Caught Between the Ocean and a Watershed, Designing Climate Change Adaptations for Two Coastal Water Supply Dams in Rhode Island

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Abstract--The North and South Easton Pond Dams are interconnected, raw water supply reservoirs in the City of Newport, Rhode Island. The 12- to 14-foot-high earthen embankment dams, constructed within the footprint of former tidal wetlands in the 1870's and 1890's are classified as High Hazard potential dams, have a combined embankment length of 12,400 feet, and comprise a critical portion of the City of Newport's long-term water supply. The dams are adjacent to the Atlantic Ocean and are vulnerable to converging risks from extreme precipitation from inland storms, sea level rise, and coastal storm surge.

This paper provides interesting and practical examples of challenges to dam owners from climate change driven flooding, assessment of coastal flooding and sea level rise vulnerabilities, and the identification of potential adaptations to enhance the resiliency of aging dams. The paper is relevant to dam owners and those involved in risk assessment, planning, or design of adaptations to existing dams against future climate driven flooding.

I. Introduction

A. Project Location

The North and South Easton Ponds are raw water supply reservoirs owned and operated by the City of Newport Water Department (NWD). The dams are in residential neighborhoods in the municipalities of Newport and Middletown, Rhode Island, immediately north of the Easton's Bay, Newport's iconic Easton's Beach, and a heavily travelled state highway. Both dams are classified as High Hazard Potential by the Rhode Island Dam Safety Program.

North Easton Pond is located immediately upstream of the South Easton Pond and adjacent to the NWD's Station 1 treatment facility. It has a total embankment length of approximately 2,800-feet, which includes a low, earthen embankment dividing the North and South Easton Ponds. Its main spillway at the eastern end of this dividing embankment is approximately 130-feet in length.

A heavily vegetated emergency overflow spillway and discharge channel exists adjacent to the treatment plant, having a spillway length of approximately 100-feet. Several gated conduits pass through this embankment, hydraulically connecting these ponds, while one or more water mains or intake pipes reportedly run below the length of the embankment to the treatment facility. A grassed earthen embankment, portions of which are maintained by mowing, continues to the north adjacent to the treatment facility.

South Easton Pond is located downstream of the North Easton Pond and the Station 1 treatment facility.

Figure 1: Project location

The earthen embankment forming the ring dike has a very narrow crest width and steep slopes which has made maintenance of the dike difficult in the past. Recent reconstruction of the impoundment's northern and western embankments has improved accessibility for maintenance equipment by widening the crests and flattening/armoring upstream and downstream slopes. The armoring of the slopes has also made the embankment more resistant to erosion damage due to reservoir wave action and flood flows in the moat.

A drainage moat surrounds the majority of the South Easton Pond Embankment. The moat was primarily intended to act as a discharge channel to convey outflow from the secondary spillway at the North Easton Pond Dam. Due to the existing topography, the moat also intercepts stormwater runoff from other upland areas to the north and west of the South Easton Pond. The moat ultimately discharges under Memorial Avenue to the south.

Figure 2: Aerial view of the Easton Pond Dams.

The connectivity between the dams, the moat, and Easton's Bay is depicted on Figure 3.

