REVISED FLOOD MAPS CAUSE WARWICK TO RECONSIDER THE SAFETY OF ITS TREATMENT PLANT

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ABSTRACT

Warwick, Rhode Island's Advanced Wastewater Treatment Facility is located in a natural depression without an outlet and surrounded on three sides by a flood control levee designed in the early 1980s to protect the site to what was then the 100-year flood level. Between March 27, 2010 and March 31, 2010 the City received 22.35 cm (8.8 inches) of rain. The river crested 0.91 m (3 feet) above the top of the dike, flooding the plant with over 3 m (10 feet) of water in a matter of hours. Beginning first with primary treatment and drip disinfection and followed by secondary treatment, the plant saw treatment slowly restored over the course of several weeks. Full recovery of permanent power and control systems took nearly a year due to the lead time associated with the switchgear, motor control centers, and emergency generator. During reconstruction, older equipment was replaced with more energy-efficient equipment using Department of Energy grants and utility rebates. After the flood, the United Stated Geological Survey began the process of updating the area's flood maps to take into account higher river flows and more frequent flooding. As a result, flood mitigation measures being considered include raising the levee surrounding the facility to at least the 500-year flood level, addressing drainage from nearby Interstate 95, and controlling seepage under the levee. This paper examines the emergency response and recovery from the flood, including equipment replacement, electrical system repair, and energy upgrades. Importantly, it then also details the steps taken to mitigate a similar event in the future.

KEYWORDS: Changing Flood Levels, Flood Recovery, Levee Improvement, Energy Efficient Retrofit

INTRODUCTION

Warwick, Rhode Island's Advanced Wastewater Treatment Facility (WWTF) and collection system are operated and maintained by the Warwick Sewer Authority (WSA). The WWTF was constructed in 1965 and discharges treated effluent to the nearby Pawtuxet River. It is designed to treat 29.2 MLD (7.7 mgd) of wastewater with a peak capacity of 67 MLD (17.7 mgd). The WSA currently serves a population of 65,000 residents and 1,500 businesses in the City of Warwick and treats an average of 18.2 MLD (4.8 mgd). The discharge point in the Pawtuxet River is located about 91 meters (300 feet) away. The collection system that transports flow to the WWTF consists of over 434 km (270 miles) of pipe and forty-eight (48) sewage pumping stations, a majority of which are located in low-lying areas adjacent to the City's 63 km (39

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miles) of coastline and the Pawtuxet River, which serves as its border with West Warwick and Cranston.

The WWTF is located in a meander of the Pawtuxet River. The river wraps around the WWTF on three sides, with Interstate 95 (I-95) bordering the WWTF to the east (refer to Figure 1). After repetitive flood damage to the WWTF in the 1960s and 1970s, the City constructed a protective levee in the mid-1980s to protect the WWTF from future damages. The City's Animal Shelter is also located within the confines of the levee. The levee was designed to protect to the 100-year flood level, plus three feet of freeboard. For all but a few days per year, treatment plant effluent flows by gravity to the Pawtuxet River. During times of high water, pumping is needed to convey the final effluent to the river.

Figure 1: Aerial of Warwick WWTF

In March of 2010, record rainfall in Rhode Island caused the Pawtuxet River to crest to the highest levels ever recorded at the United States Geological Survey (USGS) gauge on the Pawtuxet River at the Warwick-Cranston line. Between March 12 and March 15, 2010, Warwick received four straight days of heavy rain. By the end of those four days, the flooding was the worst the Pawtuxet River communities had experienced. Warwick saw localized flooding throughout the collection system, the loss of three pump stations, and a new record high river level (Burke, 2011). Refer to Figure 2 and Figure 3. The WSA staff worked continuously to prevent sanitary sewer overflows by setting up by-pass pumping and otherwise diverting sewage from the damaged areas of the collection system. The WSA sustained approximately $50,000 in damages during this time period.

