and New Canal Streets.

Westerly's Hazard Mitigation Plan (2017 expiration date) notes that the WWTF is a critical facility in the community and that it has auxiliary power generation as do most of the sewer system's pump stations.

3.2.18.1 Operator Data

The primary clarifiers, aeration tanks, secondary clarifiers and disinfection system have tank walls close to grade, potentially exposing them to floodwater inflow. Additionally, the facility's influent pump station is under capacity and back-up power generation systems are aged.

New Canal PS and Old Canal PS are located adjacent to the Pawcatuck River and they were substantially impacted by the March 2010 storm event. New generators were installed outside each of these pump stations and the low-elevation exterior building penetrations were sealed following this incident. Beach Street Pump Station resides adjacent to a river and despite being elevated, the pump station also flooded during the March 2010 storm, but the generator continued to operate. Margin Street PS resides adjacent to a river, and this pump station creates an unusual potential problem by having a pumping capacity greater than the capacity of the treatment facility's headworks. If all three pumps at the pump station are operating simultaneously, the grit chamber at the WWTF will overflow causing an SSO event.

3.2.18.2 Modeling Results

The Westerly WWTF was assessed for risk to coastal flood hazards, sea level rise and wave hazards. The coastal erosion rate was not assessed because historic shoreline changes have not been recorded in the area of the WWTF. **Figure 3-37** depicts the extent of inundation caused by the 100-year storm event with 0-, 1-, 2-, 3-, and 5-feet of SLR and the location of the four transects along which wave models were developed.

The coastal flood hazard assessment predicted that the treatment facility would not be inundated by storm surge at the 100-year return period. With the addition of 3 and 5 feet of SLR, the extent of flooding during a 100-year storm would reach the secondary clarifiers, chlorine contacts tank and operations building. The assessment did predict that the New Canal, Old Canal, Margin Street, and Beach Street Pump Stations would be inundated by storm surge at the 100-year return period (Beach Street with 2 feet of SLR) **(see Figure 3-37)**. The average water depth approaching the Beach Street pump station for a 100-year storm event would range from 2-6 feet. The average water depth associated with the New and Old Canal Pump Stations would range between 1-3 feet.

A wave analysis was conducted at four transects through the Westerly facility as shown in **Figure 3-38**, **Figure 3-39**, **Figure 3-40** and **Figure 3-41**. The analysis predicted that at **Transect 1**, the significant wave height for a 100-year storm would be approximately 5 feet as it approached the shore and then would drop off to 1-2 feet 125 feet inland and then disperse completely around 250 feet inland. With 5 feet of SLR, the significant wave height would start at 5 feet and then drop to 4 feet approximately 125 feet inland and stay at that height until the 250-foot mark where it would again drop slightly to 3 feet. Waves along **Transect 2** would be less severe because of the higher ground elevation in this area. Here, the significant wave height would start at 5 feet and drop quickly to under 1 foot 50 feet inland. With 5 feet of SLR, the wave height would start at 5 feet and drop to 3 feet at approximately 50 feet inland and stay at that level until 300 feet from shore. For **Transect 3**, the analysis predicted that the significant wave height would be 5 feet at the shore and drop quickly to 3 feet until 300 feet from shore. With 5 feet of SLR, wave heights would start at 5 feet and stay at that level until 250 feet from shore where they would drop to 1 foot. **Transect 4** shows an approximate wave height of 4 feet at the shore with a drop to 2 feet 50 feet inland from the shoreline where the wave height would stay until 450 feet. With 5 feet of SLR, the wave height would start at approximately 5 feet and stay at that level until 400 feet from shore where it would quickly decline to less than a foot.

3.2.18.3 Data Correlation Notes

Some of Westerly's pump stations are subject to inundation from both coastal and riverine flooding. The methodology used for the riverine hazard assessment, however, cannot be applied to areas within FEMA designated coastal AE zones because the source of flooding is a coastal surge rather than precipitation events. Therefore, the three pump stations that are in the coastal AE zone were inundated by the March 2010 storms but the riverine assessment mapping cannot reflect that condition. Additional evaluation of the areas subject to both coastal and riverine flooding should be considered to better understand the potential for damage from riverine flooding.

Figure 3-37: Westerly WWTF – Coastal and Riverine Hazards

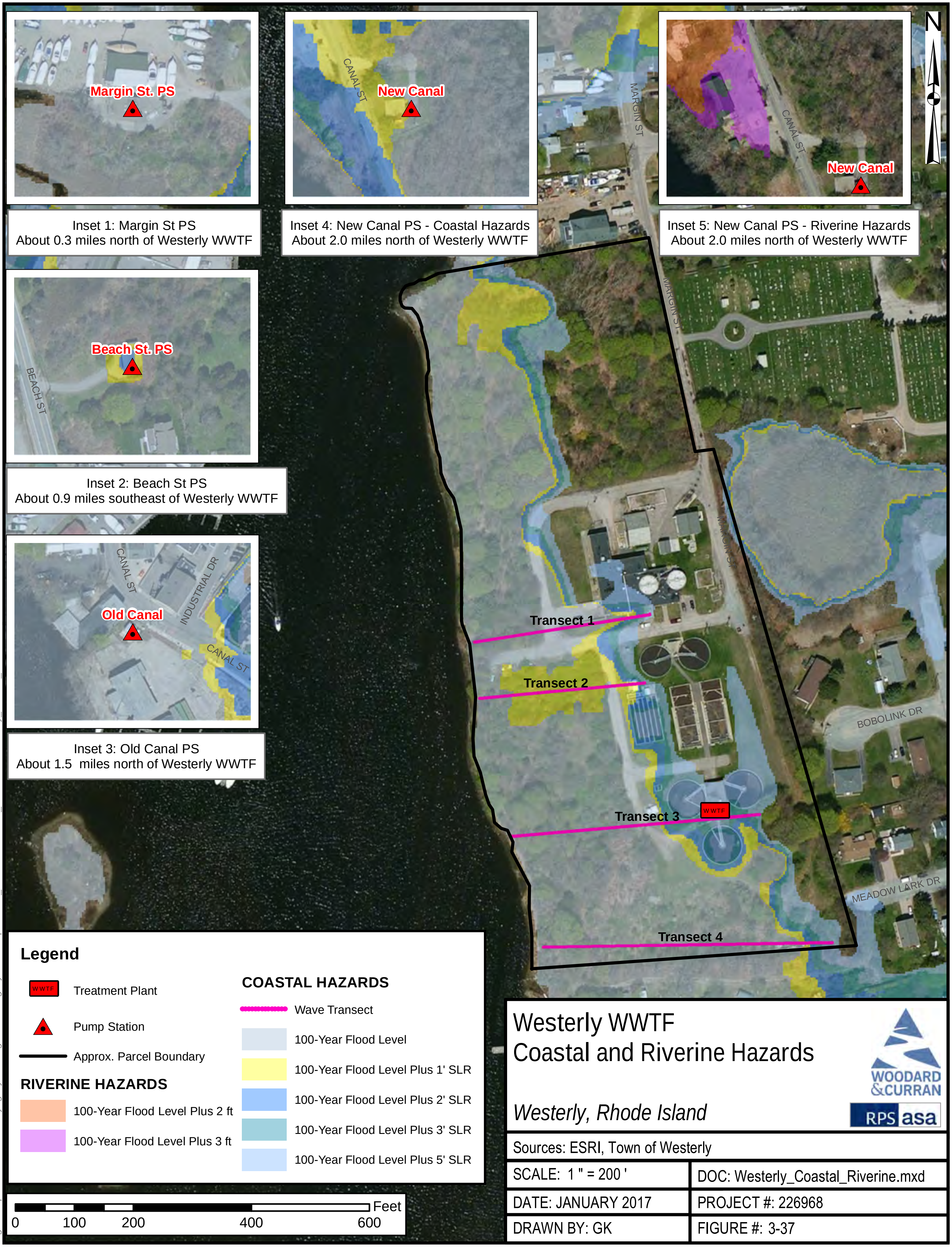
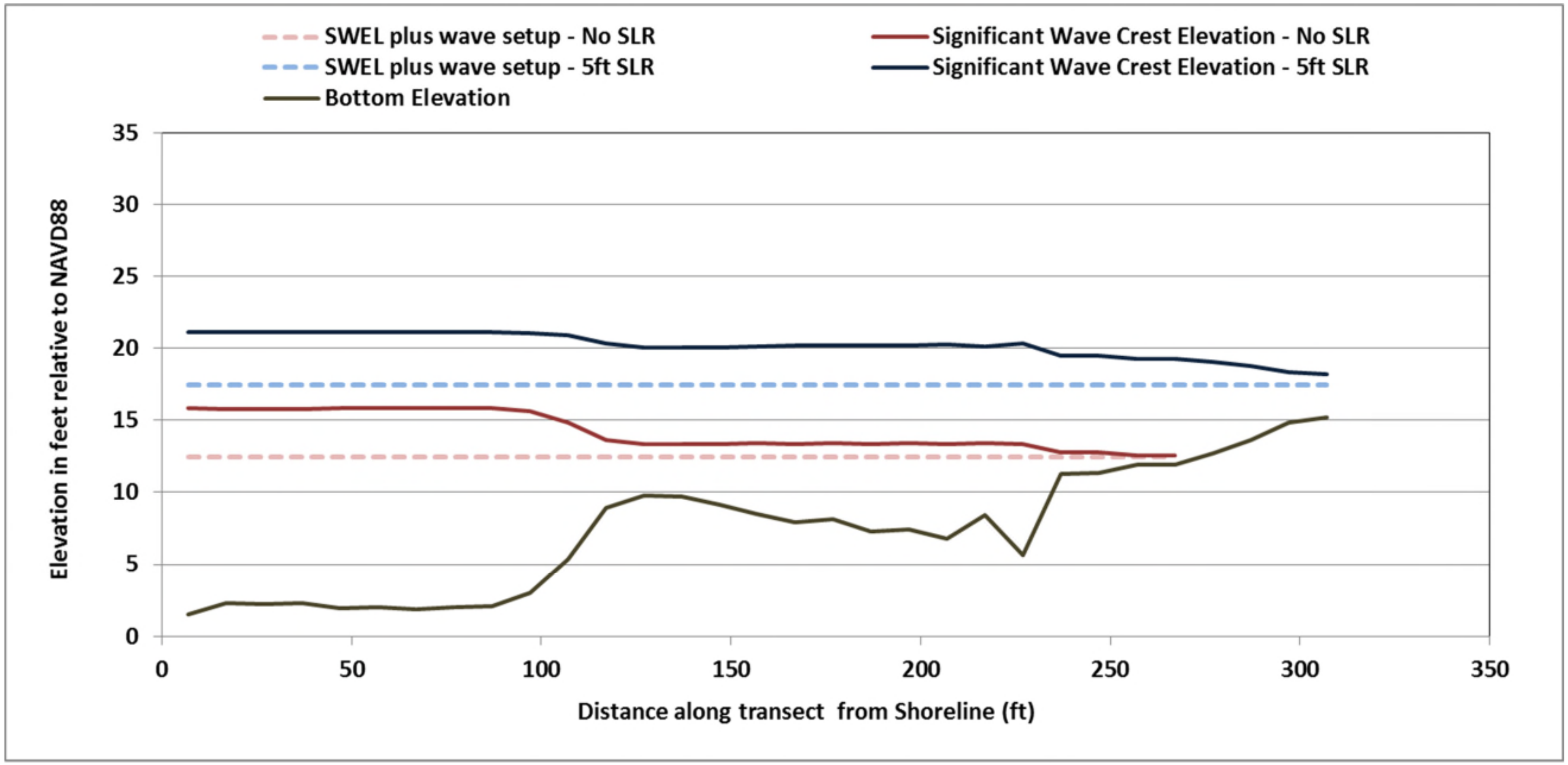


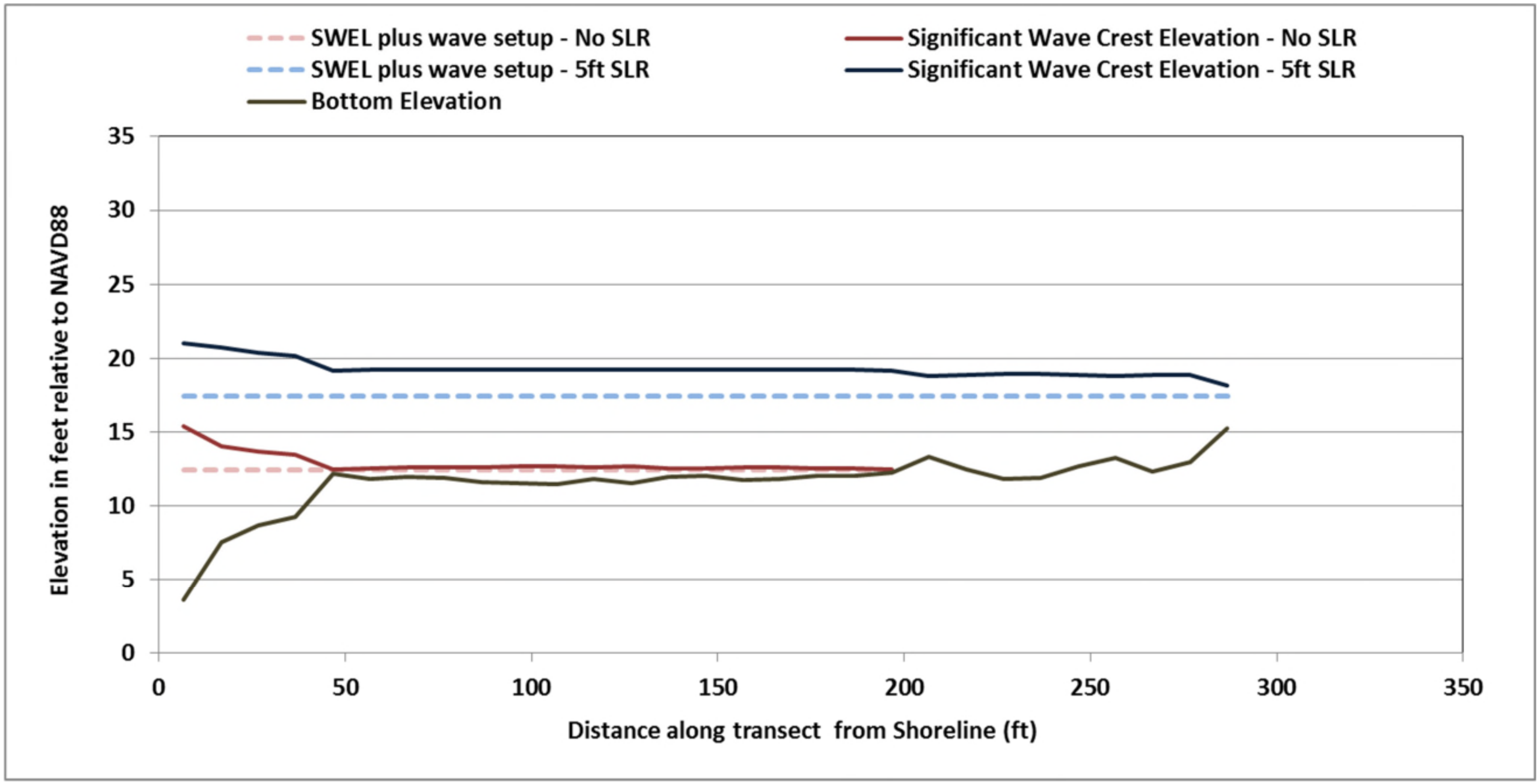
Figure Exported: 1/18/2017 By: gkayal Using: C:\Users\gkayal\Desktop\RIDEM_GIS\MXD\Coastal_RiverinePS\Westerly_Coastal_Riverine.mxd

