Ultraviolet Light Disinfection
Preliminary Design Report

Easton Beach
Newport, RI

November 2008

FUSS & O'NEILL
Disciplines to Deliver

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UV LIGHT DISINFECTION PRELIMINARY DESIGN REPORT
City of Newport, RI

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1.0 EXECUTIVE SUMMARY

Fuss & O'Neill, Inc. (Fuss & O'Neill) was retained by the City of Newport (City) to conduct a preliminary (60%) design of an ultraviolet light (UV) disinfection system of the Moat discharge to Easton's Bay. The goal of this proposed disinfection system is to significantly reduce bacteria loads that are discharged from the Moat during wet weather events. Work previously completed and related to this preliminary design included the Easton Pond Dam and Moat study and the on-site UV disinfection pilot study.

The Easton Pond Dam and Moat Study (2007) that was commissioned by the City identified the Moat discharge as the primary source of wet weather bacteria loads to Atlantic and Easton Beach. This study also identified two Town of Middletown-owned outfalls that were also significant sources of bacteria to those beaches. The City of Newport, Town of Middletown and Rhode Island Department of Transportation contribute runoff to the Moat.

The Easton Pond Dam and Moat Study recommended UV disinfection as the most efficient means to reduce bacteria loads from the Moat discharge for several reasons. That study found that conventional stormwater controls used to reduce bacteria loads were not as feasible in this watershed because of several physical and hydrogeologic constraints. UV disinfection had the unique benefits of being able to treat most of the runoff from the watershed while consistently providing disinfection of the discharge from the Moat. The study identified several potential design issues, which required evaluation to determine feasibility of a UV disinfection system. Potential design issues included: assessment of whether turbidity in the Moat discharge will limit the effectiveness of a UV system, evaluation of whether a UV system will exacerbate or alleviate flooding in the Moat, and evaluation of whether adequate electrical power is available for a UV disinfection system.

In the Fall 2007, the City commissioned a pilot test of a UV disinfection system at the Moat. The results from this pilot testing are described in the report titled "Ultraviolet Light Disinfection Pilot Study Report" dated December 2007. Pilot testing was completed over several storm events during the study period and was conducted at about 1/20 scale of a full size system. The pilot testing concluded that UV disinfection reduced bacteria loads to concentrations that are at or below the beach closure standard (104 cfu/100 ml). However, piloting found full-scale design must address challenges such as protection of the UV system from shoaling and large solids contained in the Moat discharge.

The purpose of this preliminary design was to confirm the feasibility of this system and to better understand project costs. The following paragraphs summarize major

recommendations for the UV disinfection system proposed for the Moat discharge generated during preliminary design.

Design Criteria

- The system should be designed for a peak flow of 96 cubic feet per second. This peak flow is consistent with the Water Quality Volume that is regulated by the Rhode Island Department of Environmental Management (RIDEM) for the existing watershed. This storm equals or exceeds 93% of all storm events in the Newport area. While this flow does not include runoff from the Esplanade, Esplanade flow can be accommodated by the UV disinfection system, provided the total peak flow does not exceed 105 cfs, which is the maximum capacity of the single-channel system. Flow from the existing Moat and Esplanade watersheds are not necessarily additive, and Middletown should evaluate whether hydrologic controls allow the Esplanade to be discharged to Moat within the peak 105 cfs criteria.

- Disinfection criteria for effluent from the UV system should have a 30-day geometric mean of 104 cfu/100 ml. While the beach closure standard is 104 cfu/100 ml, the geometric mean accounts for 30-50% dilution available within 300 feet of the Moat outfall and is a more reasonable performance standard for manufacturers to achieve, as opposed to an absolute numerical limit.

- Since Easton's Bay provides only 30 to 50% dilution within 300 feet of the Moat outfall, no significant dilution (5:1, 10:1 or 50:1 ratios of Easton's Bay to Moat discharge) is considered for process design purposes.

Hydraulics

- The hydraulic analysis of the Moat and UV disinfection system showed an increase water surface elevations in the moat during design storms by about 24 to 30-inches, which will exacerbate flooding conditions along the Moat. The system cannot operate by gravity alone. A pump system is therefore required to convey water from the Moat to the UV disinfection system channel.

- With a pump system, the hydraulics of the Moat may also accept the discharge from the Esplanade without any significant additional flooding in the Moat.

- Moat and UV System hydraulics must be designed to account for future sea level rise. An average sea level rise of 0.65 inches per year was used in preliminary design, which is consistent with the worst-case projections that are being offered by the Rhode Island Coastal Resources Management Council (CRMC). At this rate after 25 years, high tide would be about 16.3 inches higher than current levels. A 16.3-inch sea level rise was incorporated into the preliminary design.

Siting

- The open grassed area just north of Memorial Blvd bridge is the most appropriate location for installation of the UV disinfection system. This location protects the UV disinfection system from shoaling and storm surges compared to alternative locations south of the bridge. The recommended single-channel configuration also minimizes the need to relocate existing utilities to the west of the pump station. Other UV channel configurations or locations to the north of this site will require either relocating existing sanitary force mains or creating two UV systems to treat the eastern and western portions of the moat.