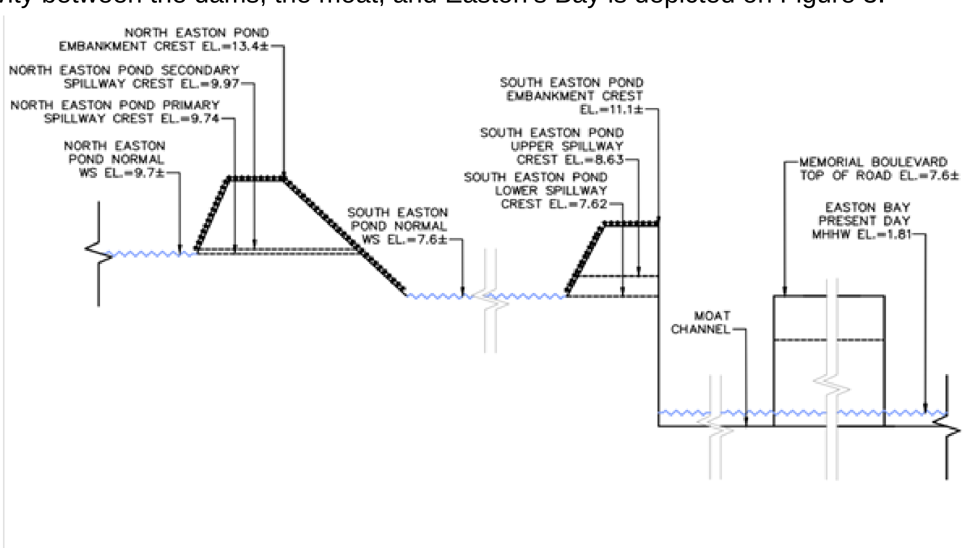

Figure 3: Hydraulic connectivity between the dams, spillways and Easton Bay.

B. Site Background

The South Easton Pond was constructed in portions of what was historically a low-lying marsh and required the construction of a ring dike around the entire impoundment (Figure 4). North and South Easton Pond Dams were constructed to provide drinking water in 1877 and 1896, respectively.

Figure 4: Footprint of the North and South Easton Pond Dams over former low-lying marsh areas.

The City of Newport draws raw water supply from a complex system of nine surface reservoirs, including the North and South Easton Ponds. The South Easton Pond is utilized daily for municipal water supply and comprises a critical portion of Newport Water's usable storage capacity.

The region experienced significant hurricane flooding in 1938, 1954, and more recently damage during a Nor'easter in spring 2007 (Figure 5) that nearly breached the embankment and required emergency repairs. The damage was primarily on the west embankment and driven by erosion due to wind driven wave action. In some sections the embankment crest width was reduced to less than one foot. City staff hauled sandbags by wheelbarrow, and they were placed by hand to stabilize the embankment.

Figure 5: Flood damage at the west embankment of the South Easton Pond Dam after the April 2007 Nor'easter.

II. VULNERABILITY ASSESSMENT

Low lying coastal area are potentially vulnerable to inundation under daily high tide conditions or due to coastal storm surge. The North and South Easton Ponds are hydraulically connected to the Bay by the moat and spillways and the dams are affected by changes in the tailwater levels (Figure 3). The potential for saltwater intrusion gradually occurring through groundwater pathways under and/or by seepage through the South Easton Pond's southern earthen embankment was not assessed as part of this study.

A. Sea Level Rise and Coastal Storm Flooding Assessment

This assessment reviewed the present day and projected future increases in Mean Higher High Water (MHHW) in Easton's Bay due to Sea Level Rise (SLR) as well as . the Mid-Atlantic and Northeast US coasts are experiencing faster-than-average sea level rise. This type of flooding is associated with increases in daily high tide level over time due to climate change and rising sea levels.

The preliminary site-specific probabilistic assessment for Easton Pond found the following:

- Woods Hole Group selected a NACCS model node representative of conditions in Easton Bay adjacent to Easton Pond, and applied the National Climate Assessment (NOAA, 2012) highest rate SLR scenarios (for 2030 and 2070) to the present day joint probability inundation profile. Further adjustments were made to the Newport Station data based on local tide range and land subsidence.
- The present day and SLR-adjusted (future) joint probability inundation profiles were applied to the most recent LiDAR data (2014 USGS CMGP Sandy or 2011 Rhode Island Statewide, as available) for the Easton Pond vicinity using a modified bathtub approach to account for connectivity in a GIS environment.
- Present day and projected joint probability inundation mapping is presented in Figure 6. The adjusted NACCS joint probability inundation profiles are presented in Table 1.