Figure 3-38: Westerly Transect 1 - Wave Analysis (Elevation vs. Distance)



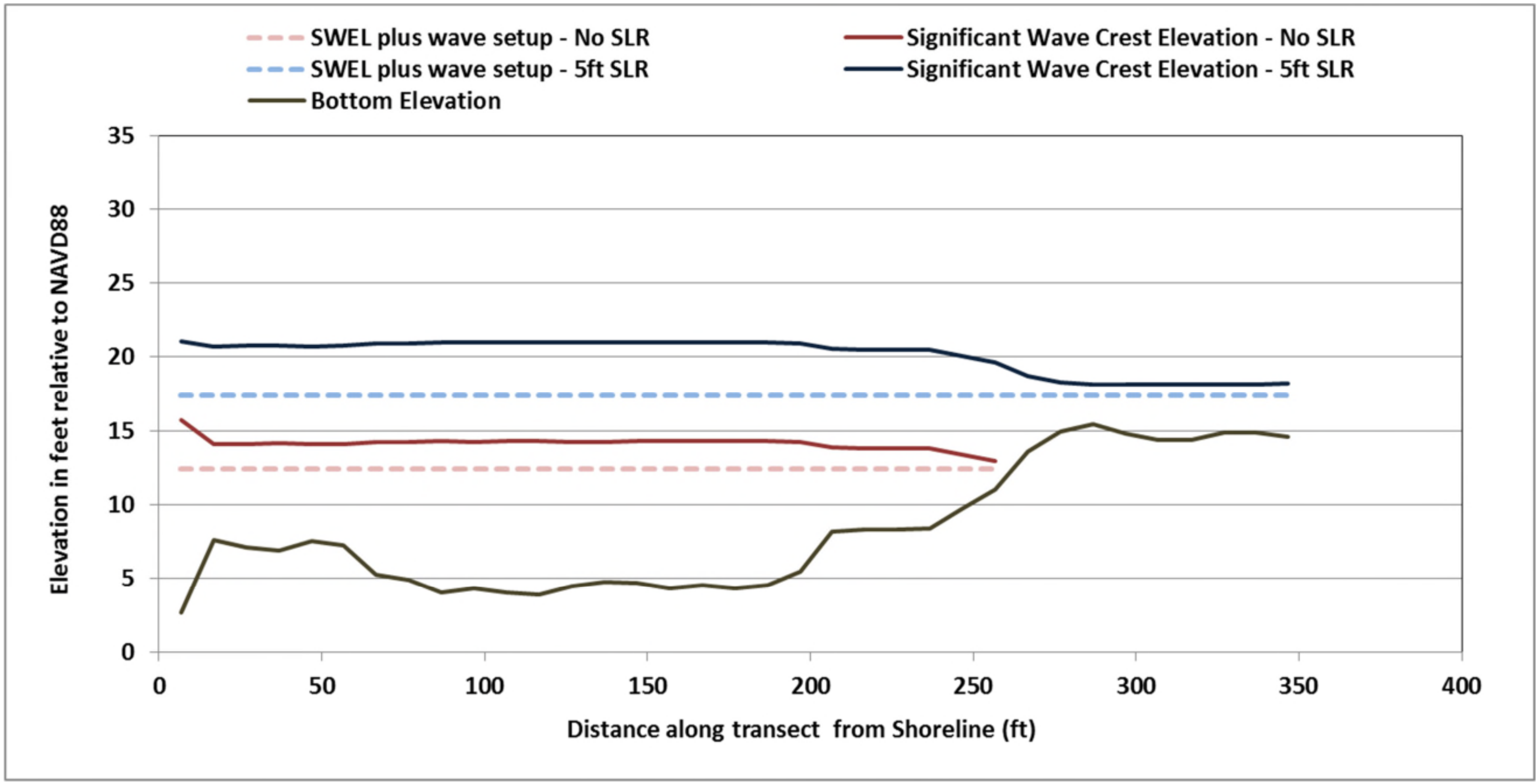
Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

Figure 3-39: Westerly Transect 2 - Wave Analysis (Elevation vs. Distance)



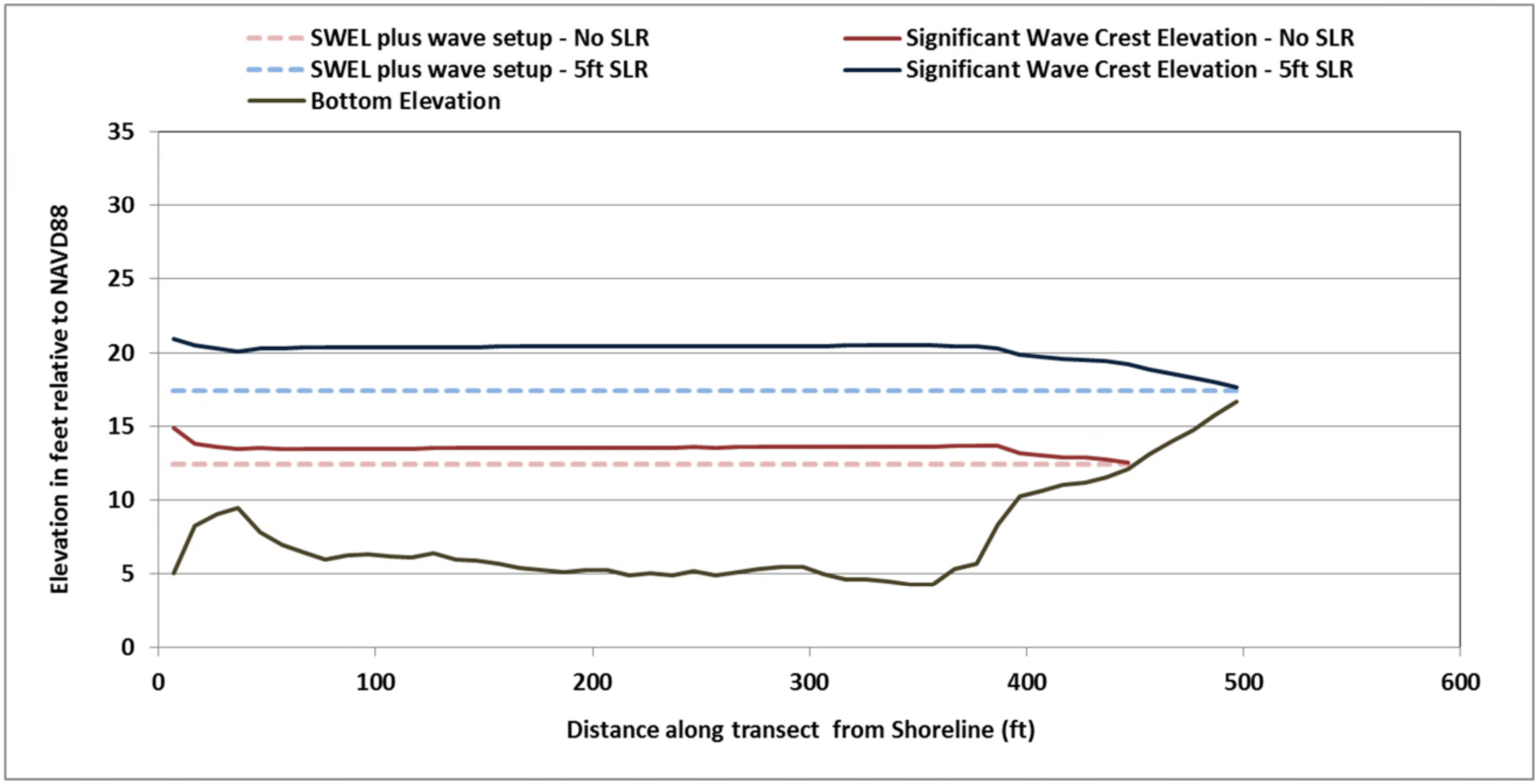
Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

Figure 3-40: Westerly Transect 3 - Wave Analysis (Elevation vs. Distance)



Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

Figure 3-41: Westerly Transect 4 - Wave Analysis (Elevation vs. Distance)



Note the Bottom Elevation has been edited to remove above ground infrastructure and vegetation to correctly represent the wave analysis, which is based on "bare earth" elevations.

3.2.19 Woonsocket

The City of Woonsocket owns the Woonsocket WWTF located at 11 Cumberland Hill Road in Woonsocket. The facility is operated by CH2M Hill and it discharges to the Blackstone River. Woonsocket is a developed community located on the northern border of the state with residential, commercial and industrial wastewater sources. The facility serves the towns of North Smithfield and Woonsocket, RI, and Bellingham and Blackstone, MA (US Census 2010 combined population of over 65,000) and an estimated 51,400 customers. The treatment facility was originally constructed in 1930 but recently received significant upgrades in 2000 and additional upgrades are on-going with an estimated completion date of July 2016. The facility has a design capacity of 16.0 MGD with average flows of 9.3 MGD. The system includes a robust array of treatment processes which is planned to be expanded further with an exceptional level of control to maximize nutrient removal. The site is shared with an incinerator system operated by Synagro which uses approximately 3 MGD of recovered wastewater flow for incinerator use. Woonsocket has an approved Hazard Mitigation Plan that expires in 2017.

3.2.19.1 Operator Data

The facility operators reported unusual spikes in influent flow indicating serious inflow and infiltration issues. When the river level reaches approximately 4.5' (unknown datum) the flows into the treatment facility begin to increase exponentially. The facility Emergency Response Plan specifically notes that there is an immediate increase in flow when a steady rain is present and inflow is a possibility from street flooding and the submergence of manholes and pump station wet wells. Planned treatment process expansion will include larger aeration tanks with anoxic zones and various types of chemical addition in anticipation of phosphorus and nitrogen discharge limits being reduced by a factor of 10. A critical system within the process will include axial pumping to convey primary effluent to the expanded aeration tanks.

Additional recent and on-going upgrades include electrical system improvements and increased electrical system resiliency. The entire facility will be re-wired with redundant power distribution systems, and the two existing 500kW generators will be abandoned in place with the installation a new 2500kW generator to be installed in a standalone building approximately 4 feet above grade.

The WWTF is partially located within low-lying flood-vulnerable areas, predominantly encompassing secondary clarification, disinfection and incineration. Secondary treatment systems exhibit some signs of vulnerability with pumping equipment and controls located below grade as is typical; however, the entryways to these facilities are slightly above grade. Site facilities include buildings that were up to 120 years old at the time of the assessment, some of which are still in use.

Operators reported that during the March 2010 statewide flooding, there were numerous SSOs throughout the collection system. In addition, several of the process buildings at the WWTF became flooded which caused some of the major process equipment units to become inoperable. The flows were so high that water backed up into the plant drain system and entered through floor drains which left several feet of water in the basements. A number of pumps and blowers were inundated with water and had to be sent out for repair. As a result, mechanical plugs are planned to be temporarily installed in the drains prior to water levels becoming that high so as to prevent future reoccurrences.

The facility is supported by numerous pump stations however few exhibited serious signs of vulnerability. Privilege Street PS resides adjacent to a pond with dry-pit pumps. Similarly, Manville Road PS and Diamond Hill Road PS reside in the vicinity of a pond but are outside of established flood zones and operate on dry-pit submersible pumps.

3.2.19.2 Modeling Results

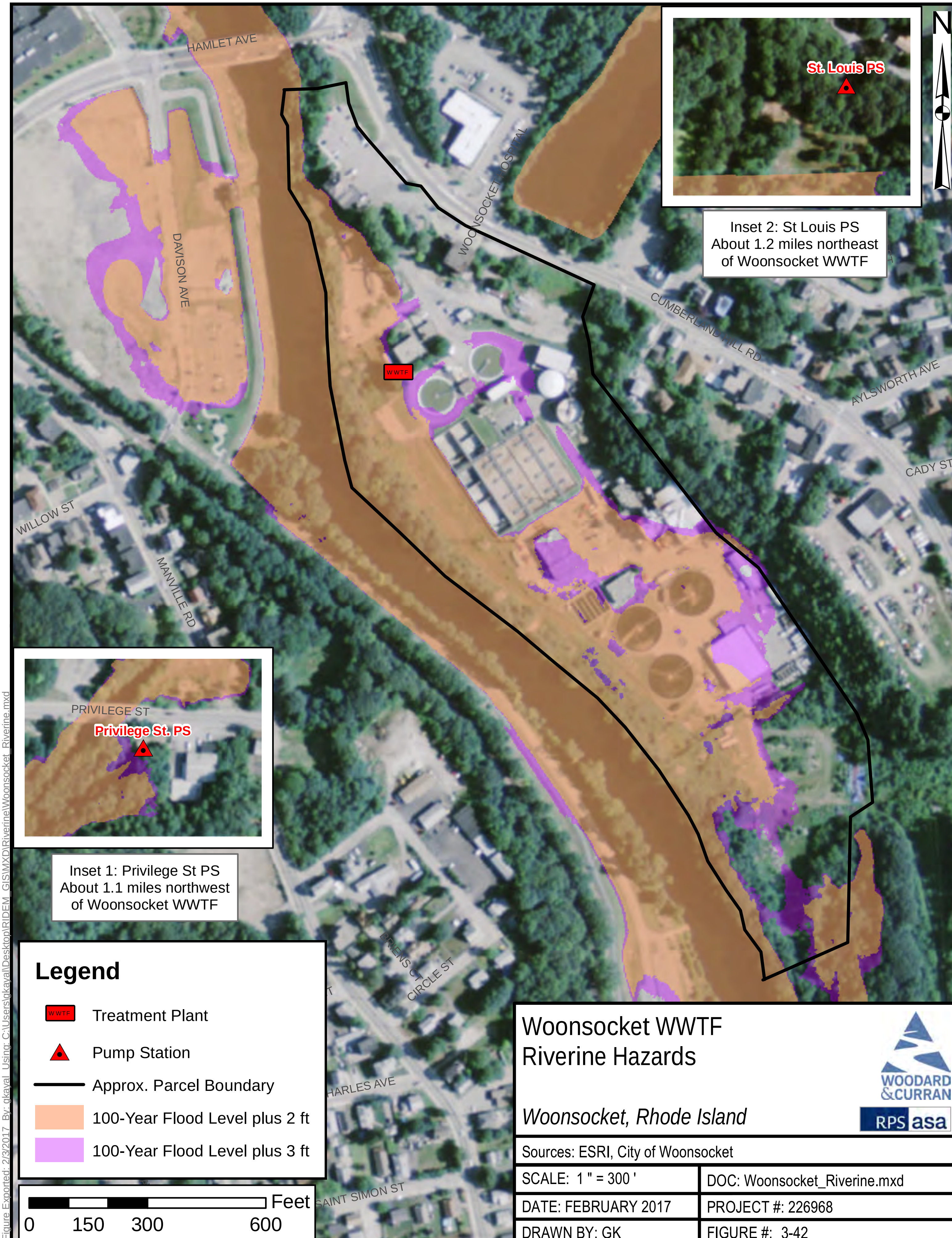
The Woonsocket WWTF was assessed for risk to riverine hazards **(Figure 3-42)**. The riverine flood hazard assessment predicted that a significant portion of the WWTF would be inundated at the 100-year flood level plus 2 feet and even more of the facility at the 100-year flood level plus 3 feet. Components of the Woonsocket WWTF that would be impacted during the 100-year flood level plus 2 feet include the secondary clarifiers, the effluent filter building, the chlorine contact tanks, and the incinerator. The flood depth in the roadway between the secondary clarifiers and the effluent filter building would be approximately 10 inches under this scenario. Buildings affected at the 100-year flood level plus 3 feet event include the chlorination building, the chemical feed building, the sludge dewatering building, the return sludge pump station, and Synagro's truck maintenance building.