- The geotechnical analysis found that a deep foundation system will be required for this site. Timber piles were identified as the most conventional system, and one that can be completed by several local contractors.

UV System Design

- A wide range of alternative UV disinfection systems were evaluated during the preliminary design. Our study found that only conventional UV systems have been developed to the point where they have the capacity to reliably manage the flows that are expected for this system. After screening potential systems, we issued a Request for Information (RFI) to five vendors to provide detailed information on their systems. One vendor who was the primary supplier of microwave systems in the United States only responded with a letter stating that the microwave technology has not yet been developed to the scale that it could be employed on this project.

- Based on evaluation of each UV vendor's response to our RFI, Trojan UV received the highest point total for the qualitative analysis. Wedeco, Aquionics and Calgon also submitted responses. The proposed Trojan UV system has the lowest estimated opinion of construction cost and 20-Year Life Cycle Cost. Trojan UV was the only vendor to offer a life time guarantee to meet the 104 *Enterococci* colonies/100 ml RIDOH beach standard (30-day geometric mean). The UV disinfection system proposed by Trojan UV was the only single channel design, which results in the smallest foot print for construction and site disturbance. Given their small construction foot print, there is no apparent need for sewer line relocation under the selected Alternative location #2.

- All UV system vendors indicated their system designs are sensitive to flow. Significant increases in design flows will increase project footprint and costs.

For example, the Trojan UV system with a single channel configuration as proposed could manage a peak flow with desired treatment results of up to 105 cfs. Peak design flow greater than 105 cfs will require adding another channel, in effect doubling UV channel footprint and increasing equipment costs.

- Pretreatment systems for large solids/particulate removal were reviewed and incorporated in preliminary design to minimize potential damage to the pump and downstream UV disinfection equipment. RFI's were provided to four vendors, and three responded. Lakeside Equipment Corporation appeared to have the best suited equipment for this project largely because its bar screen has no moving parts below the Moat water surface.

- In summary, this system will consist of a by-pass weir that will be automatically closed with rainfall and opened after the storm event passes. The pump and UV system will be activated and deactivated in conjunction with closing and opening the weir, respectively. Water diverted from the Moat by the by-pass weir will drain through the bar screen to a pump(s) that will convey the water up to the UV system. UV lamp intensity (i.e. UV dose) will be controlled using a UV transmittance sensor that will provide process feedback so that automated system adjustments provide the required UV dose.

- We have developed an opinion-of-construction cost of $5.377 million and a 20-year life-cycle cost of $21.624 million through preliminary design, which is based on current electricity costs to Newport and based on the premise of operating the UV lamps at 100% intensity for 48-hours during each of fifty four (54) rain events annually. Life cycle costs are conservative. These projections are higher than what was developed as part of the conceptual design. There are several reasons for this including:

  - RIDOT and Middletown Wave Avenue pump station outfalls must be relocated to discharge upstream of the Moat diversion weir.

  - A pump station is required to prevent exacerbation of flooding along the Moat.

  - An influent screen to remove large particulate matter and debris carried by the Moat.

  - National Grid will need to invest in some capital improvements in order to deliver the required power to this system. Preliminarily, National Grid has reported that $150,000 to $200,000 of capital improvements may be required to bring necessary service to the UV disinfection system. These costs may be shared with the City.

- Deep foundations are required for this site.
- The area of influence within the Moat at the UV system intake and discharge will require reinforced construction using cable concrete along the Moat bottom.
- A building to house the new electrical service is required due to its size.

2.0 INTRODUCTION

Fuss & O'Neill was retained by the City of Newport to conduct a preliminary design of a full-scale UV disinfection system for the Moat discharge to Easton Beach. Elements of our preliminary design include addressing the following significant questions that remain:

- What system layout will minimize the impacts of this system on moat hydraulics? We need to design this system to minimize any impacts on flooding in the moat.
- Where would the system best be located to minimize costs and operation and maintenance issues?
- What level of pretreatment will be required?
- What are the subsurface conditions on this site and how will they impact structural design and construction dewatering?
- What level of dilution is available at the beach and how does that impact costs?
- What improvements will be required to deliver power to this site?
- What other site improvements (e.g. pumps, gates, weirs, etc) are needed for a full scale system.
- What should the City budget for the construction and operation of this project?
- What operation and maintenance (O/M) is required for a full scale system? What impacts do O/M requirements have on annual operating costs?

2.1 Background

Easton Beach and Atlantic Beach are located in Newport and Middletown, respectively. The Moat is a manmade channel that surrounds the South Pond on its west, south, and east sides. The southern end of the Moat meets the eastern end of the Moat at the spillway to the South Pond. It then flows under Memorial Boulevard, splitting Easton Beach and Atlantic Beach and enters Easton's Bay between these two beaches. Over the past five years, these beaches have attracted the attention of City residents, beach goers, and State and City officials due to high bacteria levels that have closed the beaches during and after rainfall events. Sheet 1 shows existing conditions of the site.