Figure 6: "Present Day" (2013) MHHW (left), 2030 MHHW (center), and 2070 MHHW joint probability inundation mapping.

Table 1: Present Day and Adjusted (Future) NACCS Joint Probability Inundation Profiles

Return Period	Probability	Water Surface Elevation (ft.)			
		Present	2030	2050	2070
MHHW	Tides (no surge)	1.81	2.37	3.53	5.09
1	100.0%	4.55	5.11	6.27	7.83
2	50.0%	5.31	5.87	7.03	8.59
5	20.0%	6.37	6.93	8.09	9.65
10	10.0%	7.22	7.78	8.94	10.50
20	5.0%	8.13	8.69	9.85	11.41
50	2.0%	9.42	9.98	11.14	12.70
100	1.0%	10.53	11.09	12.25	13.81
200	0.5%	11.77	12.33	13.49	15.05
500	0.2%	13.43	13.99	15.15	16.71
1000	0.1%	14.62	15.18	16.34	17.90

Figure 7: Joint annual chance of inundation for “Present Day” (2013, left), 2030 (center), and 2070 (right).

Table 2: Annual Chance Probabilities of Saltwater Inundation into North and South Easton Ponds for Current and Projected 2030, 2050 and 2070 Conditions

Case	SEP Primary Spillway Lower Notch (7.62')	SEP Primary Spillway (8.63')	NEP Primary Spillway (9.74')	NEP Secondary Spillway (9.97')	SEP Embankment (11.1')	NEP Embankment (13.4')
Present day	5%	2%	1%	1%	0.5%	0.2%
2030	10%	5%	2%	2%	0.5%	0.2%
2050	20%	10%	5%	2%	2%	0.5%
2070	100%	20%	10%	10%	5%	1%

As shown in Figure 6 and Table 1, the MHHW level is below the critical elevations at the dams, therefore sea level rise effects alone do not result in overtopping of the dam embankments or spillways. therefore, the South and North Ponds do not appear vulnerable to saltwater intrusion by overtopping during daily high tides. Storm conditions would cause saltwater intrusion into both North and South Easton Ponds that could result in significant impacts to these water supplies (Figure 7 and Table 1).Table 2 indicates the following annual probabilities of flooding:

- Present day, there is a 5% annual chance of saltwater inundation at South Easton Pond and a 1% annual chance of saltwater inundation at North Easton Pond because of storm surge.
- By 2030, there will a 10% annual chance of saltwater inundation at South Easton Pond and a 2% annual chance of saltwater inundation at North Easton Pond, due to the combined effects of SLR and storm surge. By 2050, there will be a 20% annual chance of saltwater inundation at South Easton Pond and a 5% annual chance of saltwater inundation at North Easton Pond, due to the combined effects of SLR and storm surge.
- By 2070, there will be a 100% annual chance of saltwater inundation at South Easton Pond and a 10% annual chance of saltwater inundation at North Easton Pond, due to the combined effects of SLR and storm surge.

B. Inland Storm Hydraulic Capacity Assessment

A screening level hydrologic and hydraulic (H&H) analysis was completed by Fuss & O'Neill to assess the spillway capacities in response to run-off in the watershed associated with inland precipitation .

The scope of the screening level analyses included:

- Approximate the peak flow discharged to the respective impoundments under the recommended Spillway Design Flood (SDF).
- Assess the ability of the respective spillways to safely convey the SDF flow without overtopping the dam embankments.

The dams are under the jurisdiction of the Rhode Island Department of Environment Management's (RIDEM's) Office of Compliance and Inspection. The RIDEM does not provide SDF requirements in the Rules and Regulations for Dam Safety. The Massachusetts Department of Conservation and Recreation (MADCR) Dam Safety Regulations and the New York State Department of Environmental Conservation's (NYDEC) Dam Safety Regulations were considered in selecting the appropriate SDF to evaluate the hydraulic capacity of the system against inland storms. Based on the High Hazard potential classification of the dams and consultation with the MADCR and NYDEC Dam Safety Regulations, one half of the probable maximum flood (½ PMF) was selected as the SDF for both dams.