The Privilege Street Pump Station would be inundated at the 100-year flood level plus 3 feet. The St. Louis Pump Station located in Massachusetts would also be inundated at the 100-year flood level plus 2 feet however, **Figure 3-42** does not show the inundation in this vicinity because the DFIRM database does not extend into Massachusetts.

3.2.19.3 Data Correlation Notes

The riverine hazard assessment corresponds with the operators' concerns with the secondary treatment systems and reports of flooding in the March 2010 storm event caused by the backups in the plant drain system. The riverine hazard assessment also supports operators' comments regarding the proximity of some pump stations to ponds but none that had experienced flooding. This correlation indicates that the riverine hazard assessment is a good predictive tool for flooding in future circumstances and in other locations.

Figure 3-42: Woonsocket WWTF – Riverine Hazards



Legend

- WWTF Treatment Plant
- Pump Station
- Approx. Parcel Boundary
- 100-Year Flood Level plus 2 ft
- 100-Year Flood Level plus 3 ft

Woonsocket WWTF
Riverine Hazards

Woonsocket, Rhode Island

WOODARD & CURRAN RPS asa

Sources: ESRI, City of Woonsocket	
SCALE: 1 " = 300 '	DOC: Woonsocket_Riverine.mxd
DATE: FEBRUARY 2017	PROJECT #: 226968
DRAWN BY: GK	FIGURE #: 3-42

Figure Exported: 2/3/2017 By: gkayal Using: C:\Users\gkayal\Desktop\RIDEM_GIS\MXD\Riverine\Woonsocket_Riverine.mxd

4. WASTEWATER TREATMENT FACILITY RISK ASSESSMENT

Communications with the Rhode Island WWTF operators confirmed the predominant risks of concern caused by climate change are flood related. The modeling results described in Section 3 assessed potential impacts under various flood conditions. Several facilities were predicted to become predominantly inundated under the scenarios evaluated; potentially causing all or part of the facility to fail. Even facilities with a low risk of failure by inundation from the events modeled in this study could experience localized site flooding or other hazard situations that could partially or fully disable the plant. It is therefore important to prioritize systems for repair so that the most critical systems are returned to service as soon as possible. **Table 4-1** establishes the criteria for the overall repair priorities in order of importance.

Table 4-1: Wastewater System Repair Priorities

Ranking	Description
1	Collection and pumping of major flows
2	Disinfection
3	Collection and pumping of secondary flows
4	Primary treatment
5	Non-critical system components: Preliminary/secondary/advanced treatment, solids handling

Professional judgement was used to distinguish between major and secondary flows (ranking numbers 1 and 3) for the purposes of prioritizing repairs. In general, pump stations that comprised 10% or more of a plant's influent flow were prioritized as a "1". However, some exceptions were made to further prioritize when more than three pump stations fell within the major flow category. For example, four pump stations qualified as a "1" in Cranston, so the lowest flow of the four (Burnham at 16% of design flow) was dropped to a "3". Where in Westerly the 2nd, 3rd, and 4th largest pump stations had nearly identical flow rates, it was appropriate to rank them all as "1" since most or all of the plant flow comes from pump stations.

Further judgements were made depending upon whether actual flows were provided. If so, the base the flow assessment was made on Average Daily Flow. If only design flows were available, the total pump station design capacity versus the plant capacity was taken into consideration. For example, Smithfield has a plant capacity of 3.5 MGD, but the total design flow of the pump stations was closer to 9 MGD. Therefore, comparing individual pump station capacity to the overall total capacity was considered most reasonable.

For pump stations on the threshold (10-12% of plant capacity), the source of flow to the plant (gravity versus pump stations) was also taken into consideration to distinguish major from secondary flows. Where the majority of the flows enter the treatment facility by gravity, then pump stations as a whole would be a lower priority. Where pump stations were prioritized over treatment processes but much of the flow to the facility came by gravity, then a lot of wastewater would be discharged without treatment during a catastrophic event. For pump stations currently experiencing low average flows, but appeared to be designed to take on much larger flows in the near future (e.g., Maisie Quinn in West Warwick), then the evaluation was based on the future design flows.

The systems within each of the 19 WWTFs assessed in this study were assigned a ranking according to the **Table 4-1** description. The resulting rankings are presented in **Tables 4-2 through 4-20**.

Table 4-2: Bristol System Priorities

Priority	System	Comments
1	Main Lift (Influent Screw Pumps)	Low-point on site. Flood wall in control room protects electrical equipment.
5	Preliminary Treatment (Grit Removal and Screening)	Mechanical equipment mounted above grade and within elevated concrete process tanks/channels. Main electrical control equipment located in detached enclosure on an equipment pad at grade.
4	Primary Clarifiers (Rectangular)	Tank walls close to grade. Facility access at grade; pumps will cease to function if inundated.
5	Rotating Biological Contactors	Systems partially below grade. Drive units close to floor. New RBCs raised drive motors.
5	Secondary Clarifiers	Tank walls close to grade. Mechanical equipment above tank walls. Pumps will cease to function if inundated.
5	Gravity Thickener	Tank walls close to grade.
5	Primary / Blended Sludge Storage Tanks	Facility access at grade. Pumps will cease to function if inundated.
5	Solids Handling (Dewatering)	Facility access at grade. Mechanical equipment low.
2	Disinfection System (Chlorine Contact Tanks)	Facility access at grade. Mechanical equipment low.
1	Operations Building / Generator	Facility access at grade. Generator at grade.
PUMP STATIONS		
3	Ferry Road PS	Pump controls will cease to function if inundated.
3	Peter Road PS	Pump controls will cease to function if inundated.
3	Brook Farm PS	Pump controls will cease to function if inundated.
1	Broadcommon PS	Pump controls will cease to function if inundated.
1	Constitution PS	Pump controls and generator will cease to function if inundated.

Table 4-3: Bucklin Point System Priorities

Priority	System	Comments
1	Influent Pump Station (Screw Pumps)	Screw pump drive motors elevated.
5	Preliminary Treatment (Bar Screen / Vortex Grit Removal)	Highest elevated treatment system.
4	Primary Clarifiers	Mechanical systems elevated above tank walls.
5	Aeration Tanks	High risk of flooding; equipment operated remotely.
5	Secondary Clarifiers	Mechanical systems elevated above tank walls.
1	Generator	Installed at highest point on site.
5	Solids Handling / Equipment Storage	Building entrances slightly elevated above grade.
5	Digesters	Low-risk of flooding.
5	Sludge/Filtrate Holding Tanks	Low-risk of flooding.
5	Wet weather Holding Tank	Benefits of these tanks will be negated if inundated.
2	Disinfection Systems	Tanks will remain undamaged by inundation. Disinfection may cease to function if flooded.
1	Effluent Pump Station	Pumps installed at low point; equipment powered remotely.
5	Maintenance Building	No critical assets in maintenance building.
5	Operations Buildings	No critical assets in maintenance building.
PUMP STATIONS		
3	Saylesville PS	Pump controls and generator will cease to function if inundated.

Table 4-4: Burrillville System Priorities

Priority	System	Comments
1	Influent Pump Station / Preliminary Treatment	High point on site. Tank walls above grade.
4	Primary Clarifiers	Tank walls elevated above grade. Mechanical systems above tank walls.
4	Primary/Secondary Sludge Pumping	Facility entrances elevated above grade. Pumps will cease to function if submerged.
5	Aeration Tanks	Tank walls elevated above grade. Mechanical systems above tank walls.
5	Secondary Clarifiers	Tank walls elevated above grade. Mechanical systems above tank walls.
5	Advanced Treatment (Phosphorus)	Facility at low elevation.
2	Chlorine Contact Tanks/Disinfection System	Low point on site.
5	Sludge Holding Tank	Pumps will cease to function if inundated.
5	Operations / Chemical / Generator Building	Facility access at grade.
PUMP STATIONS		
3	Beach Road ES	Ejection systems will cease to function if inundated.
3	Rock Avenue ES	Ejection systems will cease to function if inundated.
1	School Street (Callahan) ES	Ejection systems and generator will cease to function if inundated.

Table 4-5: Cranston System Priorities

Priority	System	Comments
1	Influent Pump Station (Screw Pumps) / Preliminary Treatment (Screening / Grit Removal)	Highest point on site. Drive system elevated above grade.
4	Primary Clarifiers	High point on site. Drive systems elevated above tank walls.
5	Aeration Tanks	Equipment access elevated above grade; blowers will cease to function if inundated.
5	Secondary Clarifiers	Drive systems elevated above tank walls.
5	Tertiary Treatment (Phosphorus Removal)	Non-critical asset.
2	Disinfection System (Chlorine Contact Tanks)	Disinfection system at risk; tank functionality will be impacted by inundation.
5	Gravity Thickener / Sludge Storage Tanks	Mechanical equipment at grade.
5	Solids Handling	Systems at grade.
1	Generator	Multiple on site. Largest at high point.
5	Administration Building	High point on site.
PUMP STATIONS		
1	Pontiac Ave PS	Pump motors, controls and generator will cease to function if inundated.
3	Burnham Ave PS	Pump motors, controls and generator will cease to function if inundated.
3	Allard PS	Pump motors, controls and generator will cease to function if inundated.
1	Mayflower PS	Pump motors, controls and generator will cease to function if inundated.
1	Randall PS	Pump motors, controls and generator will cease to function if inundated.
3	Seaview PS	Pump motors, controls and generator will cease to function if inundated.
3	Worthington PS	Pump motors, controls and generator will cease to function if inundated.
3	Youlden PS	Pump motors, controls and generator will cease to function if inundated.

Table 4-6: East Greenwich System Priorities

Priority	System	Comments
1	Influent Pump Station (Dry-Pit Submersibles)	Electrical systems at grade; pumps are dry-pit submersibles.
5	Preliminary Treatment (Screening)	Highest point on site.
4	Primary Clarifiers	Mechanical systems elevated above tank walls.
5	Rotating Biological Contactors	Mechanical equipment operated at high elevation in building.
5	Secondary Clarifiers	Mechanical equipment elevated above tanks.
5	Biological Aerated Filters (BAF) / Denitrifying Filters (DNF)	Mechanical equipment will fail if inundated.
5	BAF/DNF Chemical Storage ($MgOH_2$, Methanol)	Mechanical equipment will fail if inundated.
2	Disinfection System (UV)	System will not function properly if inundated, electrical systems may fail if inundated.
5	Gravity Thickener	Sludge pumps will cease to function if flooded.
1	Generator	Elevated in operations building.
5	Operations Building	Location of all major secondary treatment components and solids handling.
PUMP STATIONS		
3	Cedar Heights PS	Pump controls and generator will cease to function if inundated.

Table 4-7: East Providence System Priorities

Priority	System	Comments
5	Preliminary Treatment (Screening / Grit Removal)	Highest point on site.
4	Primary Clarifiers (Rectangular)	Mechanical equipment elevated above tank walls. Sludge pumps may cease to function if flooded.
5	Circular Aeration Tanks	Tanks elevated, but mechanical systems at grade. Building must be allowed to flood to prevent structural failure potential.
5	Secondary Clarifiers	Tanks and mechanical systems elevated, but electrical and pumping systems at grade. Building must be allowed to flood to prevent structural failure potential.
2	Disinfection System (Chlorine Contact Tanks)	Tanks elevated and will remain undamaged by inundation. Disinfection system may cease to function if flooded.
5	Sludge Storage Tanks	Mechanical equipment above grade. Building must be allowed to flood to prevent structural failure potential.
5	Decant Holding Tank	Low risk of flooding.
3	Generators	Multiple generators on site elevated above grade.
5	Operations Building	Flooding may impact solids handling operations.
5	Administration Building	No critical assets in the Administration Building.
PUMP STATIONS		
3	Sabin Point PS	Pump controls and generator will cease to function if inundated.
3	Bullocks Point Avenue PS	Pump controls and generator will cease to function if inundated.
3	Merritt Road PS	Pump motors and generator will cease to function if inundated.
1	Silver Street PS	Pump motors and generator will cease to function if inundated. UST vulnerable to leakage and buoyancy damage.

Table 4-8: Fields Point System Priorities

Priority	System	Comments
1	Influent Pump Station (Ernest Street PS)	Primary source of influent flow. Pump motors and electrical system below grade; will cease to function if inundated.
5	Preliminary Treatment (Screening)	Drive system will cease to function if inundated.
5	"Deep Rock Tunnel" System	Benefits of this system may be negated if inundated by surface-water sources.
5	Wet-weather Tanks	Benefits of this system may be negated if inundated.
5	Preliminary Treatment (Grit Removal)	System below grade; will cease to function if inundated.
4	Primary Clarifiers	Mechanical systems elevated above tank walls but pumps below grade; will cease to function if electrical system at grade inundated.
5	Fine Screening	System may cease to function if electrical inundated, however, impact of short-duration failure may be negligible.
5	Intermediate Pump Station (Screw Pumps)	Drive motors elevated, but electrical supply at grade.
5	Aeration Tanks / Integrated Fixed-Film Activated Sludge Reactors	Blowers and mixers will cease to function if electrical inundated.
5	Secondary Clarifiers	Mechanical systems elevated above tank walls. Pumps will cease to function if control system inundated.
2	Disinfection System (Chlorine Contact Tanks)	Disinfection system is at grade and will cease to function if inundated.
5	Gravity Thickeners	Pumps will cease to function if control system inundated.
5	Solids Handling (Gravity Belt Thickener and Belt Press)	Systems will cease to function if electrical is inundated.
1	Generators	Generators are distributed through-out site for various systems.
5	Chemical Storage (Tank Farm)	Tanks mounted in containment at grade posing a flotation risk.
5	Operations Building	Entrances to Operations Building elevated.
5	Maintenance Building	Few critical assets in the Maintenance Building.
PUMP STATIONS		
3	Central Avenue PS	Pump controls and generator will cease to function if inundated.
3	Washington Park PS	Pump controls and generator will cease to function if inundated.