The entire watershed that drains to the Moat is 5.3 square miles in size; however, runoff from certain portions of the watershed is dampened by North and South Ponds. Overflow from South Pond's spillway discharges to the Moat only when water levels in the pond are high. The watershed that drains directly into the Moat is almost one square mile in size. Sheet 2 provides an overview of the Moat's watershed, which is largely built-out with significant amounts of connected impervious surfaces with much of the soils being characterized as poorly draining. As a result, this watershed can generate significant amounts of flow.

Fuss & O'Neill was retained by the City of Newport to complete an investigation of the sources of bacteria that are impacting this beach. The results of this study are detailed in the "Final Report Easton Pond Dam and Moat Study" dated September 2007. This study concluded that the Moat and several other outfalls owned by the Town of Middletown and Rhode Island Department of Transportation (RIDOT) were the primary sources of contamination at this beach. The Moat was also identified as having the greatest potential to impact the beach compared to these other sources because of its comparatively large bacteria load, however, water quality being discharged from these other sources also needs to be addressed.

As discussed in the study, a wide range of alternatives were considered to reduce bacteria loadings to and from the moat. Alternatives considered included both structural and non-structural approaches. Based on the analysis presented in the report, ultraviolet (UV) disinfection was determined to be the method with the best potential to reduce bacteria loadings to a level that would meet beach closure standards.

To provide proof-of-principal and data for the design of a full-scale UV treatment system, the Dam and Moat Study recommended an on-site UV disinfection pilot study to further evaluate the potential for UV disinfection to treat the moat discharge. A pilot study was commissioned by the City and conducted by Fuss & O'Neill during the summer and fall of 2007. The 3 million gallon per day (MGD) pilot UV disinfection system was operated by Fuss & O'Neill from September 15, 2007 to November 3, 2007. Water was pumped from the Moat into the pilot plant and treated by exposure to UV light prior to discharge back to the Moat approximately 100 feet downstream of the pilot intake point. The first objective was to confirm that a UV system would be effective in reducing bacteria loads to improve water quality at the beach. The second objective was to collect operational data that would be needed for final design of a full-scale UV disinfection system. Data required for full-scale design includes UV transmittance and Total Suspended Solids (TSS) of the moat discharge with related UV dose/sample response. Operation of the pilot plant was augmented by bench-scale UV disinfection testing (collimated beam testing) on stormwater collected from the Moat.

Based on data from the on-site pilot and collimated beam studies, UV disinfection was determined an effective technology for reducing *Enterococci* colonies in the Moat effluent to meet the beach closure standard of 104 *Enterococci* colonies/100 ml. Refer to Fuss & O'Neill report entitled "Ultraviolet Light Disinfection Pilot Study Report" dated December 2007 for further information and discussion of the pilot study.

2.2 Beach Closure Data

Beach closures at both Easton Beach and Atlantic Beach Club Beach occur from mid-May through Labor Day. The Rhode Island Department of Health (RIDOH) Beach Monitoring Program has a formal protocol for monitoring and closing Easton Beach. The 2008 protocol is attached in Appendix A. However, based on a review of closure and weather data RIDOH typically closes the beach if total depth of rain in the last 48 hours equals or exceeds 0.5 inches. RIDOH's use of adjusted protocol was confirmed by email (see Appendix A); however, this email did not confirm our specific observation that closures occur as a matter of course for rainfall depths of 0.5 inches in a 48-hour antecedent period. Table 1, below, provides a tabular summary of weather and *Enterococci* data on days during which the beach was closed at Easton Beach.

Table 1
Weather and *Enterococci* Data at Easton Beach
During Beach-Closure Days (June 2004 – August 2008)

Date	Depth of Rain that Day (inches)	Rain in Last 48 hours?	*Enterococci* Data (cfu/100 ml)			
			East	Center	West	Stream Mouth
July 29, 2004	Trace	Yes	NR[b]	NR	NR	NR
August 6, 2004	Trace	Yes	NR	NR	NR	NR
August 15, 2004	2.11	Yes	NR	NR	NR	NR
August 16, 2004	0.15	Yes	124	24192	24192	NR
August 17, 2004	0.01	Yes	NR	NR	NR	NR
August 31, 2004	0.99	Yes	NR	NR	NR	NR
September 1, 2004	0.01	Yes	31	24192	72	NR
August 30, 2005	2.6	Yes	17329	6488	2755	24192
June 7, 2006	2.78	Yes	24192	309	345	14136
June 25, 2006	1.13	Yes	NR	NR	NR	NR
July 6, 2006	0.56	Yes	2382	1291	1145	14136
July 11, 2006	0	No	NR	NR	NR	NR
July 12, 2006	0.3	No	NR	NR	NR	NR
July 13, 2006	0.65	Yes	107	63	41	960
August 29, 2006	0.08	Yes	NR	NR	NR	NR
June 4, 2007	2.14	Yes	278	384	262	241912
June 5, 2007	Trace	Yes	NR	NR	NR	NR
August 10, 2007	1.00	Yes	20	214	61	51
August 11, 2007	0	Yes	NR	NR	NR	NR
July 24, 2008	1.52	Yes	NR	NR	NR	NR
July 25, 2008	0	Yes	NR	NR	NR	NR
July 26, 2008	0	Yes	NR	NR	NR	NR
August 6, 2008	0.27	Yes	10	41	61	74

Notes:

a. Sources: All data from RIDOH http://www.ribeaches.org/beach.cfm?beachID=RI381265; and unpublished data from RIDOH unless otherwise indicated.
b. "NR" means no sampling reported by RIDOH.