The screening level evaluation included precipitation data for the 50-and 100-year inland flood events. Peak flow runoff rates and volumes generated by contributing subwatershed areas were calculated using the National Resources Conservation Service (NRCS) TR-20 method. Peak inflows for this study are based on present day rainfall runoff and intensity for the respective flood return period and do not account for future changes in precipitation intensity due to climate change. 24-hour precipitation values for the 50- and 100-year floods of 7.3 inches and 8.6 inches, respectively, were obtained from RIDEM's Rhode Island Stormwater Design and Installation Standards Manual (March 2015). The ½ PMF peak flow precipitation rate of 11.9 inches was obtained from the Phase I Inspection Report for the nearby Lawton Valley Reservoir Dam in Portsmouth, RI by the U.S. Army Corps of Engineers (USACE, March 1980).

The inflow and outflow rates for various storms and the peak water surface elevations for each pond are presented in Table 3. The results indicate that the South Easton Pond Dam is overtopped during the present day ½ PMF.

Table 3: North and South Easton Pond Inflows and Outflows for Present Day Inland Storms

Impoundment	50-Year Inflow / Outflow Rate (cfs)[5]	100-Year Inflow / Outflow Rate (cfs) [5]	½ PMF Inflow / Outflow Rate (cfs)[6]	50-Year Peak Elevation/ Freeboard (ft.) [5]	100-Year Peak Elevation/ Freeboard (ft.) [5]	1/2 PMF Peak Elevation/ Freeboard (ft.) [6]
North Easton Pond	1,603/ 1,424[2]	1,951 / 1,783[3]	2,841/ 2,676[4]	11.66/1.74	12.0/1.40	12.81/0.59
South Easton Pond	1,142/ 594	1,294/ 765	1,700 / 1,217	10.12/0.98	10.44/0.66	**11.17/-0.07**

III. ADAPTION ALTERNATIVES

The climate resiliency assessment for the North and South Easton Pond Dams indicate portions of the dams are vulnerable to projected future increased frequency and intensity of coastal storms and inland precipitation. The projected water surface elevations for North and South Easton Ponds presented in Table 2 suggest the most immediate and probable vulnerability for the system is raw water supply contamination by saltwater intrusion over the spillways.

Coastal flood control measures at the spillways that allow inland water to drain and prevent saltwater from flowing over the spillway crest will be the most effective adaptations in the near- to mid-term. Saltwater intrusion via embankment intrusion is less probable and has a relatively long lead time for effects to become significant. If current impact probabilities are acceptable and manageable, such as by using operational controls, a phased adaptation approach can be implemented to enhance embankment resiliency over time, as needed.

The following sections describe potential alternatives for consideration in improving the resiliency of the embankments and spillways impounding North and/or South Easton Pond. Although not within the scope of this study, other modifications and improvements could be considered in concert with these alternatives to provide protection along the beach or further seaward that may not only build resilience for the reservoirs, but other infrastructure as well (buildings, roads, etc.) in the communities of Newport and Middletown. These may consist of seawalls, natural berms, tidal control measures, etc., constructed downstream of the spillways.

Multiple spillway and embankment adaptation concepts were identified to enhance resiliency of the dams against present day and future inland storm events. Conceptual adaptations were developed to be implemented in phases, focusing on the highest priority vulnerabilities of the system first, and to be adaptable in the future, should climate projections change.

A. Resiliency Alternative No. 1

As previously stated, the South Easton Pond north and west embankments were raised by approximately one foot to El. 12.1 ft in 2014. This alternative involves raising the remaining embankments to El. 12.1 feet. this improvement would fully contain runoff generated by inland storm events up to the present day ½ PMF while providing almost one foot of freeboard.