Table 4-9: Jamestown System Priorities

Priority	System	Comments
5	Preliminary Treatment (Screening)	High point on site. Bar rack will not be damaged by submersion.
5	Aeration Tanks	High point on site. Mechanical equipment elevated above tank walls.
5	Secondary Clarifiers	Low point on site. Mechanical equipment elevated above tank walls. RAS pumps will function inundated. Facility entrance at grade.
2	Disinfection System (Chlorine Contact Tanks)	Contact tanks at low point on site, disinfection system at high point.
5	Sludge Holding Tanks	High point on site. Tank walls elevated above grade.
5	Control and Solids Handling Building	High point on site. Facility entrances at grade.
3	Generator	High point on site.
PUMP STATIONS		
3	Maple Avenue PS	Pump controls will cease to function if inundated.
3	Narragansett Avenue PS	Pump controls and generator will cease to function if inundated.
1	Beavertail Road PS	Pump controls and generator will cease to function if inundated.
1	Bayview Drive PS	Pump controls and generator will cease to function if inundated.

Table 4-10: Narragansett System Priorities

Priority	System	Comments
1	Influent Pump Station / Preliminary Treatment (Screening / Grit Removal)	Low-point on site with process penetrations at grade. Pumps below grade.
5	Aeration Tanks	High point on site. Mechanical systems elevated above tank walls.
5	Secondary Clarifier	High point on site. Mechanical systems elevated above tank walls. Facility access road at low point on site and equipment access at grade.
5	Sludge Thickening / Storage Tanks	Facility access road at low-point on site.
2	Disinfection System (Chlorine Contact Tanks)	Facility access road at low-point on site. Equipment access at grade.
1	Generator	Generator access road at low-point on site.
5	Administration Building	Facility access road at low-point on site.
5	Maintenance Building	Facility access road at low-point on site.
5	Solids Handling Building	Facility access road at low-point on site.
PUMP STATIONS		
3	Stanton Avenue PS	Pump controls will cease to function if inundated. Generator elevated above facility.
1	Galilee PS	Pump controls and generator will cease to function if inundated.
3	Mettatuxet PS	Pump controls and generator will cease to function if inundated.

Table 4-11: New Shoreham System Priorities

Priority	System	Comments
5	Preliminary Treatment (Screening / Grit Removal)	High point on site.
5	Aeration Tanks	Tank walls close to grade.
5	Secondary Clarifiers	Mechanical equipment elevated above tank walls. Facility entrance at grade.
5	Emergency Influent Storage Tanks	Tank walls at grade.
5	Sludge Storage Tanks / Dewatering / Operations	Low flood risk.
2	Disinfection System (Chlorine Contact Tanks)	Mechanical equipment at grade.
5	Effluent Discharge Pipe	Low risk of damage.
3	Generator	Mounted at grade.
PUMP STATIONS		
1	Old Harbor (Main) PS	Pump controls will cease to function if submerged.
1	Ocean Avenue #1 PS	Pump controls will cease to function if submerged.
3	Ocean Avenue #2 PS	Pump controls will cease to function if submerged.
3	Boat Basin PS	Pump motors and controls will cease to function if submerged.
3	Champlin's Marina PS	Pump motors and controls will cease to function if submerged.

Table 4-12: Newport System Priorities

Priority	System	Comments
5	Preliminary Treatment (Screening / Grit Removal	Channel walls elevated above grade, and components will function under flood waters.
4	Primary Clarifiers (Rectangular)	Tank walls at grade. Facility entrances and equipment close to grade.
1	Intermediate Pump Station (Screw Pumps)	Screw pumps at high-point on site with elevated drive motors.
5	Aeration Tanks	High point on site with mechanical equipment elevated above tank walls.
5	Secondary Clarifiers	Tank walls elevated above grade and mechanical equipment elevated above tank walls. Facility entrance elevated above grade.
2	Disinfection System (Chlorine Contact Tanks)	Contact tank walls and equipment close to grade.
1	Effluent Pump Station (Screw Pumps)	Screw pumps operated with elevated drive motors.
5	Sludge Thickening / Sludge Holding Tanks	Low-point on site with mechanical equipment close to grade.
5	Solids Handling / Chemical Storage Building	Low-point on site with facility entrances and equipment close to grade.
1	Generator	Multiple generators through-out site.
5	Administration Building	Low-flood risk.
5	Maintenance Building	Low-point on site.
PUMP STATIONS		
1	Long Wharf PS	Pump motors, controls and generator will cease to function if inundated.
3	Dyre Street PS	Pump controls and generator will cease to function if inundated.
3	Goat Island PS	Pump controls will cease to function if inundated.
3	Wellington Avenue PS/CSO	Pump motors, controls and generator will cease to function if inundated.
1	Washington Street CSO	Pump motors, controls and generator will cease to function if inundated.

Table 4-13: Quonset Point System Priorities

Priority	System	Comments
1	Influent Pump Station (Submersibles)	Pump controls and generator will cease to function if inundated.
5	Preliminary Treatment (Grinding / Screening / Grit Removal)	Highest point in the system. Bar rack will function inundated.
4	Primary Clarifiers (Rectangular)	Mechanical system will cease to function if controls inundated. Pumps will cease to function if inundated.
5	Rotating Biological Contactors	Motors elevated above tank walls; will cease to function if controls inundated.
5	Secondary Clarifiers	Mechanical systems elevated above tank walls; will cease to function if controls inundated. Pumps will cease to function if inundated.
2	Disinfection System (Chlorine Contact Tanks)	Tanks elevated and will remain undamaged by inundation. Disinfection system may cease to function if flooded.
1	Generator	Elevated in operations building. Will cease to function if inundated.
5	Digesters	Out of service.
5	Sludge Storage	Pumps will cease to function if inundated.
5	Operations Building	Elevated above grade; location of generator and electrical systems.
PUMP STATIONS		
3	Davisville Pier PS	Pump motors, controls and generator will cease to function if inundated.
1	Davisville PS	Pump motors, controls and generator will cease to function if inundated. Conveys approximately half of treatment system influent.
3	Commerce Park PS	Pump motors, controls and generator will cease to function if inundated.
3	Burlingham PS	Pump controls and generator will cease to function if inundated.

Table 4-14: Smithfield System Priorities

Priority	System	Comments
5	Preliminary Treatment (Grinding / Screening)	Mechanical equipment at or below grade.
4	Primary Clarifiers (Rectangular)	Low-point on site with tank walls close to grade. Facility access close to grade.
1	Intermediate Pump Station	Low-point on site with facility access close to grade.
5	Aeration Tanks	High-point on site. Mechanical equipment elevated above tank walls.
5	Secondary Clarifiers	Mechanical equipment elevated above tank walls. Facility access point close to grade.
5	Tertiary Treatment (Phosphorus and Zinc)	Facility access road at low elevation.
2	Disinfection System (Chlorine Contact Tanks)	Low-point on site with tank walls close to grade.
5	Sludge Holding Tank	Mechanical equipment at or below grade.
5	Solids Handling	Facility equipment at or below grade.
5	Operations/Administration Building	Facility access road at low elevation.
1	Generator	Generator at high point on site, but facility access road at low elevation.
PUMP STATIONS		
1	Whipple Avenue PS	Pump motors, controls and generator will cease to function if inundated.
3	Camp Street PS	Pump controls and generator will cease to function if inundated.
3	Burlingame Road PS	Pump controls will cease to function if inundated.
3	Latham Farm Road PS	Pump controls will cease to function if inundated.
3	Roger Williams Drive PS	Pump controls and generator will cease to function if inundated.
3	Farnum Pike PS	Pump controls and generator will cease to function if inundated.

Table 4-15: South Kingstown System Priorities

Priority	System	Comments
1	Influent Pump Station and Preliminary Treatment (Screening)	Pump station access elevated above grade.
4	Primary Clarifiers (Rectangular)	Mechanical equipment above grade. Facility access above grade. Pumps will cease to function if inundated.
5	Aeration Tanks	Blowers above grade.
5	Secondary Clarifiers	Tank walls close to grade. Mechanical equipment above tank walls. Extended shaft sludge pump motors above grade.
2	Disinfection System (Chlorine Contact Tanks)	Mechanical equipment close to grade.
5	Solids Handling (Dewatering)	Mechanical equipment at grade.
5	Operations Building	Facility entrances elevated above grade.
1	Generator	Generator installed above grade.
PUMP STATIONS		
1	Silver Lake PS	Pump motors, controls and generator will cease to function if inundated.
3	Salt Pond PS	Pump motors, controls and generator will cease to function if inundated.
3	Middlebridge North PS	Pump motors, controls and back-up combustion engine will cease to function if inundated.
3	Middlebridge South PS	Pump motors, controls and back-up combustion engine will cease to function if inundated.

Table 4-16: Warren System Priorities

Priority	System	Comments
5	Preliminary Treatment (Grit Removal / Screening)	Lowest point on site and lowest structure. Manual bar rack will function under flood conditions.
4	Primary Clarifiers	High risk of flooding. Pumps will not function when inundated. Building must be allowed to flood to prevent structural failure.
1	Electrical Switchgear and motor control centers (MCCs)	Electrical systems elevated.
5	Secondary Pipe/Pump Gallery	Sludge and scum pumps will cease to function when inundated.
5	Secondary Clarifiers	Mechanical equipment elevated above tanks.
2	Disinfection System (Chlorine Contact Tanks)	Gates will function under flood conditions and will remain undamaged. Mechanical mixer would not function if inundated.
5	Proposed Reactors	Mechanical equipment elevated above tanks.
5	Solids Handling (Gravity and Rotary Drum Thickening)	Sludge and scum pumps below grade will be cease to function if inundated.
5	Operations Building	Lower level equipment includes plant water pumping, which will cease to function if flooded.
1	Generator	Electrical systems vulnerable to flooding.
PUMP STATIONS		
1	Wood St PS	Pump motors and generator will cease to function if inundated.
1	Patterson Ave PS	Pump controls and generator will cease to function if inundated.
1	North PS	Pump controls and generator will cease to function if inundated.
3	Locust Terrace PS	Pump controls and generator will cease to function if inundated.
3	Cole School PS	Pump controls and generator will cease to function if inundated.

Table 4-17: Warwick System Priorities

Priority	System	Comments
5	Preliminary Treatment (Screening / Grit Removal)	Control systems for all preliminary treatment are at grade.
4	Primary Clarifiers (Rectangular)	Clarifier equipment at low-elevation will function when flooded. Building entrance at grade and equipment below grade.
5	Aeration Tanks	Tanks at grade but will be undamaged by flooding.
5	Blower Building	Blower equipment mounted close to grade.
5	Secondary Clarifiers	Drive mechanisms mounted above tank walls. Building entrance at grade and equipment below grade.
5	Tertiary Treatment (Phosphorus Removal)	Non-critical asset; systems elevated above grade.
1	Effluent Pump Station (Axial Flow)	Critical for process functionality in high river levels; vertical axial pumps elevated.
2	Disinfection System (Chlorine Contact Tanks)	Tank functionality will be negated by inundation.
5	Gravity Thickener	Building entrance at grade and equipment below grade; existing tank covers may be damaged if tanks not allowed to flood.
5	Digesters	Out of service.
5	Solids Handling (Thickening)	System close to grade.
1	Generator	Generator and fuel tank at grade; will not function if inundated.
3	Standby Equipment Storage	Equipment will be inaccessible if flooded.
5	Operations Buildings	Operations building at grade. SCADA is located on 2nd floor.
5	Administration Building	Administration building at grade.
PUMP STATIONS		
1	Knight Street PS	Pump motors, controls and generator will cease to function if inundated.
3	East Natick 1 PS	Pump motors, controls and generator will cease to function if inundated.
3	East Natick 2 PS	Pump motors and controls will cease to function if inundated.
3	Bellows Street PS	Pump controls and generator will cease to function if inundated.
3	Oakland Beach PS	Pump controls and generator will cease to function if inundated.

Table 4-18: West Warwick System Priorities

Priority	System	Comments
5	Preliminary Treatment (Screening / Grit Removal)	Highest point in the system. Bar rack will function inundated.
4	Primary Clarifiers	Mechanical equipment elevated above tank walls. Sludge pumps are below grade and will cease to function if flooded.
5	Aeration Tanks	Mechanical systems elevated above grade.
5	Secondary Clarifiers	Mechanical equipment elevated above tank walls. Sludge pumps are below grade and will cease to function if flooded.
5	Biological Aerated Filters (BAF) / Denitrifying Filters (DNF)	Tank walls elevated but mechanical systems at grade.
5	BAF/DNF Chemical Storage	Chemicals systems throughout site; none are critical for primary treatment or disinfection.
5	Tertiary Treatment (Phosphorus Removal)	Mechanical systems elevated above grade.
2	Disinfection System (UV)	System elevated on effluent tank wall; may cease to function if tank inundated.
1	Effluent Pump Station	Submersible pumps critical for effluent discharge with high river level.
5	Solids Handling (Dewatering)	Sludge dewatering systems at grade.
5	Thickened Sludge Tank / Waste Sludge Tank	Hatchways on pad above grade.
1	Generator	Equipment close to grade.
5	Operations Buildings	Close to grade with vulnerable control systems.
5	Administration Building	No critical assets in administration building.

PUMP STATIONS

3	Clyde PS	Pump controls and generator will cease to function if inundated. Entry and accessway is above the 100-year storm event.
1	Maisie Quinn PS	Pump controls and generator will cease to function if inundated. Entry and accessway is above the 100-year storm event.

Table 4-19: Westerly System Priorities

Priority	System	Comments
5	Preliminary Treatment (Screening / Grit Removal)	High point on site. Mechanical equipment elevated above grade.
4	Primary Clarifiers	Tank walls close to grade. Mechanical equipment elevated above tank walls. Pumps will cease to function if inundated.
5	Aeration Tanks	Tank walls close to grade.
5	Secondary Clarifiers	Tank walls close to grade. Mechanical equipment elevated above tank walls. Pumps will cease to function if inundated.
5	Alkalinity System	Low point on site. Equipment and tanks at or below grade.
2	Disinfection System (Chlorine Contact Tanks)	Low point on site. Equipment and tanks at or below grade.
5	Sludge Holding Tanks	High point on site. Tank walls above grade.
5	Digesters / Gravity Thickeners	High point on site. Pumps will cease to function if inundated.
5	Operations / Administration / Generator Building	Low risk of flooding.

PUMP STATIONS

1	New Canal PS	Pump motors, controls and generator will cease to function if inundated.
1	Old Canal PS	Pump controls and generator will cease to function if inundated.
1	Margin Street PS	Pump controls and generator will cease to function if inundated.
1	Beach Street PS	Pump motors, controls and generator will cease to function if inundated.

Table 4-20: Woonsocket System Priorities

Priority	System	Comments
5	Preliminary Treatment (Screening)	High point on site. Manual racks will function under water.
5	Preliminary Treatment (Grit Removal)	High point on site. Channel walls elevated above grade.
4	Primary Clarifiers	Mechanical systems elevated above tank walls. Tank walls close to grade. Pumps will cease to function if inundated.
1	Intermediate Pump Station (Axial Flow)	Drive system will cease to function if inundated.
5	Aeration Tanks	Tank walls elevated above grade.
5	Secondary Clarifiers	Low point on site. Mechanical systems elevated above tank walls. Pumps will cease to function if inundated.
5	Tertiary Treatment (Sand Filtration)	High point in isolated section of the site.
2	Disinfection System (Chlorine Contact Tanks)	Low point on site. Mechanical systems close to grade.
5	Sludge Holding / Gravity Thickener Tanks	High point on site. Pumps will cease to function if inundated.
5	Operations Building	Low-flood risk.
5	Administration Building	Low-flood risk.
5	Chemical Feed Building	High point on site. Mechanical systems close to grade.
1	Electrical / Generator Building	High point on site.
PUMP STATIONS		
3	Privilege Street PS	Pump motors, controls and generator will cease to function if inundated.
3	St. Louis PS	Pump motors, controls and generator will cease to function if inundated.