Generally speaking, Easton Beach is closed only when substantial rain occurs. There were four days, however, during which the beach was closed, but rain did not occur. These days are July 11, 2006, August 11, 2007, July 25, 2008, and July 26, 2008. Below is a brief discussion of each of these days:

- July 25, 2008 and July 26, 2008—Although no rain occurred on July 25 or July 26, heavy rains occurred on July 24, 2008 (i.e., 1.52 inches). No *Enterococci* sampling was conducted by RIDOH on either July 24,July 25, or July 26; therefore, we conclude the closures on July 25 and July 26 were due to rains that occurred on July 24.

- June 5, 2007—A trace amount of rain occurred on June 5; however, substantial rains occurred on June 4 (2.14 inches). No sampling was conducted by RIDOH on June 5. We conclude that the closure on June 5 was due to the rain on June 4.

- August 11, 2007 – No rain occurred on August 11; however, substantial rains occurred on August 10 (1.0 inches). No sampling was conducted by RIDOH on August 11. We conclude that the closure on August 11 was due to the rain that occurred on August 10.

- July 11, 2006—No rain occurred on July 11; however, substantial rains occurred on July 12 and July 13 (0.3 inches and 0.65 inches, respectively). No sampling was conducted by RIDOH on July 11 or July 12. We conclude that rain must have been predicted for July 11, but that sampling was not possible and the beach was closed as a precaution.

In summary, only one of these closure events was not related to a wet weather event. Wet weather is the primary cause of closures to Easton Beach. Atlantic Beach Club is located adjacent to Easton Beach, but does not have a formal protocol for beach monitoring. Table 2, below, provides a tabular summary of weather and *Enterococci* data on days during which the beach was closed at Atlantic Beach Club.

Table 2
Weather and *Enterococci* Data at Atlantic Beach Club
During Beach-Closure Days (June 2004 – August 2008)

Date	Depth of Rain that	Rain in Last 48	*Enterococci* Data (cfu/100 ml)

			Center	Esplanade Outfall 1 (Beach)	Esplanade Outfall 2
July 29, 2004	Trace	Yes	84	NR	NR
August 6, 2004	Trace	Yes	85	NR	NR
August 15, 2004	2.11	Yes	NR	NR	NR
August 16, 2004	0.15	Yes	NR	NR	NR
			31	NR	NR
			30	NR	NR
August 17, 2004	0.01	Yes	20	NR	NR
August 20, 2004	0.03	No	24192	NR	NR
August 21, 2004	0.71	Yes	NR	NR	NR
August 22, 2004	0	Yes	NR	NR	NR
August 23, 2004	0.01	Yes	NR	NR	NR
August 31, 2004	0.99	Yes	NR	NR	NR
September 1, 2004	0.01	Yes	61	NR	NR
August 30, 2005	2.6	Yes	17329	NR	NR
August 31, 2005	Trace	Yes	63	NR	NR
June 7, 2006	2.78	Yes	24192	NR	NR
June 8, 2006	0.01	Yes	355	NR	NR
June 9, 2006	0.12	Yes	110	NR	NR
June 10, 2006	0.24	Yes	NR	NR	NR
July 11, 2006	0.05	No	NR	NR	NR
July 12, 2006	0.27	Yes	NR	NR	NR
July 13, 2006	0.65	Yes	256	2755	NR
July 14, 2006	0	Yes	359	1669	NR
July 15, 2006	0	Yes	NR	NR	NR
July 16, 2006	0	No	NR	NR	NR
July 17, 2006	0.01	No	NR	NR	NR
			86	323	NR
			20	NR	NR
July 18, 2006	0.64	Yes	10	NR	NR
July 19, 2006	0.16	Yes	231	NR	NR
July 20, 2006	0.04	Yes	NR	NR	NR
July 21, 2006	0.01	No	30	932	NR
July 22, 2006	0.25	Yes	NR	NR	NR
July 23, 2006	Trace	Yes	NR	NR	NR
July 24, 2006	0	Yes	10	433	NR
July 29, 2006	0.01	Yes	NR	NR	NR
July 30, 2006	0	Yes	NR	NR	NR
August 1, 2006	0	No	NR	NR	NR