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Figure 2: Western Side of Levee at Warwick Wastewater Treatment Facility, March 15, 2010. ***Photo by Patrick Doyle.***

Figure 3: Knight Street Pumping Station, located in a Pawtuxet River floodway, during March 15, 2010 flood. ***Photo by Patrick Doyle.***

As O&M crews struggled to get the damaged pumping stations operational, Rhode Island continued to receive more rain. Less than two weeks later, meteorologists and emergency management professionals started to warn local Emergency Management Agencies about heavy rain and flooding predictions. On March 27, 2010, heavy rain began again. On Tuesday morning (March 30th), although it continued to rain hard, the National Oceanographic and Atmospheric Agency (NOAA) was still predicting Pawtuxet River elevations that were below

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the elevation of the WWTF's levee. Over the course of that morning, the WWTF received flows that were five times the average, exceeding the WWTF peak flow rating. The facility experienced frequent, intermittent power losses. The storm drain system for I-95 began backing up and running off into the plant site.

It soon became clear that NOAA was under-predicting the peak river elevation. The Superintendent, in an effort to reduce flows, decided to shut down several pumping stations located in low-lying areas along the Pawtuxet River. The neighborhoods served by these stations had already been evacuated by this time. All non-essential staff were ordered to evacuate the facility at 1:00 pm. At approximately 1:15 pm, the Pawtuxet River breached the western side of the levee and began flooding the treatment facility. The flood waters quickly filled up the approximately 7.3 hectares (18 acres) located within the confines of the levee and then flooded a portion of the highway. Essential staff remained as long as possible to remove and/or secure as many pieces of equipment and documents as possible but had to evacuate at about 1:45 pm on March 30th.

When the storm ended on March 31, 2010 the City had received another 22.35 cm (8.8 inches) of rain. The river crested 0.91 meters (3 feet) above the top of the dike, flooding the plant with over 3 m (10 feet) of water in a matter of hours. Flood waters filled the WWTF campus with an estimated 284 ML (75 million gallons) of stormwater and wastewater, putting an end to all treatment. The flood also completely inundated six (6) pumping station located along the banks of the Pawtuxet River.

This flood was initially classified as between a 100-year and a 500-year event. The month of March set two new records for river level and was the wettest month on record. Figure 4 displays a photo of the site shortly after the levee was breached. Figure 5 displays a photo of the site after the flood waters began to recede.

Figure 4: Pawtuxet River crests the western side of the levee at approximately 1:15 PM on Tuesday, March 30, 2010, and begins flooding the treatment facility. ***Photo by Peter Ginaitt.***

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Figure 5: Flooding at the WWTF on April 1, 2010. ***Photo by Janine Burke.***

EMERGENCY RESPONSE

In the immediate aftermath of the storm, wastewater continued to flow into the non-functioning facility. Every building and pump room on the site was submerged in raw wastewater, river water, and debris. The general contractor who completed the last upgrade was immediately hired under an emergency declaration. The first priority was to pump out the treatment plant campus and assess the damage to the facilities. Re-establishing communications with 47 pumping stations was also a priority. After these initial emergency actions, a short term action plan to place treatment facilities on-line was needed followed by a long-term action plan to include replacing electrical and instrumentation wiring and establishing automatic control of equipment and data collection.

On Thursday, April 1st, portable electrical power was set up. With the river starting to recede by late afternoon, dewatering operations were immediately initiated with any available pumping equipment. O&M staff continued to monitor the 47 pumping stations as all alarms and communication systems had been destroyed. Maintenance crews worked to repair the damaged pumping stations to restore wastewater collection throughout the City.

On Friday, April 2nd, large 0.3 m (12-inch) pumps obtained by contractors began arriving from as far away as Indiana. Once these large pumps were set up, the dewatering operations picked up speed. Damage assessments were initiated as soon as equipment became accessible. Problem areas in the collection system had been successfully by-passed while repairs could be completed. Figure 6 shows some of these portable pumps in the early dewatering operation.

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Figure 6: Portable Pumps Dewatering the WWTF Site. ***Photo by Janine Burke.***

On Saturday, April 3rd, more permanent but still temporary electrical power was established with the cooperation of National Grid. As tanks were dewatered, wastewater flow was directed through the primary and aeration tanks at the plant to the chlorine contact basin where a temporary chlorine drip disinfection process was assembled. Because the river was still high, wastewater could not flow by gravity through the outfall. Temporary pumps were set up at the chlorine contact basin as shown in Figure 7 to pump flow into the river. Because none of the equipment was operational, wastewater flowing to the plant was receiving the rough equivalent of primary treatment and disinfection. The flood water was gone at this point, leaving behind thick layers of sludge and debris. By Sunday, April 4th, maintenance crews succeeded in restoring all remote pumping operations and flushing restrictions were eased.

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Figure 7: Portable Pumps Pumping Effluent. ***Photo by Erik Meserve.***

RESTORATION OF TREATMENT

The week after the storm and after the plant site was dewatered, WSA staff and AECOM developed a critical path schedule to provide a logical restoration plan for treatment facility operations. This plan assessed equipment condition, identified the critical processes and equipment that needed to be restored and in what order, and the method of restoration for each piece of equipment. The short term path included re-establishing forward flow through the process tanks, establishing temporary electrical power to various processes, restoring preliminary and primary treatment and solids handling, and setting up a temporary location for disinfection of wastewater before discharge to the Pawtuxet River. Restoration methods for secondary and advanced treatment were then identified.

As restoration began, portable generators were connected to newly installed temporary electrical patch panels at each of the different buildings. Buildings were cleaned and disinfected, mechanical equipment was inspected and service needs identified and then performed, and electrical motors were either baked or replaced depending on criticality of operations and availability. When replaced, motors over 1HP is size were replaced with Premium Efficiency motors. Beginning first with primary treatment and drip disinfection and followed by secondary treatment, the plant saw treatment slowly restored over the course of several weeks. Figure 8 and Figure 9 display effluent quality during the months after the flood with major milestones noted.

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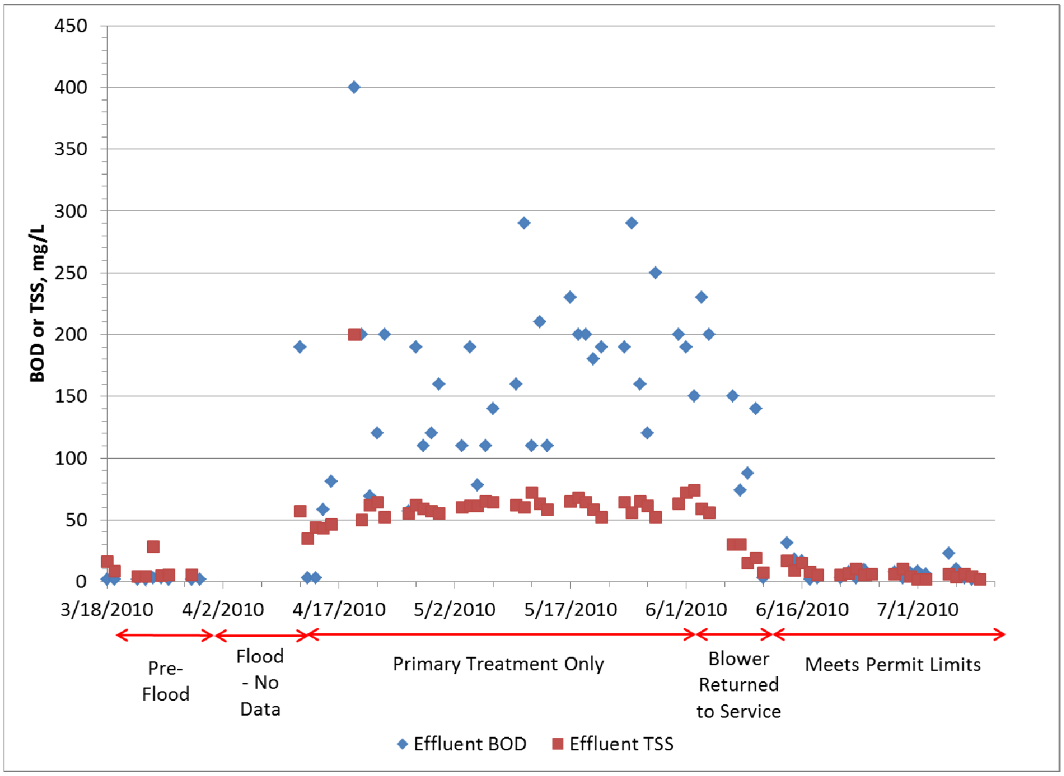

Figure 8: WSA Effluent Data for BOD and TSS

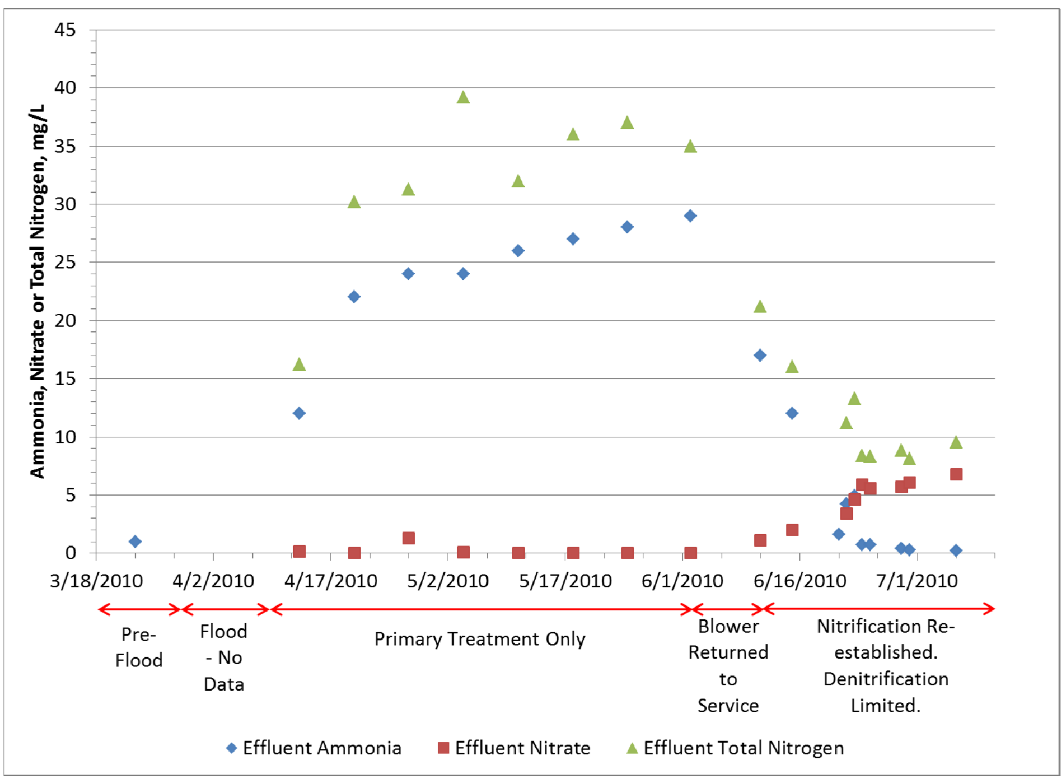

Figure 9: WSA Effluent Data for Ammonia, Nitrate and Total Nitrogen

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By the time the biological nutrient removal process was operating again in mid-July, building cleaning and restoration had progressed enough to allow staff to re-occupy administrative, laboratory, and treatment facility buildings. However, full recovery of permanent power and control systems took nearly a year due to the lead time associated with the switchgear, motor control centers (MCCs), and the emergency generator as well as the sheer number of power and control wires that needed to be replaced. The following sections will detail steps taken in replacing the electrical system and energy efficiency upgrades that were able to be made during plant restoration.

Electrical System Replacement

As the plant was pumped out and systems evaluations were performed and restoration began, it became clear that the critical path to full restoration would be the electrical and control systems. The plant's main switchgear, emergency generator, MCCs, most local control panels, and every conductor on-site had been submerged. This equipment could not be simply re-started without the risk of catastrophic failures due to corroded connections or direct grounds. As a result, a multi-step process was used to bring power back to the site on a temporary basis while replacement equipment was built and while new conductors were installed.

As buildings were pumped out, motors were removed and taken off-site. One motor for each critical system was baked and re-installed to get these systems working again as fast as possible. Standby and non-critical motors were generally baked if it was less expensive to dry them out as opposed to purchase new. As motors were re-installed, new conductors were installed.

Power distribution on the site during this time was initially done via portable generators at each building. Temporary distribution panels were constructed for each piece of equipment and systems were fed via these panels. The main switchgear, emergency generator and MCCs were removed and replacement equipment ordered. To avoid having to run on portable generators for months while this equipment was manufactured, a temporary switchgear was installed and the portable generators were kept on-site as emergency backup. All equipment at this point manually operated and run at a constant speed with the exception of the aeration blowers which were powered through temporary variable frequency drives.

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Figure 10: Temporary Switchgear Housing. ***Photo by Ron Demers.***

Removing and replacing all the conductors on-site would have been extremely time consuming and expensive. Instead, an innovative gaseous nitrogen drying technique was used on conductors 4/0 AWG and larger to speed up restoration and reduce costs. Using this system on smaller conductors was not cost effective. Nitrogen gas at approximately 1.02 atm (15 psi) was forced into each conductor to force the water out of the insulation. This method of drying out the conductors was tried on a small scale at first and then expanded to larger gas manifolds. Refer to Figure 11 and Figure 12 below. Each conductor was dried for a total of approximately four days. At first, water was seen bubbling out of the other end at a constant rate. The rate of water exiting the conductor constantly decreased until it had typically stopped after three days. The protocol used kept nitrogen gas flowing through the conductor for one additional day after the water had stopped. Prior to any drying, all conductors were megger tested to ground and to one another. If the conductor failed the initial test, they were removed and replaced as a failed megger test was an indication of another issue besides water in the insulation. A very small percentage of conductors needed to be immediately replaced. After drying was completed, the conductors were again megger tested to ground and to one another to prove that the insulation was not damaged during the drying process. This recovery method saved the facility over $500,000 and weeks of reconstruction.

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Figure 11: Nitrogen Gas Drying Test. ***Photo by Ron Demers.***

Figure 12: Nitrogen Gas Drying Manifold. ***Photo by Ron Demers.***

While the nitrogen gas drying was completed, electricians began work on replacing all the smaller conductors on-site. The SCADA system prior to the flood relied on hundreds of signaling wires. These were replaced with a new fiber loop that is rated for submergence in case of another flood. The plant ran with this temporary electrical system for approximately five months while the replacement MCCs, switchgear, and emergency generator were manufactured.

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Energy Efficient Replacement Equipment

The flood became an opportunity for WSA to replace some older equipment with more energy-efficient equipment. After the flood, EPA and Warwick looked to replace some of the equipment under a program to identify methods to improve treatment plant efficiency with a goal to a carbon neutral process. The first step in this process was to identify those processes that would qualify. EPA, its vendor, and AECOM worked together to determine which flooded plant processes could qualify for grants or rebates. AECOM then used this list to identify those processes that had a reasonable return on investment (established as less than 10 years) in energy savings and would therefore qualify for funding. Under this program, and utilizing local NGrid utility rebates and a $1M Department of Energy grant, energy efficient motors and variable frequency drives, condensing boilers, instrumentation improvements, and high speed blowers were installed. The cost breakdown is as follows:

- Plant water system ($96,000)
- Blowers and controls ($632,000)
- DO probes ($10,000)
- VFD equipment and motors ($123,000)
- Condensing boilers ($42,000)

This equipment is conservatively estimated to save WSA over 550,000 kwHr per year.

FUTURE STEPS

As a result of the flood, an evaluation of ways to increase flood protection at the facility to withstand a 500-year flood event was completed. The existing flood protection system includes the levee, interior drainage system, effluent pumping, and groundwater seepage control. Flood mitigation measures considered included raising the levee surrounding the facility to at least the 500-year flood level, addressing drainage from nearby I-95 which is either transported through the site via pipeline or enters the local site drainage system, and controlling seepage under the levee. This section summarizes those efforts and the proposed plan for protecting the facility in the future.

Levee Improvements

After the flood, the USGS began the process of updating the area's flood maps to take into account higher river flows and more frequent flooding. Preliminary results indicate that the 100-year flood level will rise by approximately 0.12 m (0.4 feet) and that the 500-year flood level will decrease by more than 1.3 m (4 feet).

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Table 1: Key Levee Elevation Data

Pertinent Elevations	**Feet, NAVD**	**Feet, NGVD**
Current 100-year flood elevation	26.3	27.1
Estimated future 100-year flood elevation as reported by USGS	26.7	27.5
Current 500-year flood elevation	35	35.8
Estimated future 500-year flood elevation as reported by USGS	30.7	31.5
Flood elevation during the March 2010 flood event	30.8	31.6
Minimum top-of-levee elevation (western crest)	27.3	28.1

Based on the results of the USGS model and the desire to protect to the flood of record and likely future 500-year flood elevation, a future levee height of 34 NAVD was selected for the following reasons:

- Meets Federal Emergency Management Agency (FEMA) levee accreditation requirements and is above the 100-year flood elevation,
- Provides over 0.91 m (3-feet) of freeboard for the flood-of-record,
- Provides almost 0.91 m (3-feet) of freeboard above the estimate of the future 500-year flood level,
- Ability to be certified if classified as a critical facility in the future.

Three potential levee alignments were then evaluated. One expanded outward toward the river, one maintained the existing levee alignment, and one expanded inward with an earthen levee and wall system where needed . Of these three alignment alternatives, the option that expands inward was recommended as it is the most feasible to be implemented quickly and had less impact than other alternatives. Outward expansion of the levee presents numerous regulatory hurdles and environmental impacts including construction activities within wetlands and the need for compensatory flood storage and wetland replication. The recommended alignment minimizes impacts to the adjacent wetlands and minimizes expansion on the inboard side of the existing levee. This alignment will require the use of mechanically stabilized earth such as gabion walls or a walled flood protection system so that the expanded footprint does not encroach upon existing or future facilities.

Using the selected levee alignment, an earthen levee in combination with gabion walls in the vicinity of existing structures, a vinyl sheeting floodwall along the entire length of the existing levee, and a combination of these two approaches were compared. All alternatives require use of a new 91.4 m (300 foot) section of vinyl sheeting floodwall to protect the WWTF site from floodwaters passing over a low point along I-95 near the access road to the WWTF. The earthen levee with gabion walls is the least cost option, however, it requires a larger footprint thereby reducing the already limited space on site, placing increased lateral pressure on existing structures, and making future construction of a sixth secondary clarifier difficult. The vinyl sheeting floodwall was the most expensive option but has a very small impact to the site access and onsite structures and is expected to provide the most aesthetically pleasing product. The combination approach is only 15% more expensive than the earthen levee with gabion wall

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option and provides many of the same benefits of the vinyl sheeting floodwall option. After considering the advantages, disadvantages, and the estimated construction cost, the combination earthen levee and floodwall option was selected as it provides a cost effective means to increase the flood protection at the WWTF while not sacrificing inboard space nor making future construction more expensive. This option is expected to cost approximately $3,000,000.

Groundwater Seepage Improvements
There are three modes of levee failure: overtopping, levee failure due to seepage, and breakthrough of groundwater on the inboard side of the levee during an extended period of high floodwaters. Protection against overtopping is being addressed by raising the height of the existing levee. Groundwater seepage through the existing levee is controlled by an existing toe drain system. The toe drains are intended to prevent seepage from channeling or piping through the levee thereby weakening its integrity and stability.

Because the evaluation included looking at an extended period of flooding, preliminary groundwater modeling was performed. This modeling shows that the existing toe drain system continues to provide seepage control and "breakthrough" prevention during the 500-year flood. However, the amount of protection is limited under this stressed condition. Breakthrough on the inboard side is projected to occur in as little as two days. Further refinement of the model following more geotechnical investigation is necessary. At this time, no changes to the existing toe drain system other than extending the clean outs to the grade level of the raised levee are recommended. Maintaining the location of the existing toe drain system will position it in a more central location below the levee and will improve seepage and piping control.

However, a deeper drain system that would operate independently of the toe drain system to prevent breakthrough throughout the site may be recommended pending the results of further groundwater modeling. If necessary and as currently envisioned, this system would be deeper than the existing toe drain and only operate during severe storm events.

Interior Drainage Improvements
Hydraulic modeling was used to evaluate the ability of the existing effluent pump station to process the plant's maximum day wastewater flow and the storm discharge under current and future situations. The model was calibrated to two historical storms, and looked at the 10-, 100-, and 500-year storm events. The effluent pump station is adequately sized for both historical storms, the October 2005 and March 2010 storms, during either the present or future maximum day wastewater flows. The pump station is also able to handle the 10-year storm under present day conditions; however under 2030 conditions, when additional wastewater flows are expected, the firm capacity of the pumps will be exceeded. If all pumps remain operable during the 2030 scenario however, there will be no flooding. The capacity of the pump station is exceeded during the 100-year and 500-year storm events during present and future day scenarios.

It is important, however, to look at the length of time that the pump station is overwhelmed. The peak discharge rates of these design storms do not last long and, as shown in Table 2, the length of time that the pump station is overwhelmed is relatively short and does not necessarily result in large volumes of flooding.

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Table 2: Flood Volumes (acre-feet) and Durations (minutes) for Design Storms

Results Assuming Firm Pump Capacity (91 MLD or 24 mgd)				
	Present		Future (2030)	
	Volume (acre-feet)	Duration (minutes)	Volume (acre-feet)	Duration (minutes)
10-year	-	-	86.3 m^3 (0.07 ac-ft)	19 minutes
100-year	875 m^3 (0.71 ac-ft)	40 minutes	1480 m^3 (1.2 ac-ft)	61 minutes
500-year	3058 m^3 (2.48 ac-ft)	71 minutes	4168 m^3 (3.38 ac-ft)	116 minutes
Results Assuming Total Pump Capacity (121 MLD or 32 mgd)				
	Present		**Future (2030)**	
	Volume (acre-feet)	**Duration (minutes)**	**Volume (acre-feet)**	**Duration (minutes)**
10-year	-	-	-	-
100-year	259 m^3 (0.21 ac-ft)	22 minutes	580 m^3 (0.47 ac-ft)	32 minutes
500-year	1060 m^3 (0.86 ac-ft)	31 minutes	1492 m^3 (1.21 ac-ft)	39 minutes

Upon completion of this hydraulic modeling, it was decided that no changes would be made to the existing interior drainage system. The area and depth of flooding on-site during the 100-year storm was mapped and minor modifications will be made to the structures in these areas (raising walls of the chlorine contact tank and relocating some electrical panels) to protect them against this short-term flooding. In the opinion of the WSA and AECOM, the benefits of upgrading the existing system for full protection against the 100-year storm event or protecting against a 500-year storm for the interior drainage system with no site flooding did not justify the cost. The 100-year storm event will result in small-scale, short-term flooding on the northwestern corner of the site that will be easily mitigated. The 500-year event is extremely rare (a 0.2% chance of occurring in any given year), and, as seen in Table 2, the volume and duration of a 500-year flood inside the levee would be similar to the volume and duration of the 100-year storm event if all the effluent pumps are operated. At most, the flooded area will amount to two feet of water depth in the flooded area. Additionally, the 100-year design level is consistent with FEMA's regulations for accreditation.

CONCLUSIONS

Total damages from the flood were approximately $15 million, $10 million of which was covered by insurance. The City hopes to recoup 90% of the remainder of the damages from FEMA. By far, the majority of damage and cost was related to the electrical systems. The WSA has applied for grants from both FEMA's hazard mitigation program as well as the Economic Development Administration's supplemental disaster relief funds, and has also explored numerous other grant opportunities. To prevent the treatment facility from flooding in the future, the City has begun the process of raising the levee and improving both the groundwater seepage and interior drains systems to protect against the 500-year flood. The City plans to recoup the construction costs for this effort through grant funding.

Although FEMA regulations and many local regulations commonly require the levee to protect to the 100-year flood level, storm events in the Pawtuxet River basin are more frequent than in the past as is the greater intensity of these storms. Communities with similar critical infrastructure protected by levees should consider the impacts of these storm events to preclude

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the major cost implications to repair the damage. The benefit of raising levees from a 100 year to a 500 year level may not be that costly. In the case of Warwick, the benefit to cost ratio is greater than 6.0, even for the 500 year event. Communities should evaluate the level of protection their current levee provides, perform a risk assessment, and evaluate the benefit of raising the levee height or look into means of reducing the impact on a critical facility.

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