5. RECOMMENDED ADAPTIVE STRATEGIES

For each of the WWTF processes, adaptive strategies are suggested for the WWTF systems that were identified as vulnerable to climate change impacts. These are presented in **Tables 5-1 through 5-19**. Consistent with the intent to support planning efforts, the adaptive strategies listed are not exhaustive or absolute, but proposed to provide guidance for future system upgrades. Accordingly, some systems list more than one adaptive strategy that could be implemented. The strategies fall within one of five categories listed below. Examples of resiliency measures for each category are provided as guidance.

1. Hardening
    a. Retaining water by constructing walls, dikes, etc.
    b. Water proofing by installing submersible pumps, water resistant electrical enclosures, general waterproofing
    c. Installing flood-proof doors
    d. Temporary flood barriers
2. Relocating
    a. Elevating equipment
    b. Relocating systems or equipment to higher points on site and off site
3. Install equipment that is readily repairable or readily replaceable
    a. Spare equipment/parts on hand or readily replaceable
    b. Contingency plans – written plan on how to replace quickly, who to call, set up components to disconnects set up for quick disconnect
4. Redundancy
    a. Ability to move wastewater to two plants or two pump stations
    b. Augment with additional equipment such as portable, temporary pumps
    c. Redundancy within processes (wet weather storage)
5. Construct wet weather bypass
    a. Not a desired strategy to protect the equipment but would be a preferred alternative to overflow within streets

Additionally, an estimated ball park cost range was identified for each of the recommended adaptive measures. Letters A through D represent these cost ranges noted in the following tables:

A = < $50,000
B = $50,000 to $250,000
C = $250,000 - $1,000,000
D = > $1,000,000

Additionally, adaptive strategies can include updating emergency management plans to identify specific emergency measures that can be performed in-house with essentially no cost implications. For example, secondary treatment is a lower priority than pumping, disinfection, and primary treatment. In anticipation of severe flooding conditions and with permission from the permitting authority(s) having jurisdiction, secondary system components could simply be taken off-line immediately prior to an event and stored safely for reinstallation after flood waters recede. Since maintaining primary treatment through and/or immediately following flood conditions is a higher priority, leaving sacrificial equipment (motors) on the primaries through the event with the intent of replacing them afterwards if they fail may be a reasonable plan. Facility operators are encouraged to review their emergency management plans, consider whether additional mitigating procedures should be included and, if so, update their plan so that they are prepared to implement specific actions.

There are no site-specific prescriptive design criteria corresponding to the implementation of the above strategies. *TR-16, Guides for the Design of Wastewater Treatment Works* prepared by the New England Interstate Water Pollution Control Commission (NEIWPCC), has been the primary design reference for New England wastewater treatment facilities for over 50 years. This publication was revised in 2016 to address resiliency and adaptation considerations for extreme storm events. The current recommendation for new facilities, similar to the new Federal Flood Risk Management Standards (FFRMS), is to add 3 feet for critical equipment and 2 feet for non-critical equipment to the FEMA 100-year flood elevation. TR-16 states that existing pump stations and treatment facilities that are planned for upgrades or expansion should be improved to the maximum extent possible to meet the flood protection criteria for new facilities.

Concurrently with the development of this report, RIDEM is developing guidelines for planning and designing expansions and upgrades for existing municipal wastewater collection and treatment infrastructure as well as new wastewater systems. The purpose of the guidelines is to clarify the relationship between the existing studies, resources, and coastal efforts available regionally and within Rhode Island, most notably this report, TR-16, and STORMTOOLS. Fundamentally, and in accordance with TR-16, the guidelines are intended to protect wastewater systems from the impacts of climate change to the maximum extent practicable based on a cost-benefit evaluation to achieve:

1) Continuous operation at an appropriate 100-year flood elevation throughout the design life of the newly constructed infrastructure; and

2) Survivability of the structural and electrical components at an appropriate 100-year flood elevation plus a designated amount of additional freeboard.

A cost-benefit evaluation needs to account for costs associated with repairing damages from natural hazards. There are at present publicly available tools for assessing costs of damages associated with natural hazards, including one being developed specifically for storm flooding of coastal Rhode Island real estate, which is STORMTOOL's Coastal Environmental Risk Index Damage Calculator. Other resources and tools will most certainly become available in the future.

Table 5-1: Bristol Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Main Lift PS (Influent Screw Pumps)					C	Provide alternate route for influent from second screw pump to disinfection and discharge if primary and secondary treatment is flooded.
Preliminary Treatment (Screening and Grit Removal)						Unnecessary or low priority.
Primary Clarifiers (Rectangular)	B		B	B		Pumps may be temporarily augmented. Replace sludge pumps with submersibles. Store replacement drive components on site.
Rotating Biological Contactors	B					Extend perimeter walls upward, install stop logs, and elevate all RBC drive motors.
Secondary Clarifiers	B		B	B		Pumps may be temporarily augmented. Extend perimeter walls upward and install stop logs.
Gravity Thickener	B					Extend perimeter walls upward and install stop logs.
Primary/Blended Sludge Storage Tanks	A					Protect building with flood barriers and elevate critical equipment.
Solids Handling (Dewatering)	A					Protect building with flood barriers and elevate critical equipment.
Disinfection System (Chlorine Contact Tanks)	B					Protect building with flood barriers and elevate critical equipment. Extend contact tank perimeter walls upward.
Operations Building / Generator	A	C				Protect building with flood barriers and elevate critical equipment. Provide alternative access road to facility from higher ground.

PUMP STATIONS

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Peter Road PS	A			B		Elevate electrical systems. Provide permanent back-up power generator.
Brook Farm PS	A			B		Elevate electrical systems. Provide permanent back-up power generator.
Broadcommon PS	A			B		Elevate electrical systems. Provide permanent back-up power generator.
Constitution PS	A	D				Elevate pump station building above flood elevation, or relocate pump station inland.
Ferry Road PS	A			B		Elevate electrical systems. Provide permanent back-up power generator.

A = <\$50,000 B = \$50,000 to \$250,000 C = \$250,000 to \$1,000,000 D = >\$1,000,000

Table 5-2: Bucklin Point Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Influent Pump Station (Screw Pumps)	D		B			Raise and extend perimeter berm.[1] Store replacement pump components on-site.
Preliminary Treatment (Screening/Grit Removal)	D					Raise and extend perimeter berm.[1]
Primary Clarifiers	D		B	B		Raise and extend perimeter berm.[1] Pumps may be temporarily augmented. Replace sludge pumps with submersibles. Store replacement drive components on-site.
Aeration Tanks	D					Raise and extend perimeter berm.[1]
Secondary Clarifiers	D			B		Raise and extend perimeter berm.[1] Pumps may be temporarily augmented.
Generator						Generator mounted at elevated location.
Solids Handling / Equipment Storage	D					Raise and extend perimeter berm.[1] Equipment may be relocated prior to flood event.
Digesters						Minimal flood vulnerability.
Sludge/Filtrate Holding Tanks						Minimal flood vulnerability.
Wet Weather Holding Tank	D					Raise and extend perimeter berm.[1]
Disinfection System	D	B		B		Raise and extend perimeter berm.[1] Relocate critical components to high ground. Maintain back-up temporary chemical storage and pumping system.
Effluent Pump Station	D	B				Raise and extend perimeter berm.[1] Relocate drive systems to high ground.
Maintenance Building	D					Raise and extend perimeter berm.[1]
Operations Building	D					Raise and extend perimeter berm.[1]
PUMP STATIONS						
Saylesville PS	A					Protect building with flood barriers, and seal penetrations.

1. Raising and extending the perimeter berm will address multiple systems under one project.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

Table 5-3: Burrillville Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Influent Pump Station / Preliminary Treatment						Unnecessary or low priority.
Primary Clarifiers	B		A	B		Store replacement drive components on-site. Protect entrances with flood barriers. Replace sludge pumps with submersibles. Pumps may be temporarily augmented.
Aeration Tanks			B			Store replacement drive components on-site.
Secondary Clarifiers	A		A	B		Store replacement drive components on-site. Protect entrances with flood barriers. Replace sludge pumps with submersibles. Pumps may be temporarily augmented.
Advanced Treatment (Phosphorus)	A					Protect entrances with flood barriers.
Disinfection System (Chlorine Contact Tanks)	A					Protect building with flood barriers and elevate critical equipment.
Sludge Holding Tank	A					Protect entrances with flood barriers.
Operations / Chemical / Generator Building	A					Protect building with flood barriers and elevate critical equipment.
PUMP STATIONS						
Beach Road ES		C		B		Provide permanent back-up power. Relocate ES when existing equipment reaches the end of its useful life.
Rock Avenue ES				B		Provide permanent back-up power.
School Street (Callahan) ES		C				Relocate ES when existing equipment reaches the end of its useful life.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

Table 5-4: Cranston Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Influent Pump Station (Screw Pumps) / Preliminary Treatment (Screening / Grit Removal)						Unnecessary or low priority.
Primary Clarifiers	A		B	B		Protect pipe gallery with flood barriers. Store replacement drive components on site. Pumps may be temporarily augmented.
Aeration Tanks	A					Protect pipe gallery with flood barriers.
Secondary Clarifiers	A		B	B		Protect pipe gallery with flood barriers. Store replacement drive components on site. Pumps may be temporarily augmented.
Tertiary Treatment (Phosphorus Removal)						Unnecessary or low priority.
Disinfection System (Chlorine Contact Tanks)	A	B				Elevate critical equipment or relocate critical equipment and tanks to elevated location.
Gravity Thickener / Sludge Storage Tanks						Unnecessary or low priority.
Solids Handling	A					Protect building with flood barriers.
Generator	B					Elevate generator equipment.
Administration Building						Unnecessary or low priority.
PUMP STATIONS						
Pontiac Avenue PS	A					Protect building with flood barriers. Elevate generator equipment.
Burnham Avenue PS	A					Protect building with flood barriers. Elevate generator equipment.
Allard PS	A					Protect building with flood barriers. Elevate generator equipment.
Mayflower PS	A					Protect building with flood barriers. Elevate generator equipment.
Randall PS	A					Protect building with flood barriers. Elevate generator equipment.
Seaview PS	A					Protect building with flood barriers.
Worthington PS	A					Protect building with flood barriers. Elevate generator equipment.
Youlden PS	A					Protect building with flood barriers. Elevate/relocate fuel tank.

A = <$50,000　　B = $50,000 to $250,000　　C = $250,000 to $1,000,000　　D = >$1,000,000

Table 5-5: East Greenwich Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy		Bypass	Mitigation Strategy
Influent Pump Station (Dry-Pit Submersibles)	A						Protect facility entrances with flood barriers.
Preliminary Treatment (Screening)							Unnecessary or low priority.
Primary Clarifiers	A		B	B			Protect facility entrances with flood barriers. Store replacement drive components on-site. Pumps may be temporarily augmented.
Rotating Biological Contactors	A						Protect facility entrances with flood barriers.
Secondary Clarifiers	A		B	B			Protect facility entrances with flood barriers. Store replacement drive components on-site. Pumps may be temporarily augmented.
Biological Aerated Filters (BAF) / Denitrifying Filters (DNF)	A						Protect facility entrances with flood barriers.
BAF/DNF Chemical Storage ($MgOH_2$, Methanol)	A	B					Ensure tanks are adequately secured or elevated within the facility to prevent flotation. Protect facility entrances with flood barriers.
Disinfection System (UV)	A	A					Elevate disinfection equipment and relocate electrical equipment (transformer) to higher elevation.
Gravity Thickeners							Protect facility entrances with flood barriers.
Operations Building	A						Protect facility entrances into critical areas (generator room) with flood barriers.
PUMP STATIONS							
Cedar Heights PS	A						Elevate electrical equipment above grade.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

Table 5-6: East Providence Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Preliminary Treatment (Screening / Grit Removal)						Unnecessary or low priority.
Primary Clarifiers	A			B		Protect facility entrances with flood barriers. Pumps may be temporarily augmented.
Aeration Tanks (Circular)	A					Protect facility entrances with flood barriers.
Secondary Clarifiers	B		B	B		Replace glass entranceway with flood resistance walls. Protect facility entrance with flood barriers. Store replacement drive components on-site. Pumps may be temporarily augmented.
Disinfection System (Chlorine Contact Tanks)	A					Protect facility entrances with flood barriers.
Sludge Storage Tanks	A					Protect facility entrances with flood barriers.
Decant Storage Tank	A					Protect facility entrances with flood barriers.
Generators						Unnecessary or low priority.
Operations Building	A					Protect facility entrances with flood barriers.
Administration Building	A					Protect facility entrances with flood barriers.
PUMP STATIONS						
Sabin Point PS	C					Enclose pump equipment in flood resistance structure.
Bullocks Point Avenue PS	A					Protect facility entrances with flood barriers.
Merritt Road PS	A					Protect facility entrances with flood barriers.
Silver Street PS	A	B				Protect facility entrances with flood barriers. Relocate fuel tank.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

Table 5-7: Field's Point Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Influent Pump Station (Ernest Street PS)	A					Protect facility entrances with flood barriers.
Preliminary Treatment (Screening)	A					Protect facility entrances with flood barriers.
"Deep Rock Tunnel" System	A					Protect facility entrances with flood barriers.
Wet-Weather Tanks	A					Protect facility entrances with flood barriers and relocate building penetrations for ventilation.
Preliminary Treatment (Grit Removal)	A					Protect facility entrances with flood barriers.
Primary Clarifiers	B		B	B		Protect facility entrances with flood barriers. Replace sludge pumps with submersibles. Pumps may be temporarily augmented. Store replacement drive components on-site.
Intermediate Pump Station (Screw Pumps)	A					Protect facility entrances with flood barriers.
Secondary Clarifiers	A		B	B		Protect facility entrances with flood barriers. Store replacement drive components on-site. Pumps may be temporarily augmented.
Disinfection System (Chlorine Contact Tanks)	A					Protect facility entrances with flood barriers.
Gravity Thickeners						Unnecessary or low priority.
Solids Handling (Gravity Belt Thickener and Belt Press)						Unnecessary or low priority.
Generators	A					Protect facility entrances with flood barriers and elevate generator equipment.
Chemical Storage (Tank Farm)						Ensure tanks are adequately secured to prevent flotation and resist potential wave impacts.
Operations Building						Unnecessary or low priority.
Maintenance Building						Unnecessary or low priority.

PUMP STATIONS

Central Avenue PS	A					Protect facility entrances with flood barriers and elevate generator equipment.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

Table 5-8: Jamestown Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Preliminary Treatment (Screening)						Unnecessary or low priority.
Aeration Tanks						Unnecessary or low priority.
Secondary Clarifiers						Unnecessary or low priority.
Disinfection System (Chlorine Contact Tanks)						Unnecessary or low priority.
Sludge Holding Tanks						Unnecessary or low priority.
Control and Solids Handling Building		C				Provide alternative emergency access road on Route 138 between the toll booth facility and bridge to access the WWTF and the portion of the island south of Great Creek.
Generator						Unnecessary or low priority.