Date	Depth of Rain that Day (inches)	Rain in Last 48 hours?	*Enterococci* Data (cfu/100 ml)		
			Center	Esplanade Outfall 1 (Beach)	Esplanade Outfall 2
August 2, 2006	0.01	No	40	30	NR
August 28, 2006	1.94	Yes	2282	15,530	NR
August 29, 2006	0.11	Yes	NR	NR	NR
May 31, 2007	0.04	No	NR	NR	NR
June 4, 2007	2.14	Yes	5475	NR	NR
June 5, 2007	T	Yes	NR	NR	NR
June 17, 2008	Trace	Yes	NR	NR	NR
June 19, 2008	0	No	NR	NR	NR
June 24, 2008	0.37	Yes	84	9208	NR
June 25, 2008	0	Yes	20	2723	NR
July 1, 2008	0	No	NR	NR	NR
July 10, 2008	0.13	No	NR	NR	NR
July 11, 2008	0	No	NR	NR	NR
July 15, 2008	0	No	NR	NR	NR
July 25, 2008	0	Yes	NR	NR	NR
July 26, 2008	0	Yes	NR	NR	NR
August 1, 2008	0	No	NR	NR	NR

There are several dates on which Atlantic Beach Club was closed yet the closures did not seem to follow the formal or alternative rationale for closing Easton Beach. Possible explanations for such closures include the presence of seaweed mats in the water and wrack management procedures.

According to RIDOH, Atlantic Beach Club Beach experienced significant seaweed in early summer 2008 and, as a result, was closed quite often. Although Easton Beach experienced seaweed in late summer 2008, sampling was conducted both in and out of the seaweed to determine seaweed's actual impact on the beach. Appendix A also provides correspondence with RIDOH explaining this rationale along with a discussion of other typical factors weighed in determining beach closures.

To address closures, RIDOH will have to agree that the proposed UV treatment system will effectively reduce pathogen levels associated with rain events such that they change their automatic closure protocols. The City should, therefore, continue to take steps to develop clear consensus with RIDOH around this issue.

3.0 HYDRAULIC ANALYSIS

Because of historic flooding problems in the Moat, the hydraulic performance of the Moat is a critical issue that needs to be addressed when considering the installation of a UV disinfection system to treat Moat storm water runoff. Installing a UV disinfection system adjacent to or in-line with the Moat will create additional energy or head loss in the Moat that will cause water levels to rise upstream of the system. Therefore, the objective of our hydraulic analysis was to select a location and a design for this system that will minimize increases in Moat water surface elevations during storm events, thereby minimizing impacts to flooding currently experienced along the Moat.

The Easton Pond Dam and Moat Study, dated September 2007, relied upon a HEC-RAS model to understand hydraulic conditions in the Moat. Although this model was initially used to assess the hydraulic performance of the Moat during storm events, no physical or actual data was available at that time to calibrate the model. Hydraulic data was collected in the Moat, in the vicinity of the Memorial Boulevard Bridge, from May through July 2008. This data was used to calibrate the hydrologic and hydraulic models under existing conditions and to evaluate several proposed scenarios for the location, size, and design of the UV disinfection system.

3.1 Field Data Collection

The following data was collected for model calibration/verification purposes:

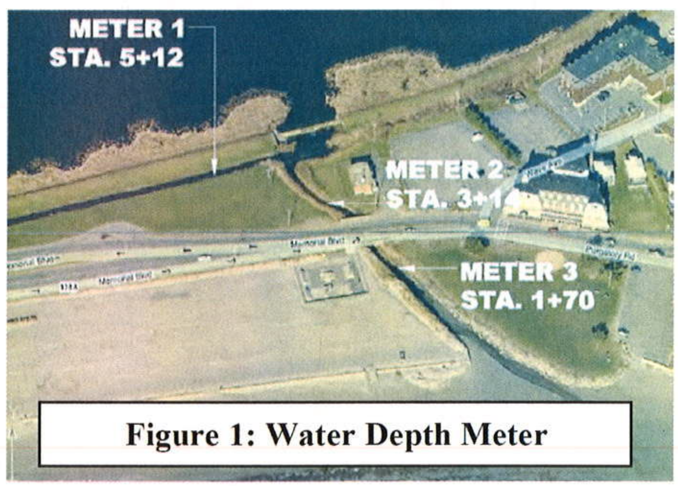


Figure 1: Water Depth Meter

- **Water depth measurements at three locations within the Moat adjacent to Memorial Boulevard Culvert, as indicted in <u>Figure 1</u>.** Meter 1 was located approximately 250 feet north of Memorial Boulevard, slightly upstream of the confluence of the Newport and Middletown sections of the Moat. Meter 2 was located approximately 50 feet north of Memorial Boulevard, downstream of the confluence of the Newport and Middletown section of the Moat. Meter 3 was located approximately 40 feet south of Memorial Boulevard. The measurements were taken over a one month period between May 6, 2008 and June 5, 2008 at five-minute intervals. During that time frame, six storm events with total precipitation amounts in excess 0.10 inches over a 24-hour period occurred. Refer to Appendix B for summaries of the depth measurements collected.