The South Easton Pond's existing spillway and North Easton Pond's secondary spillway would require a storm barrier to prevent saltwater from backing up through the spillways. The barriers may consist of inflatable or bottom hinged gates. These spillway gates would be raised to prevent saltwater intrusion during a coastal flood event, while still passing inland storm runoff during flood events from inland precipitation. However, operating the gates to the raised position would reduce the spillway flood conveyance capacity.

The embankments surrounding South Easton Pond are also recommended to be protected against damage due to overtopping. Under this alternative, while the North Easton Pond Dam embankment is expected to have sufficient freeboard, the proposed emergency spillway modifications described below would be armored to limit the potential of erosion during flood events.

To provide sufficient hydraulic capacity to convey the SDF will approximately one foot of freeboard, a 1,700-foot-long emergency spillway (with a crest elevation of El. 11.1) is required along South Easton Pond's southern embankment. This proposed emergency spillway for South Easton Pond would also need to be equipped with a storm surge control structure (i.e., inflatable bladder) to prevent saltwater intrusion. North Easton Pond would also be retrofitted to include a 350-foot-long emergency spillway (with a crest elevation of El. 12.9) along North Easton Pond's southern embankment.

Based on the coastal storm surge elevations provided for present day and various sea-level rise scenarios, this alternative would protect the drinking water supply reservoir from saltwater intrusion and embankment failures for coastal flood events for the 100-year return period (1% AEP) up to 2050 and for the 200-year return period (0.5% AEP) coastal flood up to 2030.

An order of magnitude opinion of construction cost for this alternative is provided in Table 4.

One disadvantage of this alternative is the 1,700 foot long emergency spillway. Although the height of the emergency spillway is only 12 inches high, the 1,700 foot long inflatable bladder is not feasible due to its relatively long length. Considering that the crest of the dam is accessible to pedestrian traffic, a guardrail will be required to prevent unauthorized contact with the bladder dam. The guardrail is likely to impede flow through the emergency spillway and would need further evaluation.

Table 4: Alternative No. 1 Order of Magnitude Opinion of Cost Range

Embankment Improvements	$11,600,000	-	$ 24,800,000
Spillway Reconstruction	$ 3,600,000	-	$ 7,000,000
Crest Gates at Existing Spillway	$ 2,500,000	-	$ 5,300,000
Total Order of Magnitude Opinion of Cost	$ 17,700,000	-	$ 37,100,000

B. Resiliency Alternative No. 2

This adaptation involves raising the southern and eastern embankments of South Easton Pond to El. 12.1 ft. and providing armor to protect against overtopping as described under Resiliency Alternative No. 1. Alternative 2 does not include the proposed emergency spillway provisions noted in Alternative 1 at the South Easton Pond. Omitting the emergency spillway results in higher peak SDF water surface elevations at the north and south ponds compared to Alternative 1. Armoring would be required at the North Easton Pond Dam to protect against erosion during wave driven overtopping. The crest of the North Easton Pond Dam embankment would remain at the current elevation of 13.4 ft. Under Alternative 2, while the embankment and spillways would have sufficient hydraulic capacity to accommodate the SDF without overtopping, there would be no freeboard during SDF conditions. Considering that the proposed alternative includes armoring to protect from damage related to wave run-up induced overtopping, the lack of freeboard under SDF conditions poses a lower risk compared to an un-armored embankment. The existing South Easton Pond Dam spillway and the North Easton Pond Dam secondary spillway would still need to be retrofitted/reconstructed with coastal storm barriers, such as combination sluice-flap gates to prevent saltwater from backing up through the spillways.

Based on WHG’s present day and projected sea-level rise coastal storm surge elevations, this alternative provides protection against saltwater intrusion and embankment failures for coastal flood events for the 100-year return period (1% AEP) up to 2050 and for the 200-year return period (0.5% AEP) coastal flood up to 2030.

An order of magnitude opinion of construction cost for this alternative is provided in Table 5.

Table 5: Alternative No. 2 Order of Magnitude Opinion of Cost Range

Embankment Improvements	$11,600,000	-	$ 24,800,000
Spillway Reconstruction	$ 3,600,000	-	$ 7,000,000
Crest Gates at Existing Spillway	$ 2,500,000	-	$ 5,300,000
Total Order of Magnitude Opinion of Cost	$ 17,700,000	-	$ 37,100,000

C. Resiliency Alternative No. 3

Considering that the North Easton Pond is further inland and and the South Easton Pond and existing abutting infrastructure naturally act as a barrier between the North Easton Pond and Easton Bay, a third potential resiliency alternative would be to focus mid-term improvements on North Easton Pond.

Under this alternative, South Easton Pond would be permitted to inundate during significant coastal storm events and North Easton Pond would function as the sole water supply source until the saltwater from South Easton Pond could be managed with treatment processes or pumped out and the water supply restored. For the same magnitude of cost as Alternatives Nos. 1 and 2, focusing efforts on the North Pond would provide longer-term resiliency of the system. By raising the southern embankment of the North Easton Pond by one foot, the drinking water for North Easton Pond could be protected from inland flooding up the to the ½ PMF and between the 500 to 1000 year coastal storm (0.2% to 0.1% AEP) up to 2030.

An order of magnitude opinion of construction cost for this alternative is provided in Table 6. It is noted that this table does not include costs for additional operational management of saltwater incursion.

Table 6: Alternative No. 3 Order of Magnitude Opinion of Cost Range

Embankment Improvements	$ 3,500,000	-	$ 7,500,000
Spillway Reconstruction	$ 500,000	-	$ 1,100,000
Crest Gates	$ 2,900,000	-	$ 6,100,000
Misc. Pumps	$ 1,400,000	-	$ 2,900,000
Total Order of Magnitude Opinion of Cost	$ 8,300,000	-	$17,600,000

D. Resiliency Alternative No. 4

Rather than retrofitting or reconstructing the existing spillways in kind as discussed in Alternatives 1 and 2, the spillway at SEPD could potentially be reconstructed to provide sufficient hydraulic capacity for the SDF with operable components that can be manipulated to meet the design flood requirements for inland storm runoff and prevent saltwater incursion during coastal storm surge events.

The proposed spillway should be sized to provide appropriate freeboard during SDF conditions in conjunction with embankment modifications that would provide armor protection against erosion due to overtopping. This alternative would also include the embankment modifications to raise the crest of the northern, southern and eastern embankments to El. 12.1 ft. A series of downward opening slide gates or hinged crest gates at the South Easton Pond primary spillway can provide adaptive hydraulic capacity that can be lowered to temporarily gain hydraulic capacity during inland storms or raised to store additional water in the reservoir. These gates, which control the impoundment level, can be hydraulically actuated and operated remotely. The existing secondary spillway at the North Easton Pond Dam may be removed and reconstructed in a similar manner considering that the secondary spillway is vulnerable to saltwater incursion via the moat. An example of a spillway arrangement similar in concept to the Alternative No. 4 modifications is provided as Figure 8 which depicts a spillway comprised of aluminum downward opening slide gates to manage discharge from inland storms.

Figure 8: Example Spillway Configuration for Adaptive Spillway

The impoundment can be protected from saltwater intrusion from Easton Bay by installing combination sluice-flap gates (Figure 9) at the downstream side of the spillway and in-series with the gates which control the impoundment level. When the sluice gate is down and the hinge at the top of the gate is unlocked, convey flow from the impoundment when the hydrostatic pressure in the impoundment exceeds the hydrostatic pressure in the downstream area. When the hydrostatic pressure in the downstream area is higher than the impoundment, the gate will seal and prevent water from entering the impoundment from the downstream side of the dam through the spillway opening. The combination gate can also be raised and lowered as a traditional sluice gate to control flow from the impoundment. An order of magnitude opinion of construction cost for this alternative, including embankment modifications at the South Easton Pond embankments and spillway removal and replacement, is provided in Table 7.

Figure 9: Combination sluice/flap gate.

Table 7: Alternative No. 4 Order of Magnitude Opinion of Cost Range

Embankment Improvements	$ 11,600,000	-	$ 24,800,000
Spillway Reconstruction	$ 2,100,000	-	$ 4,500,000
Gates	$ 2,700,000	-	$ 5,800,000
Total Order of Magnitude Opinion of Cost	$ 16,400,000	-	$ 35,100,000

Alternatives 2 and 4 were selected for further study. Alternative 1 was not selected due to the 1,700 foot auxiliary spillway required. Alternative 2 was not selected since the South Easton Pond Dam is a critical element of the City's water supply system.

IV. North Dam Interim Repairs

The RIDEM and City of Newport executed a consent agreement in March 2021 for the purpose of resolving the notice of violation issued in 2016 related to the poor condition rating at several City-owned dams. The City is required to repair the auxiliary spillway at the North Easton Pond Dam due to the poor condition of the spillway. The City intends to advance a comprehensive solution to improve the resilience of the dams against future intense coastal and inland storms, but the North Dam auxiliary spillway repairs were required before the plan could was developed. The design approach involved replacing the auxiliary spillway weir and training walls in-kind (similar length, weir crest height, weir configuration, training wall configuration) with cast in place concrete and restoring the existing stone armor in-kind (similar size, footprint) to streamline the environmental permitting and leverage existing H&H modelling, which demonstrates that the north dam is hydraulically adequate to convey the present day ½ PMF inland storm.

Figure 10: North Easton Pond Auxiliary Spillway

As described under the preferred alternatives above, a crest gate will be required for the North Easton Pond Dam secondary spillway to prevent flooding from future coastal storms. The exact elevation and design of the crest gate has not yet been finalized. Because of the likely future need of a crest gate, the secondary spillway was designed to allow it to be retrofitted in the future with a crest gate and minimize the need for substantial reconstruction of the spillway. The hand sketches in Figures 11 and 12 depict potential adaptations to the North Pond Dam auxiliary spillway. The rudimentary sketches were developed as part of a due-diligence workshop with the infrastructure design team including structural engineers, water resources engineers, and climate resilience specialists.

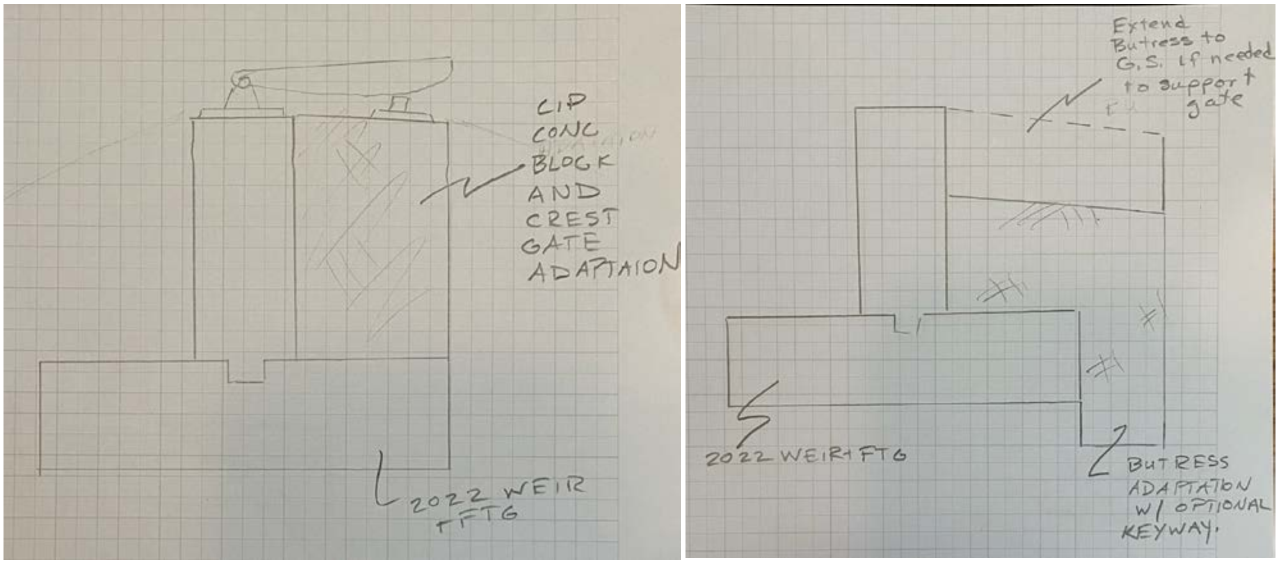

Figure 11: Section view of a potential spillway crest adaptation including a bottom hinged crest gate and cast in place buttress and bearing section to support the gate (left) and a potential spillway crest adaptation including a bottom hinged crest gate and cast in place buttress, bearing section to support the gate and keyway (right, gate not shown).

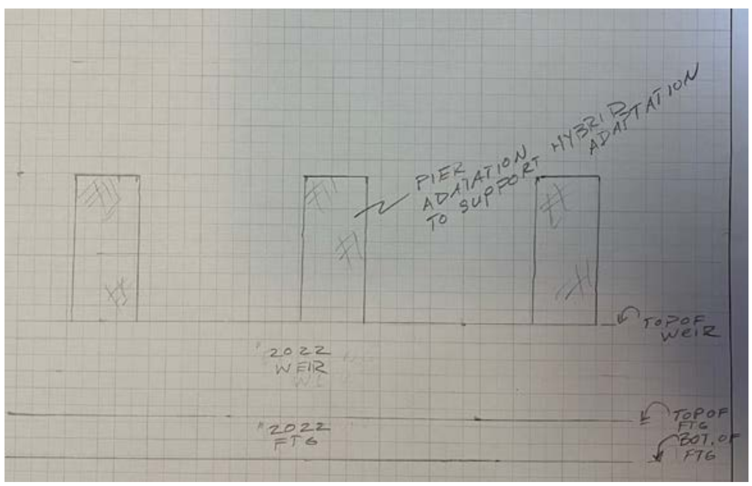

Figure 12: Elevation view of a potential spillway crest adaptation including piers to abut future gates (gates not shown).

V. Lessons Learned and Next Steps

A. Lessons Learned

Coastal and Inland flood risk is non-stationary. Guidance documents and projections evolve quickly as well, since the initial assessment in 2018, new guidance is available that will be considered in future phases. New resources reinforcing the use of Flood Magnification Factors for application to inland precipitation are available, such as the State of Colorado Department of Natural Resources Rules and Regulations for Dam Safety and Dam Construction (2020), Resilient Massachusetts Climate Resilience Design Standards & Guidelines (Draft 2020/Updated in 2022).

B. Next Steps

The City received a grant from the FEMA Building Resilient Infrastructure and Communities program to perform a detailed scoping study including field data collection, refine the screening level hydrologic and hydraulic (H&H) model for inland precipitation, to finalize a recommended approach to enhance the resiliency of the system against coastal and inland . Since the spillway sizing is a significant factor in the overall cost of the project, an incremental hazard evaluation will be performed to explore the possibility of selecting a lower magnitude for the inflow design flood for the proposed spillway design. The feasibility of raising the embankment higher than 12.1 feet will be evaluated. Raising the embankment may aggravate flooding in the surrounding neighborhood and these effects should be avoided. The scoping study will be completed by winter 2023.

VI. Acknowledgment

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