PUMP STATIONS

Maple Avenue PS	C			B		Provide enclosed elevated pump station equipment structure. Provide permanent back-up power.
Narragansett Avenue PS	A					Protect facility entrances with flood barriers. Relocate generator louver building penetrations.
Beavertail Road PS	A					Protect facility entrances with flood barriers. Relocate generator and ventilation louver building penetrations.
Bayview Drive PS						Unnecessary or low priority.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

Table 5-9: Narragansett Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Influent Pump Station and Preliminary Treatment (Screening / Grit Removal)	B					Replace influent pumps with submersibles.
Aeration Tanks	A		B			Protect facility entrances with flood barriers. Store replacement drive components on-site.
Secondary Clarifiers	B		B	B		Protect facility entrances from contact tank surcharge with flood barriers. Replace sludge pumps with submersibles. Pumps may be temporarily augmented. Store replacement drive components on-site.
Sludge Thickening / Storage Tanks	A					Protect facility entrances from contact tank surcharge with flood barriers.
Disinfection System (Chlorine Contact Tanks)	A					Protect facility entrances from contact tank surcharge with flood barriers.
Generator	A					Protect facility entrances from contact tank surcharge with flood barriers.
Administration Building	A					Protect facility entrances from contact tank surcharge with flood barriers.
Maintenance Building	A					Protect facility entrances from contact tank surcharge with flood barriers.
Solids Handling Building	A					Protect facility entrances from contact tank surcharge with flood barriers.
PUMP STATIONS						
Stanton Avenue PS	A					Protect facility entrances with flood barriers.
Galilee PS	A					Protect facility entrances with flood barriers. Ensure tanks are adequately secured to prevent flotation.
Mettatuxet PS	B	C				Protect slab penetrations and equipment with flood barriers or slab perimeter wall. Relocate pump station inland.

A = <\$50,000   B = \$50,000 to \$250,000   C = \$250,000 to \$1,000,000   D = >\$1,000,000

Table 5-10: New Shoreham Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Preliminary Treatment (Screening / Grit Removal)						Unnecessary or low priority.
Aeration Tanks						Unnecessary or low priority.
Secondary Clarifiers			A			Store replacement drive components on site.
Emergency Influent Storage Tanks						Unnecessary or low priority.
Sludge Storage Tanks / Solids Handling (Dewatering) / Operations Building						Unnecessary or low priority.
Disinfection System (Chlorine Contact Tanks)						Unnecessary or low priority.
Effluent Discharge Pipe						Unnecessary or low priority.
Generator						Unnecessary or low priority.
PUMP STATIONS						
Old Harbor (Main) PS	B				A	Modify structure to withstand wave impact and elevate building penetrations. Establish station shutdown plan for implementation during conditions of seawater inundation.
Ocean Avenue #1 PS	A					Elevate control panels above grade.
Ocean Avenue #2 PS	A					Elevate control panels above grade.
Boat Basin PS	B					Replace pumps with dry-pit submersibles and elevate electrical and control systems above grade.
Champlin's Marina PS	B					Replace pumps with dry-pit submersibles and elevate electrical and control systems above grade.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

Table 5-11: Newport Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Preliminary Treatment (Screening / Grit Removal)						Unnecessary or low priority.
Primary Clarifiers	B		B	B		Protect facility penetrations (and electrical equipment) with flood barriers. Store replacement drive components on site. Replace sludge pumps with submersibles. Pumps may be temporarily augmented.
Intermediate Pump Station (Screw Pumps)						Unnecessary or low priority.
Aeration Tanks	A					Protect facility entrances with flood barriers.
Secondary Clarifiers	B		B	B		Protect facility entrances with flood barriers. Store replacement drive components on site. Replace sludge pumps with submersibles. Pumps may be temporarily augmented.
Disinfection System (Chlorine Contact Tanks)	A					Protect facility entrances with flood barriers.
Effluent Pump Station (Screw Pumps)	A					Protect facility entrances with flood barriers.
Sludge Thickening / Sludge Holding Tanks	A					Protect facility entrances with flood barriers.
Solids Handling / Chemical Storage Building	A					Protect facility entrances with flood barriers.
Generator	A					Protect facility entrances with flood barriers.
Administration Building						Unnecessary or low priority.
Maintenance Building	A					Protect facility entrances with flood barriers.
PUMP STATIONS						
Long Wharf PS	A					Protect facility entrances with flood barriers and relocate building penetrations for louvers.
Dyre Street PS	A					Protect facility entrances with flood barriers. Elevate generator equipment.
Goat Island PS	C	C				Provide enclosed elevated pump station equipment structure. Relocate pump station inland.
Wellington Avenue PS/CSO	A					Protect facility entrances with flood barriers.
Washington Street CSO	A					Protect facility entrances with flood barriers.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

Table 5-12: Quonset Point Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Influent Pump Station (Submersibles)	A					Protect facility entrances with flood barriers. Extend perimeter walls upward.
Preliminary Treatment (Grinder / Screening / Grit Removal)	A					Protect facility entrances with flood barriers. Pumps may be temporarily augmented. Replace sludge pumps with submersibles.
Primary Clarifiers (Rectangular)	A			B		Protect facility entrances with flood barriers. Pumps may be temporarily augmented.
Rotating Biological Contactors	A					Protect facility entrances with flood barriers.
Secondary Clarifiers	A		B	B		Protect facility entrances with flood barriers. Extend perimeter walls upward. Store replacement drive components on site. Pumps may be temporarily augmented. Replace sludge pumps with submersibles. Pumps may be temporarily augmented.
Disinfection System (Chlorine Contact Tanks)	A					Protect facility entrances with flood barriers.
Generator	A					Protect facility entrances with flood barriers and relocate building penetrations for louvers.
Digesters						Unnecessary or low priority.
Sludge Storage	A					Unnecessary or low priority.
Operations Building	A					Protect facility entrances with flood barriers.
PUMP STATIONS						
Davisville Pier PS				B		Provide allocated back-up power in an elevated enclosure.
Davisville PS	B					Protect facility entrances with flood barriers. Elevate generator equipment.
Commerce Park PS	A					Protect facility entrances with flood barriers and relocate building penetrations for louvers.
Burlingham PS	A					Elevate generator and electrical equipment.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

Table 5-13: Smithfield Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Preliminary Treatment (Grinding / Screening)	A					Protect facility entrances with flood barriers.
Primary Clarifiers (Rectangular)	B		B	B		Protect facility entrances with flood barriers. Extend tank perimeter wall upward. Store replacement drive components on site. Pumps may be temporarily augmented. Replace sludge pumps with submersibles.
Intermediate Pump Station	A					Protect facility entrances with flood barriers.
Aeration Tanks	A					Protect facility entrances with flood barriers.
Secondary Clarifiers						Unnecessary or low priority.
Tertiary Treatment (Phosphorus and Zinc)						Unnecessary or low priority.
Disinfection System (Chlorine Contact Tanks)						Unnecessary or low priority.
Sludge Holding Tank	A					Protect facility entrances with flood barriers.
Solids Handling	A					Protect facility entrances with flood barriers.
Operations/Administration Building	A					Protect facility entrances with flood barriers.
Generator	A					Protect facility entrances with flood barriers.
PUMP STATIONS						
Whipple Avenue PS	A					Protect facility entrances with flood barriers.
Camp Street PS	A					Protect facility entrances with flood barriers.
Burlingame Road PS				B		Provide permanent back-up power.
Latham Farm Road PS				B		Provide permanent back-up power.
Roger Williams Drive PS						Unnecessary or low priority.
Farnum Pike PS						Unnecessary or low priority.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

Table 5-14: South Kingstown Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Influent Pump Station and Preliminary Treatment (Screening)						Unnecessary or low priority.
Primary Clarifiers (Rectangular)						Unnecessary or low priority.
Aeration Tanks						Unnecessary or low priority.
Secondary Clarifiers						Unnecessary or low priority.
Disinfection System (Chlorine Contact Tanks)						Unnecessary or low priority.
Solids Handling (Dewatering)						Unnecessary or low priority.
Operations Building						Unnecessary or low priority.
Generator						Unnecessary or low priority.
PUMP STATIONS						
Silver Lake PS	A					Protect facility entrances with flood barriers. Elevate electrical equipment above grade.
Salt Pond PS	A					Elevate fuel tank, ventilation pipe, and electrical equipment.
Middlebridge North PS	A					Protect facility entrances with flood barriers and relocate building penetrations for louvers.
Middlebridge South PS	A					Protect facility entrances with flood barriers and relocate building penetrations for louvers.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

Table 5-15: Warren Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Preliminary Treatment (Grit Removal / Screening)			B			Allow headworks and screen to flood. Manual bar rack will continue to function. [1]
Primary Sludge Pump Station		A	C			Allow pumps in primary sludge pump station basement to flood. Electrical MCC and SCADA equipment on first floor located above flood elevation. [1]
Primary Settling Tanks		B				Allow primary settling tanks to flood. Locate collector drives above flood elevation. [1] Replace sludge pumps with submersibles. Store replacement drive components on site. Pumps may be temporarily augmented. [2]
Intermediate Pump Station and Secondary Gallery		A	C			Allow pumps in basement to flood. Electrical MCC and SCADA equipment on first floor relocated above flood elevation. [1] Replace primary effluent pumps with submersibles. [2]
Electrical Switchgear and Motor Control Centers (MCCs)		C				Relocate above flood elevation. [1]
Proposed Reactors	A					Locate above flood elevation. [1]
Secondary Clarifiers		B				Locate collector drives above flood elevation. [1] Replace sludge pumps with submersibles. [2]
Disinfection System (Chlorine Contact Tanks)		B				Locate mixer drive above flood elevation or install submersible mixer. [1]
Solids Handling (Gravity and Rotary Drum Thickening)		C				Locate thickening equipment above flood elevation. [1] Allow pumps in station basement to flood. Electrical switchgear, MCCs and SCADA equipment above flood elevation. [2]
Operations Building		B	B			Allow pumps in station basement to flood. Electrical switchgear, MCCs and SCADA equipment above flood elevation. [1]
Generator		B				Locate above flood elevation.
PUMP STATIONS						
Wood St PS	B					Replace extended shaft pumps with submersibles.
Patterson Ave PS	A					Protect facility entrances with flood barriers.
North PS	B					Convert to natural gas fuel source if available.
Locust Terrace PS						Unnecessary or low priority.
Cole School PS	B	B				Provide sealable structure and protect facility entrances with flood barriers. Elevate generator equipment.

1. Adaptive measures planned for implementation in the near term as part of the proposed WWTF Upgrades project.
2. Adaptive measures that the Town of Warren may consider implementing at a future time.

A = <$50,000　B = $50,000 to $250,000　C = $250,000 to $1,000,000　D = >$1,000,000

Table 5-16: Warwick Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Preliminary Treatment (Screening / Grit Removal)		D	B			Store replacement drive components on site. Pump influent to Cranston WWTF. [1]
Primary Clarifiers (Rectangular)		D	B	B		Store replacement drive components on site. Pumps may be temporarily augmented. Pump influent to Cranston WWTF. [1]
Aeration Tanks		D				Pump influent to Cranston WWTF. [1]
Blower Building		D				Pump influent to Cranston WWTF. [1]
Secondary Clarifiers		D	B	B		Store replacement drive components on site. Pumps may be temporarily augmented. Pump influent to Cranston WWTF. [1]
Disinfection System (Chlorine Contact Tanks)		D		B		Maintain back-up temporary chemical storage and pumping system. Pump influent to Cranston WWTF. [1]
Effluent Pump Station	C	D				Replace effluent pumps with submersibles and relocate drive systems to high ground. Pump influent to Cranston WWTF. [1]
Tertiary Treatment (Phosphorus Removal)		D				Pump influent to Cranston WWTF. [1]
Gravity Thickener		D				Pump influent to Cranston WWTF. [1]
Digesters		D				Pump influent to Cranston WWTF. [1]
Solids Handling (Thickening)		D				Pump influent to Cranston WWTF. [1]
Generator	B	D				Elevate back-up electrical systems above berm elevation. Pump influent to Cranston WWTF. [1]
Operations Building		D				Pump influent to Cranston WWTF. [1]
Administration Building		D				Pump influent to Cranston WWTF. [1]
PUMP STATIONS						
Knight Street PS		C				Relocate pump station inland.
East Natick 1 PS	A					Protect facility entrances with flood barriers and relocate building penetrations for louvers.
East Natick 2 PS	A			B		Elevate electrical systems. Provide permanent back-up power generator.
Irving Road PS	A			B		Elevate electrical systems. Provide permanent back-up power generator.
Oakland Beach PS						Unnecessary or low priority. Hardening and generator replacement in progress.
Bellows Street PS						Unnecessary or low priority. Recently upgraded to protect from 500-year flood.

1. Redirecting influent flow to the Cranston WWTF would address multiple systems under one project. This long term plan should be considered in conjunction with West Warwick.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

Table 5-17: West Warwick Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Preliminary Treatment (Screening / Grit Removal)		D				Pump influent to Cranston WWTF. [1]
Primary Clarifiers	B	D	B	B		Protect facility entrances with flood barriers. Extend tank perimeter wall upward. Pump influent to Cranston WWTF.[1] Store replacement drive components on site. Pumps may be temporarily augmented. Replace sludge pumps with submersibles.
Aeration Tanks	B	D				Protect facility entrances with flood barriers. Extend tank perimeter wall upward. Pump influent to Cranston WWTF.[1]
Secondary Clarifiers	B	D	B	B		Protect facility entrances with flood barriers. Extend tank perimeter wall upward. Pump influent to Cranston WWTF.[1] Store replacement drive components on site. Pumps may be temporarily augmented. Replace sludge pumps with submersibles.
Biological Aerated Filters (BAF) / Denitrifying Filters (DNF)	A	D				Protect facility entrances with flood barriers. Pump influent to Cranston WWTF. [1]
BAF/DNF Chemical Storage	A	D				Protect facility entrances with flood barriers. Pump influent to Cranston WWTF. [1]
Tertiary Treatment (Phosphorus Removal)	A	D				Protect facility entrances with flood barriers. Pump influent to Cranston WWTF. [1]
Disinfection System (UV)	A	D				Protect facility entrances with flood barriers. Pump influent to Cranston WWTF. [1]
Effluent Pump Station	A	D				Protect facility entrances with flood barriers. Pump influent to Cranston WWTF. [1]
Solids Handling (Dewatering)	A	D				Pump influent to Cranston WWTF. [1]
Thickened Sludge Tank / Waste Sludge Tank	A	D				Protect facility entrances with flood barriers. Pump influent to Cranston WWTF. [1]
Generator	A	D				Protect facility entrances with flood barriers. Pump influent to Cranston WWTF. [1]
Operations Building	A	D				Protect facility entrances with flood barriers. Pump influent to Cranston WWTF. [1]
Administration Building	A	D				Protect facility entrances with flood barriers. Pump influent to Cranston WWTF. [1]
PUMP STATIONS						
Clyde PS	A					Protect facility entrances with flood barriers and relocate building penetrations for louvers.
Maisie Quinn PS	A					Protect facility entrances with flood barriers and relocate building penetrations for louvers. Elevate back-up generator systems.