- **Velocity measurements of flow passing through the Memorial Boulevard Culvert**. Velocity measurements were taken between June 12, 2008 and July 15, 2008 at ten-minute intervals. During that time frame, several storm events occurred. The most significant and intense of these storm events occurred on June 16, 2008. This storm yielded a total of 0.56 inches of rainfall over a 3-hour period (between 9:30 PM and 12:30 AM). Refer to Appendix C for summaries of the velocity measurements collected.

- **Supplemental Channel Geometry.** A major component in calibrating the hydraulic model of the Moat was the incorporation of supplemental topographical information of the Moat and its adjacent bank areas. Twenty-two (22) channel cross-sections were added to the hydraulic model upstream of Memorial Boulevard while nine channel cross-sections were added to the model downstream of Memorial Boulevard. Refer to Figure 2 for a depiction of the location of the additional and previously surveyed cross-sections used in the analysis in the vicinity of the Memorial Boulevard culvert. The sections in red indicate newly surveyed sections, while the sections in gray indicate previously surveyed sections.

Figure 2
Additional Cross Section Locations

3.2 Model Calibration

The previous hydrologic and hydraulic models were calibrated to better represent actual flow conditions experienced within, and conveyed by, the Moat during dry weather (base flow) and wet weather (storm flow) conditions.

3.2.1 Base Flow Calibration

Water depth measurements recorded by each meter (between May 6th and June 5th) were averaged during dry-weather conditions. The computed average water depths at each location within the Moat were then used to calculate the average base flow experienced at each meter location within the Moat.

FlowMaster, a FEMA-approved software program used to perform hydraulic calculations for pipes and open channels, was utilized to compute the base flows at each meter location. In order for the program to compute peak flow rates conveyed by the Moat, the slope of the Moat, the depth of flow, and the cross-sectional channel geometry were required at each meter location. The overall average slope of the Moat, as opposed to the slope of the Moat at each meter location, was utilized since slope variations occur locally throughout the Moat. The following table summarizes the results of our base flow computations:

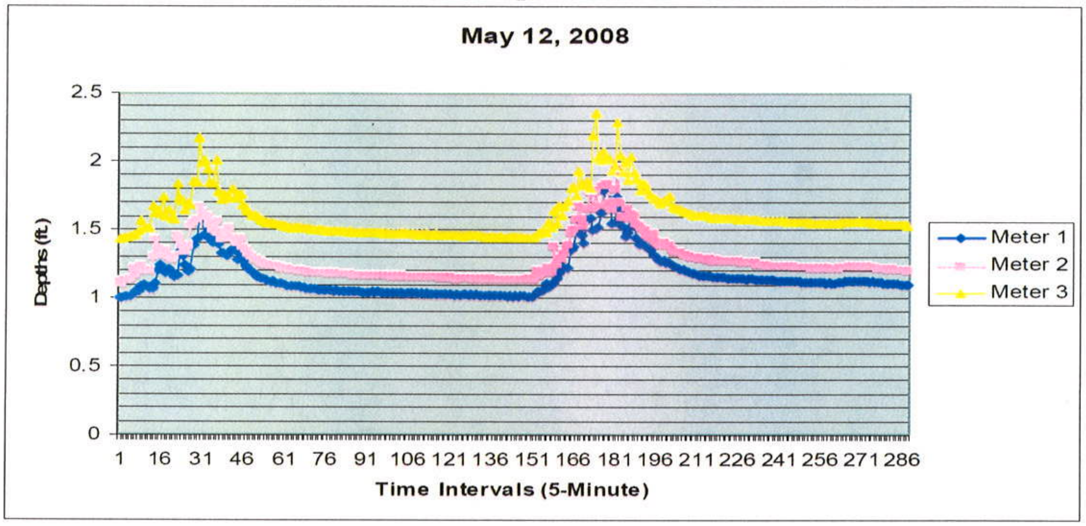
Table 3
Base Flows in Moat

Meter Location	Avg. Flow Depth (feet)[1]	Base Elev. of Channel (feet)	Average Water Surface Elevation (feet)[2]	Computed Base Flow (cfs)[3]
Meter 1 (Sta. 05+12)	1.08 feet	2.24 feet	3.32 feet	12.49 cfs
Meter 2 (Sta. 03+14)	1.51 feet	1.79 feet	3.30 feet	13.39 cfs
Meter 3 (Sta. 01+70)	1.83 feet	1.36 feet	3.19 feet	16.50 cfs

Notes:
1 The average flow depths at each meter location were computed by averaging the depths of flow recorded during dry-weather conditions between May 6, 2008 and June 5, 2008 at five-minute intervals.
2 The average water surface elevations were computed by combining the average depth of flow at each meter with the base elevation of the Moat channel (as determined by Survey) where each meter was located.
3 The base flows were computed using FlowMaster.

As determined through velocity data recorded and illustrated by Figure 3, the Moat is tidally influenced as it receives an influx of saltwater from Easton Bay during the semi-diurnal tidal cycle. As a result, water surface elevations in the Moat are also impacted by high tides. Therefore, the computed base flows are anticipated to be slightly conservative since the computed average depths include spikes in water depths that occurred during high tide events. Please refer to Appendix D for base flow computations.

Figure 3
Typical Moat Depths over 24-Hour Period



3.3 Storm Flow Calibration

Velocity data recorded between June 12, 2008 and July 15, 2008 (at ten-minute intervals) was compared to rainfall data recorded from the Naval Underwater Warfare Center (NUWC) weather station in Middletown during the same time frame. As anticipated, the highest velocity measurements recorded corresponded to the most significant storm events that occurred during that period. The storm event selected for calibration occurred on June 16, 2008 and yielded a total of 0.56 inches of rainfall over a 3-hour period (between 9:30 PM and 12:30 AM). The maximum velocity recorded within the Memorial Boulevard culvert (of 1.37 cubic feet per second) occurred on June 16, 2008 at 11:10 PM. High tide on June 16th occurred at 7:10PM while low tide occurred on June 17th at 1:32AM.

Although depth readings within the Moat were not recorded during the June 16th storm event, a storm event with a similar magnitude and duration occurred on May 20, 2008 between 5:45PM and 10:05PM in which depth readings were recorded. This storm produced 0.44 inches of rainfall over an approximate four-hour period. Therefore, it was assumed (for model calibration purposes) that the water surface elevations/depths recorded at the three meter locations during the May 20th storm event should theoretically correlate to the depths that occurred within the Moat during the June 16th storm event. Refer to Appendix E for rainfall data recorded at the NUWC for both events. It should be noted that the time at which the peak rainfall occurred during this storm (between 7:45PM and 7:50PM) closely corresponded to the time at which high tide occurred on May 20th (at 8:56PM). Therefore, the depth recorded during this time may result in a slightly conservative estimate of peak flows used for calibration because depths may be somewhat impacted by high tide, creating a larger cross-sectional area from which peak flow is calculated.

The following equation, known as the Continuity Equation, was then used to compute the peak flow rate discharged through the culvert during the June 16th storm event:

$Q=VA$ where Q=flow (in cubic feet per second)
V=velocity of flow (in feet per second)
A= cross-sectional area of the culvert (in sq. feet)

Since the peak velocity (V) was measured to be 1.37 feet per second, the only variable remaining to be computed was the cross-sectional area (A) of flow within the culvert. To approximate this, the width of the culvert (measured to be approximately 10 feet) in addition to the depth of flow experienced within the culvert during the May 20th storm event (approximately 2.4 feet at 8:18PM) was used. Therefore, the cross-sectional area of flow estimated to occur within the Memorial Boulevard culvert during the June 16th storm event was 24 square feet. With the velocity and cross-sectional area known, the total peak flow experienced during this storm event was calculated to be approximately 32.9 cubic feet per second (cfs) including a base flow of 13.4 cfs. Therefore, storm flow generated during this storm event was estimated to be 19.5 cfs (32.9cfs – 13.4cfs).

This calculated storm flow rate was used to calibrate the hydrologic model and determine the flow conveyed by the Moat during selected storm events, including the water quality storm event. Since the hydrologic model is based on a 24-hour storm duration, the Atlas of Short-Duration Precipitation Extremes for the Northeastern United States and Southeastern Canada (May 1995) published by Cornell University was utilized to translate the 3-hour storm event into a 24-hour storm event. Using the Huff and Angel factor as presented in this publication, 3-hour precipitation amounts can be correlated to 1-day storm event amounts by dividing the 3-hour rainfall amount by a factor of 0.72. This resulted in an equivalent precipitation amount of 0.78 inches over a 1-day storm event. This storm event was then input into the "un-calibrated" hydrologic model to determine how closely the model represented actual conditions. Using the "un-calibrated" hydrologic model, a peak flow of approximately 28 cfs was computed for the June 16th storm event which was approximately 1.4 times larger than the estimated actual peak flow rate of 19.5 cfs.

In comparing the time at which the peak rainfall intensity occurred during the June 16th storm (at 10:15PM) versus the time at which the peak flow velocity was experienced within the Memorial Boulevard culvert (at 11:10PM), it was concluded that the Moat provides for some detention (flood storage) of storm flows and increased flow travel times due to its length and relative flatness. To account for this, the Moat was modeled as a reach. Subsequently, the peak flow rate conveyed by the Moat within the Memorial Boulevard culvert was computed to be approximately 20.4 cfs (excluding base flow). This corresponded to the actual peak flow rate recorded during the storm event of 19.5 cfs (excluding base flow). It was, therefore, concluded that detention (flood storage) provided by the Moat was significant enough to impact peak flow rates conveyed by the Moat.