1. Redirecting influent flow to the Cranston WWTF would address multiple systems under one project. This long term plan should be considered in conjunction with Warwick.

A = <\$50,000 B = \$50,000 to \$250,000 C = \$250,000 to \$1,000,000 D = >\$1,000,000

Table 5-18: Westerly Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Preliminary Treatment (Screening / Grit Removal)					B	Allow flows exceeding the preliminary treatment system's hydraulic capacity to bypass the system.
Primary Clarifiers			B			Store replacement drive components on site.
Aeration Tanks	A					Protect facility entrances with flood barriers.
Secondary Clarifiers	B		B	B		Protect facility entrances with flood barriers. Replace sludge pumps with submersibles. Store replacement drive components on site. Pumps may be temporarily augmented.
Alkalinity System		B				Relocate alkalinity system to higher ground.
Disinfection System (Chlorine Contact Tanks)	A	B				Elevate or relocate disinfection system components.
Sludge Holding Tanks						Unnecessary or low priority.
Digesters / Gravity Thickeners	A					Protect facility entrances with flood barriers.
Operations / Administration / Generator Building	A					Protect facility entrances with flood barriers.
PUMP STATIONS						
New Canal PS	A					Protect facility entrances with flood barriers and relocate building penetrations for louvers. Elevate back-up generator systems.
Old Canal PS	A					Protect facility entrances with flood barriers. Elevate back-up generator systems.
Margin Street PS	A					Protect facility entrances with flood barriers.
Beach Street PS	A					Protect facility entrances with flood barriers and relocate building penetrations for louvers. Elevate, relocate or secure chemical tanks.

A = <$50,000   B = $50,000 to $250,000   C = $250,000 to $1,000,000   D = >$1,000,000

Table 5-19: Woonsocket Adaptive Strategies

System	Hardening	Relocating	Readily Repairable/ Replaceable	Redundancy	Bypass	Mitigation Strategy
Preliminary Treatment (Screening)						Unnecessary or low priority.
Preliminary Treatment (Grit Removal)						Unnecessary or low priority.
Primary Clarifiers						Unnecessary or low priority.
Intermediate Pump Station (Axial Flow)						Unnecessary or low priority.
Aeration Tanks	A					Protect facility entrances with flood barriers.
Secondary Clarifiers	A			B		Protect facility entrances with flood barriers. Pumps may be temporarily augmented.
Tertiary Treatment (Sand Filtration)	A					Protect facility entrances with flood barriers.
Disinfection System (Chlorine Contact Tanks)	A					Protect facility entrances with flood barriers.
Sludge Holding / Gravity Thickener Tanks						Unnecessary or low priority.
Operations Building						Unnecessary or low priority.
Administration Building						Unnecessary or low priority.
Chemical Feed Building	A					Protect facility entrances with flood barriers.
Electrical / Generator Building						Protect facility entrances with flood barriers.
PUMP STATIONS						
Privilege Street PS	B					Protect facility entrances with flood barriers and relocate building penetrations for louvers. Replace pumps with dry-pit submersibles.
St. Louis PS	B					Protect facility entrances with flood barriers and relocate building penetrations for louvers. Replace pumps with dry-pit submersibles.

A = <$50,000 B = $50,000 to $250,000 C = $250,000 to $1,000,000 D = >$1,000,000

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APPENDIX A: PLANT OPERATORS QUESTIONNAIRE

Rhode Island Wastewater Collection and Treatment Infrastructure Emergency Management and Climate Change Study Information
Return by February 20, 2015

WOODARD &CURRAN

GENERAL INFORMATION

Contact Name:	
Work Phone:	
Cell Phone:	

Facility Name and Main Address:	Design Flow Capacity (MGD)	Average Daily Flow (MGD)	Year Constructed	Most Recent Upgrade Date
Pump Stations & CSOs – List Locations:	**Capacity**	**Average Daily Flow**	**Year Constructed**	**Most Recent Upgrade Date**

QUESTIONS

1. Attached is a listing of reported non-standard events from 2009 to present that have occurred at your facility or collection system.

    - Please identify those events that were caused or complicated by a natural event—flooding, freezing, storm surge, excessive heat, etc—and include any additional information that would be helpful to explain the challenges you faced.
    - Also, please note those events that you feel could reoccur under conditions related to natural hazards.
    - Then please add other events that occurred in that time at your WPCF, pumping stations, or CSOs where there was direct damage or the threat of damage from natural events. Please provide as much detail as possible. This can include an approximate costs to repair the damage or other information.

2. Above attached is a listing of wastewater pumping stations that the state and DEM have on file in our GIS database. Also, a GIS map of these stations can be found here. Please review and make any additions corrections so that we may update our records for this project and future efforts.

3. Does your facility or pumping station have underground fuel storage tanks that are subject to flooding?

4. Has access to the WPCF, pumping stations, or CSOs ever been restricted during storm events due to flooding or other obstacles? If so, what access roads have been affected and by what obstacle? If rain-related, please estimate (if you can) how much rain (or how fast it falls) that has caused such problems.

5. Are any parts of the facility or pumping stations protected by a berm or other means to prevent floodwaters from entering?

6. What process constraints are you aware of that have been (or may be) worsened by natural events, such as increased precipitation, drought, etc?

7. Have any site mitigation projects been done at your facility or pump stations? (i.e. roof replacement, storm windows/doors, moving electrical equipment to higher locations, etc.) in response to the March 2010 floods or other events? If so, please summarize.

8. How would you like to improve standby power capabilities at your plant or stations?

9. Do you have access to spare pumps, generators, of other support from other utilities for use in an emergency? Have you had to acquire and use such equipment in the past?

10. What are some other major issues that your facility is facing or has faced in the past? In other words, what worries you the most about maintaining the ongoing operations at your plant? List other information that you feel is important to share.

DOCUMENTS REQUESTED

- Site Plan with contours of the WPCF, Pump Stations and CSOs
- Insurance claims
- Photos of facilities and past floods or other damages
- Emergency Response Plan

FOLLOW UP DISCUSSION POINTS

- Facility asset information for risk analysis (see attached example)
- Photos to be used for facility profile sheets
- Generator fueling and use (dedicated or portable)
- Historic aspect of facilities
- Restrictions associated with sensitive habitat areas

Please Return by February 20, 2015 to: *Joyce Quirk, jquirk@woodardcurran.com*
Woodard & Curran, 95 Cedar Street, Suite 100, Providence, Rhode Island 02093
Phone: (401) 273- 1007 Fax: (401) 273-5087

APPENDIX B: PARAMETERS, RANKING SPREADSHEET AND HISTOGRAM

Implications of Climate Change for RI Wastewater Collection and Treatment Infrastructure
Parameters for Preliminary Matrix Ranking of WWTF Systems
March 4, 2015

Ranking exercise to establish the relative likelihood of climate related physical impacts on each WWTF system.

1. Location on FEMA flood map

   1 – Within X Zone
   2 – Within A Zone
   3 – Within V Zone

2. History of natural hazard events impacting facility/infrastructure critical assets

   1 – None or 1 since 2009
   2 – 2 or 3 since 2009
   3 – More than 3 since 2009

3. Analysis of documented damage and mitigation costs from previous events

   1 – None
   2 – Miscellaneous expenses
   3 – Major repairs required

4. Infrastructure that would be inundated by sea level rise and storm surge under 1, 2, 3 and 5 foot scenarios

   1 – Less than 10% system capacity loss under 5-foot scenario
   2 – Between 10% and 50% system capacity loss under 5-foot scenario
   3 – Greater than 50% system capacity loss under 5-foot scenario

5. Inundation by sea level rise and storm surge

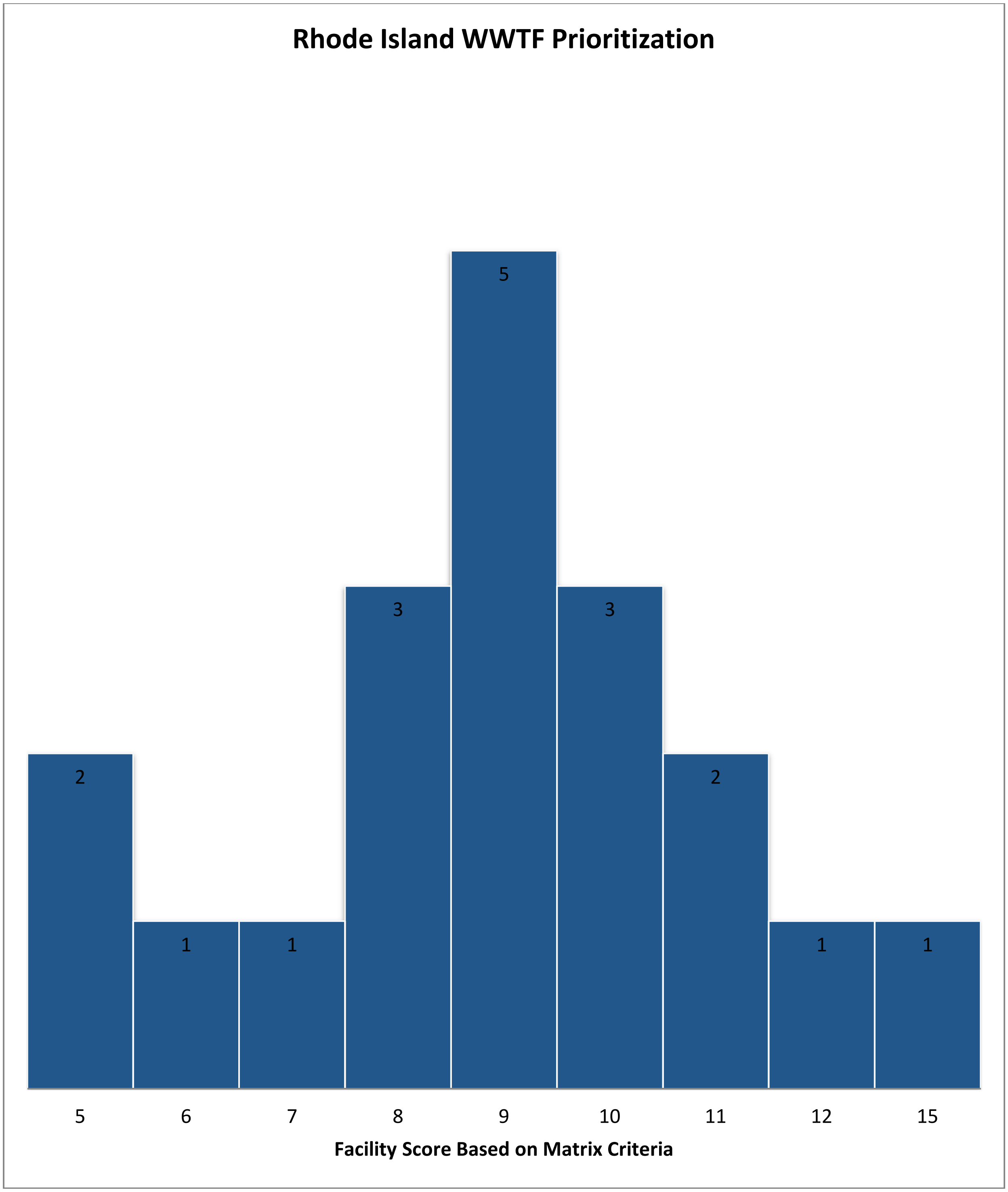
   1 – Greater than 50 years for 1-foot impacts
   2 – Between 20 and 50 years for 1-foot impacts
   3 - Less than 20 years for 1-foot impacts

All parameters equally weighted.

Facility	Location on FEMA FIRM	Value	Hazard History	Value	Documented losses and costs since 2009	Value	Infrastructure Inundation	Value	Projection of Inundation	Value	TOTAL
East Providence WWTF	Within V Zone	3	More than 3 since 2009	3	Major Repairs	3	Greater than 50% system capacity loss under 5-ft scenario	3	Greater than 50% system capacity loss for 1-ft impacts	3	**15**
Warren United Water	Within V Zone	3	2-3 since 2009	2	None	1	Greater than 50% system capacity loss under 5-ft scenario	3	Greater than 50% system capacity loss for 1-ft impacts	3	**12**
Cranston WPCF	Within A Zone	2	2-3 since 2009	2	Major Repairs	3	Between 10% and 50% system capacity loss under 5-ft scenario	2	Between 10% and 50% system capacity loss for 1-ft impacts	2	**11**
Quonset Development Corporation	Within V Zone	3	1 or less since 2009	1	None	1	Greater than 50% system capacity loss under 5-ft scenario	3	Greater than 50% system capacity loss for 1-ft impacts	3	**11**
Bristol WWTF	Within X Zone	1	2-3 since 2009	2	Major Repairs	3	Between 10% and 50% system capacity loss under 5-ft scenario	2	Between 10% and 50% system capacity loss for 1-ft impacts	2	**10**
East Greenwich WWTF	Within A Zone	2	1 or less since 2009	1	None	1	Greater than 50% system capacity loss under 5-ft scenario	3	Greater than 50% system capacity loss for 1-ft impacts	3	**10**
West Warwick Regional WWTF	Within A Zone	2	1 or less since 2009	1	Major Repairs	3	Greater than 50% system capacity loss under 5-ft scenario	3	Less than 10% system capacity loss for 1-ft impacts	1	**10**
NBC Bucklin Point WWTF	Within X Zone	1	1 or less since 2009	1	None	1	Greater than 50% system capacity loss under 5-ft scenario	3	Greater than 50% system capacity loss for 1-ft impacts	3	**9**
NBC Fields Point WWTF	Within X Zone	1	1 or less since 2009	1	None	1	Greater than 50% system capacity loss under 5-ft scenario	3	Greater than 50% system capacity loss for 1-ft impacts	3	**9**
Newport WWTF	Within X Zone	1	More than 3 since 2009	3	None	1	Between 10% and 50% system capacity loss under 5-ft scenario	2	Between 10% and 50% system capacity loss for 1-ft impacts	2	**9**
Warwick Sewer Authority	Within X Zone	1	1 or less since 2009	1	Major Repairs	3	Between 10% and 50% system capacity loss under 5-ft scenario	2	Between 10% and 50% system capacity loss for 1-ft impacts	2	**9**
Westerly United Water	Within X Zone	1	2-3 since 2009	2	Major Repairs	3	Less than 10% system capacity loss under 5-ft scenario	1	Between 10% and 50% system capacity loss for 1-ft impacts	2	**9**
Jamestown Sewer Division	Within X Zone	1	2-3 since 2009	2	Miscellaneous Expenses	2	Less than 10% system capacity loss under 5-ft scenario	1	Between 10% and 50% system capacity loss for 1-ft impacts	2	**8**
Narragansett WWTF	Within V Zone	3	2-3 since 2009	2	None	1	Less than 10% system capacity loss under 5-ft scenario	1	Less than 10% system capacity loss for 1-ft impacts	1	**8**
South Kingstown Regional WWTF	Within X Zone	1	2-3 since 2009	2	None	1	Between 10% and 50% system capacity loss under 5-ft scenario	2	Between 10% and 50% system capacity loss for 1-ft impacts	2	**8**
Woonsocket WWTF	Within X Zone	1	1 or less since 2009	1	Major Repairs	3	Less than 10% system capacity loss under 5-ft scenario	1	Less than 10% system capacity loss for 1-ft impacts	1	**7**
Burrillville WWTF	Within A Zone	2	1 or less since 2009	1	None	1	Less than 10% system capacity loss under 5-ft scenario	1	Less than 10% system capacity loss for 1-ft impacts	1	**6**
New Shoreham Sewer Division	Within X Zone	1	1 or less since 2009	1	None	1	Less than 10% system capacity loss under 5-ft scenario	1	Less than 10% system capacity loss for 1-ft impacts	1	**5**
Smithfield Veolia Water	Within X Zone	1	1 or less since 2009	1	None	1	Less than 10% system capacity loss under 5-ft scenario	1	Less than 10% system capacity loss for 1-ft impacts	1	**5**

Key

if unconfirmed by facility manager


Rhode Island WWTF Prioritization
2
1
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Facility Score Based on Matrix Criteria

APPENDIX C: FACILITY DATA (ELECTRONIC ONLY)

APPENDIX D: RIVERINE GIS DATA (ELECTRONIC ONLY)

APPENDIX E: RIDEM DATABASE PUMPSTATIONS AND APPARENT FLOOD RISK

RIDEM DATABASE PUMP STATIONS AND APPARENT FLOOD RISK

Pump stations listed are those within the WWTF service area and include those owned and operated by other communities or entities for which information was available at the time of this report.

WWTF Service Area	Evaluated Pump Station	Risk Identified by Modeling
Bristol	Brook Farm PS#9	Localized; Backup Power
	Colt1 PS – State owned	Coastal
	Colt2 PS – State owned	Coastal
	Colt3 PS – State owned	Coastal
	Constitution PS#4	Coastal – Access
	Ferry Rd. PS#3	Coastal
	Kickemuit PS (Kickamuit PS#7)	Coastal
	Leila Jean Dr. PS#1	Riverine - Access
	Main Lift (Main St. PS#2)	Coastal
	Mount Hope PS#6	Coastal
	Peter Rd. PS (Peter Dr. PS#8)	Backup Power
	Silver Creek PS#5	Coastal; Localized Impacts Possible
Bucklin Point	Andrews Drive PS	Localized Impacts Possible
	Angell Road South PS	Localized Impacts Possible
	Angle Road North PS	Localized Impacts Possible
	Applewood Lane PS	Localized Impacts Possible
	Arlington Drive PS	Localized Impacts Possible
	Ashley Drive PS	Localized Impacts Possible
	Birchwood Drive PS	Localized Impacts Possible
	Branch St. PS	Localized Impacts Possible
	Butterfly Estates PS	Riverine - Access
	Cider Mill Lane PS	Localized Impacts Possible
	Davies Vocational PS	Localized Impacts Possible
	Dexter Rd. PS	Localized Impacts Possible
	Eagle Nest Drive PS	Localized Impacts Possible
	Edge Hill Ave PS	Localized Impacts Possible
	Gauge Chamber	Riverine
	Great Road North PS	Localized Impacts Possible
	Great Road South PS	Riverine
	Heidi Rd. PS	Localized Impacts Possible
	Hillside Ave PS	Localized Impacts Possible
	Jason Drive PS	Localized Impacts Possible
	Kirkbrae. PS	Localized Impacts Possible
	Lincoln Center PS	Localized Impacts Possible
	Lori Ellen Drive PS	Localized Impacts Possible
	Lower River Road PS	Localized Impacts Possible
	Maria Street PS	Localized Impacts Possible
	Mauran Ave. PS	Coastal
	Middle Street PS	Localized Impacts Possible

Pump stations listed are those within the WWTF service area and include those owned and operated by other communities or entities for which information was available at the time of this report.

WWTF Service Area	Evaluated Pump Station	Risk Identified by Modeling
	Mount Ave PS	Localized Impacts Possible
	Narr. Race Track PS	Localized Impacts Possible
	Newland Ave PS	Localized Impacts Possible
	Oakhills Estates PS	Localized Impacts Possible
	Old River Road PS	Localized Impacts Possible
	Omega PS	Coastal; Riverine
	Paddock Drive PS	Localized Impacts Possible
	Parkside Ave. PS	Localized Impacts Possible
	Pinecrest Ave. PS	Riverine
	Rockaway Ave. PS	Coastal; Riverine
	Rollingwood Drive PS	Localized Impacts Possible
	Rt 246 PS	Localized Impacts Possible
	Saylesville. PS	Riverine
	Warren Ave. PS	Localized Impacts Possible
	Washington Hwy. PS	Localized Impacts Possible
	Woodridge Estates PS	Localized Impacts Possible
Burrillville	Beach Rd. Ej. Sta.	Riverine; Backup Power
	Eagle Peak Ej. Sta.	Localized Impacts Possible
	Mapleville PS	Riverine
	Oakland PS	Riverine
	Old Victory Highway	Localized Impacts Possible
	Reservoir Rd. PS	Localized Impacts Possible
	Rock Ave. Ej. Sta.	Backup Power
	School St. Ej. Sta.	Riverine
	South Main St. PS	Riverine
	Spring Lake PS	Riverine
Cranston	Allard PS	Riverine
	Amanda PS	Riverine
	Bay PS	Coastal
	Burham PS	Riverine
	Byfield St PS	Localized Impacts Possible
	East PS	Localized Impacts Possible
	Emmons St PS	Coastal
	Gleason PS	Riverine
	Hollow Tree PS	Localized Impacts Possible
	Howard PS	Riverine - Access
	Mayflower PS	Coastal; Riverine
	Plainfield PS	Localized Impacts Possible
	Pontiac PS	Riverine; Coastal - Access

Pump stations listed are those within the WWTF service area and include those owned and operated by other communities or entities for which information was available at the time of this report.

WWTF Service Area	Evaluated Pump Station	Risk Identified by Modeling
	Randall PS	Riverine
	Reservoir Ave. PS	Localized Impacts Possible
	Seaview PS	Coastal
	Sheldon PS	Coastal
	Sherman PS	Riverine
	Starline PS	Localized Impacts Possible
	Wellington PS	Localized Impacts Possible
	Woodbury PS	Coastal; Riverine
	Worthington PS	Riverine
	Youlden PS	Coastal; Riverine
	Unnamed PS (Deborah Rd)	Localized Impacts Possible
	Unnamed PS (Northampton St)	Coastal; Riverine
East Greenwich	None	
East Providence	Adams Pt. Ej. Sta.	Coastal
	Argyle Ave. PS	Coastal
	Boyden Blvd. PS	Localized Impacts Possible
	Brickyard Pond PS	Coastal
	Bullocks Pt. Ave. PS	Backup Power
	Forbes St. PS	Localized Impacts Possible
	Francis Ave. PS	Coastal; Riverine
	Fremont Ave. PS	Coastal
	Juniper St. Ej. Sta.	Coastal
	Merritt Rd. PS	Capacity
	Nyatt Pt. Ej. Sta.	Coastal
	Police Sta. PS	Coastal
	Prince's Pond PS	Coastal
	Read Ave PS	Coastal
	Rounds Ave. PS	Localized Impacts Possible
	Rumstick PS	Coastal
	Sabin Pt. PS	Coastal; Backup Power
	Silver St. PS	Coastal
	Universal Optical PS	Localized Impacts Possible
	Village Green PS	Localized Impacts Possible
	Walnut Rd. PS	Coastal
	Wampanoag Ej. Sta.	Coastal
	Wannamoisett Rd. PS	Localized Impacts Possible
	Watchemoket PS	Coastal

Pump stations listed are those within the WWTF service area and include those owned and operated by other communities or entities for which information was available at the time of this report.

WWTF Service Area	Evaluated Pump Station	Risk Identified by Modeling
Fields Point	Allendale Ave. PS	Localized Impacts Possible
	Allendale Insur. PS	Localized Impacts Possible
	Central PS	Riverine
	Charles Street PS	Localized Impacts Possible
	Dyer PS	Riverine - Access
	Ernest St PS (Main PS)	Coastal
	Newman Ave. PS	Riverine
	Reservoir Ave. PS (Cranston WWTF)	Localized Impacts Possible
	Washington Park PS (Shipyard St)	Coastal
Jamestown	Bayview Drive PS	Coastal - Access
	Beavertail Rd. PS	Coastal
	Maple Ave. PS	Coastal
	Narragansett Ave. PS	Coastal; Capacity
Narragansett	Burnside Ave. PS	Coastal
	Congdon St. PS	Coastal
	Fishermans PS	Coastal
	Galilee PS	Coastal
	Lakewood Dr. PS	Localized Impacts Possible
	Mumford Rd. PS	Localized Impacts Possible
	Stanton Ave. PS	Coastal
	Wanda St. PS	Coastal
New Shoreham	Boat Basin PS (Block Is. Marina)	Coastal
	Champlin's Marina PS	Localized Impacts Possible
	Ocean Ave. PS#1	Coastal
	Ocean Ave. PS#2	Coastal
	Old Harbor PS (Main Lift)	Coastal
Newport	Almy Pond PS	Coastal
	Beach PS (Memorial Blvd)	Coastal
	Bliss Mine Rd PS (Ellery St)	Coastal
	Carroll Ave PS	Localized Impacts Possible
	Coddington Wharf	Coastal
	Dyre St. PS	Coastal
	Lees Wharf	Coastal
	Long Wharf PS	Coastal
	Maple Ave. PS	Localized Impacts Possible
	Paradise PS	Coastal
	Training Sta. Rd.	Coastal
	Wave Ave. PS	Coastal

Pump stations listed are those within the WWTF service area and include those owned and operated by other communities or entities for which information was available at the time of this report.

WWTF Service Area	Evaluated Pump Station	Risk Identified by Modeling
Quonset Point	Commerce Park PS	Coastal
	Davisville Pier PS	Coastal
	Davisville PS	Coastal
Smithfield	Burlingame Rd. PS	Backup Power
	Camp St PS	Riverine
	Commerce St. PS	Riverine
	Latham Farm Rd PS	Backup Power
	Log Rd PS	Localized Impacts Possible
	Rogler Farm Rd. PS	Localized Impacts Possible
	Whipple St PS	Riverine
South Kingstown	Birchwood PS	Localized Impacts Possible
	Fairgrounds PS	Localized Impacts Possible
	Hospital PS	Coastal
	Kingston PS	Riverine
	Middlebridge N PS	Coastal; Backup Power
	Middlebridge S PS	Coastal; Backup Power
	Potters Farm	Localized Impacts Possible
	PS#12	Coastal
	PS#5	Coastal
	PS#7	Coastal
	PS#9	Coastal
	Salt Pond PS	Coastal
	Shadow Farm PS	Localized Impacts Possible
	Silver Lake PS	Coastal
	Sweet Allen Farm PS	Localized Impacts Possible
	URI GSO PS	Localized Impacts Possible
	Urycelestial Dr. PS	Localized Impacts Possible
	Waites Corner PS	Localized Impacts Possible
Warren	Asylum Rd PS (Cole School)	Coastal
	Barker Ave. Ej. Sta.	Coastal
	Locust Ter.	Coastal
	Metacom PS	Coastal
	North PS	Coastal
	Patterson Ave	Coastal
	St. Theresa Ej. Sta.	Coastal
	Wood St (East PS)	Coastal

Pump stations listed are those within the WWTF service area and include those owned and operated by other communities or entities for which information was available at the time of this report.

WWTF Service Area	Evaluated Pump Station	Risk Identified by Modeling
Warwick	Bellows St PS (Unnamed, Cranston WWTF)	Coastal - Access; Riverine - Access
	Cedar Swamp Rd PS	Coastal; Riverine
	Glenham St PS	Localized Impacts Possible
	Hilton St PS	Coastal
	Irving Rd PS (Unnamed, Cranston WWTF)	Coastal; Riverine
	Knight St PS	Riverine
	Lake Shore Dr PS	Coastal; Riverine
	Loveday St PS	Localized Impacts Possible
	Oakland Beach PS (Suburban St)	Coastal
	Stanmore St PS	Localized Impacts Possible
	Warwick Lake Rd PS	Localized Impacts Possible
	Williamsburg St PS	Localized Impacts Possible
	Unnamed PS (Greenwich Ave)	Localized Impacts Possible
	Unnamed PS (Greenwich Ave)	Riverine
	Unnamed PS (Lambert Lind Hwy)	Riverine
	Unnamed PS (Lambert Lind Hwy)	Riverine
	Unnamed PS (Shalom Dr)	Localized Impacts Possible
	Unnamed PS (Thrush Rd)	Localized Impacts Possible
West Warwick	Brookfield Hills PS	Localized
	Centerville Rd PS	Coastal
	Clyde PS	Riverine
	Duke St PS	Riverine
	Glen Drive PS	Riverine
	Hardig Rd PS	Localized Impacts Possible
	Natick PS	Riverine
	Quaker Lane PS	Riverine
	Sandy Bottom	Riverine - Access
	Showcase Cinema PS	Localized Impacts Possible
	Unnamed PS (Angelina Rd)	Localized Impacts Possible
	Unnamed PS (Centerville Rd)	Riverine
	Unnamed PS (Cedar Pond Dr)	Riverine
	Unnamed PS (Tollgate Rd)	Localized Impacts Possible
Westerly	Beach St. PS	Coastal; Riverine - Unmapped
	Bradford PS	Localized Impacts Possible
	Margin St. PS	Coastal; Capacity
	New Canal (PS #2)	Coastal; Riverine - Unmapped
	Old Canal (PS#1)	Coastal; Riverine - Unmapped
	Wilson Street	Localized Impacts Possible

Pump stations listed are those within the WWTF service area and include those owned and operated by other communities or entities for which information was available at the time of this report.

WWTF Service Area	Evaluated Pump Station	Risk Identified by Modeling
Woonsocket	Branch River PS	Riverine
	Diamond Hill PS	Localized Impacts Possible
	Main St PS	Localized Impacts Possible
	Manville Rd. PS	Riverine - Access
	Pound Hill Rd. PS	Riverine
	Privilege St. PS	Riverine - Access
	St. Louis PS	Riverine

Note:

1. Apparent flood risk is based on whether the pump station database locations fall within the mapped flood zones defined in this study.

2. This table only lists the 239 pump stations that were provided by RIDEM in February 2015 via GIS shapefile. Of the 72 pump stations identified as "Most Vulnerable" in this study, 12 were not found in the RIDEM GIS Database file and are therefore, not listed in this table. (These include: Broadcommon, Cedar Heights PS, Mettatuxet, Goat Island PS, Washington St CSO Facility, Wellington PS & CSO Facility, Burlingham PS, Farnum Pike PS, Roger Williams Dr PS, East Natick 1, East Natick 2, and Maisie Quinn.)

3. Some modifications to the RIDEM Database list have been made in this table:
    - If a pump station's name or WWTF has been modified based on operator data, the name and WWTF found in the RIDEM GIS file is shown in parentheses.
    - If a pump station is unnamed in the RIDEM GIS file, the name of the street that it is located on is shown in parentheses.

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