With the hydrologic model calibrated to account for detention and increased flow travel times provided by the Moat channel, the following table illustrates calibrated peak flow rates conveyed by the Moat at several cross-sections throughout the Moat for selected storm events:

Table 4
Peak Flow Rates Conveyed by Moat During Storm Events

Cross Section Location	Description	Water Quality Storm	2-Inch, 24-Hour Storm	2-Year, 24-Hour Storm	5-Year, 24-Hour Storm	10-Year, 24-Hour Storm	25-Year, 24-Hour Storm
Sta. 65+34	Near Ellery Rd. & Daniel St. Intersection	16.4 cfs	28.0 cfs	54.8 cfs	73.6 cfs	86.5 cfs	91.3 cfs
Sta. 62+57	Downstream of Pedestrian Bridge	78.2 cfs	188.6 cfs	407.8 cfs	553.4 cfs	651.0 cfs	781.1 cfs
Sta. 57+20	Near Eustis Ave. & Champlin St. Intersection	85.2 cfs	210.1 cfs	459.2 cfs	625.2 cfs	736.5 cfs	884.9 cfs
Sta. 50+21	Near Eustis Ave. & Catherine St. Intersection	85.0 cfs	214.3 cfs	475.3 cfs	650.1 cfs	767.5 cfs	924.3 cfs
Sta. 41+67	Near Eustis Ave. & Old Beach Rd. Intersection	84.5 cfs	218.1 cfs	491.9 cfs	676.7 cfs	801.3 cfs	967.9 cfs
Sta. 33+88	Near Old Beach Rd. & Memorial Blvd. Intersection	84.4 cfs	218.5 cfs	494.2 cfs	680.5 cfs	806.3 cfs	974.7 cfs
Sta. 05+55	300 feet Upstream of Memorial Blvd. (Just Upstream of South Easton Pond Spillway Confluence)	77.6 cfs	207.4 cfs	479.6 cfs	664.7 cfs	789.9 cfs	957.8 cfs
Sta. 02+65	Upstream Side of Memorial Blvd. Bridge	**95.7 cfs**	**255.8 cfs**	599.5 cfs	833.6 cfs	991.8 cfs	1,203.9 cfs

Note:
1 Values in bold indicate peak flows that were considered in sizing the ultraviolet light disinfection system. These peak flow rates do not account for the inclusion of the potential Esplanade outfall relocation.

2 The value in parentheses and ***bold italics*** indicates the peak flow accounting for the inclusion of the potential Esplanade outfall relocation.

3 Rainfall amounts of 3.4 inches, 4.3 inches, 4.9 inches, and 5.7 inches were used to generate peak flows generated by the 2-, 5-, 10-, and 25-year storms, respectively. These values were obtained from Technical Paper 40 (published in May 1961). Flow conveyed by the Moat during the 100-year, 24-hour storm was not analyzed since the Flood Insurance Study (FIS) for Middletown concludes that the Moat and its surrounding areas (including Easton Pond) will be completely inundated.

4 Peak flows included within this table were generated using TR-20. Refer to Appendix F for a summary of output data generated by TR-20.

5 Refer to Sheet 2 for a depiction of all contributing watersheds included in the hydrologic analysis.

It should be noted that reductions in peak flow rates from up- to down-stream cross-sections shown in Table 4 further illustrates that the Moat (due to its relative flatness) provides flood storage and increased flow travel times, and consequently, a reduction in peak flow rates.

3.3.1 Hydraulic Model Verification

Storm flow hydrographs generated by all contributing subwatershed areas that discharge flow to the Moat, during the June 16th storm event, were input into the hydraulic model. The tide elevation at 11:10 PM, the same time the maximum peak flow velocity through the Memorial Boulevard culvert was recorded, was also input into the model at the downstream boundary (the confluence of the Moat with Easton Beach). Since the tide elevations were between high and low tides at 11:10 PM, the elevation was interpolated to be approximately 0.61 feet (NGVD29). Since this elevation is lower than bottom of channel elevations within the Moat, a downstream water surface elevation of 3.30 feet (NGVD29) was used as the downstream boundary condition. This elevation was selected because it yielded the same water surface elevation (of 3.63 feet) recorded at Meter 3 during the peak of this storm event.

Table 5 summarizes the results obtained from our hydraulic model versus actual depth and velocity data recorded within the Moat during May and June of 2008:

Table 5
Comparison of Recorded Data during May 20th Calibration Storm versus Results Obtained from Analysis

Location	Actual Water Surface Elevation (feet)[1]	Computed Water Surface Elevation (feet)[2]	**Difference in Elevations (feet)**	Actual Peak Flow (cfs)[3]	Computed Peak Flow (cfs)[4]	**Differences in Peak Flow (cfs)**
Meter 1 (Sta. 05+12)	4.14 feet	3.80 feet	**-0.34 feet**	N/M	28.81 cfs	N/A
Meter 2 (Sta. 03+14)	3.78 feet	3.73 feet	**-0.05 feet**	N/M	29.98 cfs	N/A
Memorial Boulevard	3.78 feet	3.72 feet	**-0.06 feet**	32.88 cfs	32.38 cfs	**-0.50 cfs**
Meter 3 (Sta. 01+70)	3.63 feet	3.63 feet	**-0.00 feet**	N/M	32.38 cfs	N/A

Notes: