SAWMILL BROOK WATERSHED
FLOOD MITIGATION STUDY
SUMMARY OF CONCEPTUAL PROJECTS
BENEFITS AND CONCERNS

Project Elements	Project Benefit	Project Concerns	Feasibility Level Opinion of Probable Cost
Central Street Culvert Option 1			
Remove Tidegate	improved hydraulic capacity	temporary water quality impacts	$ 860,000.00
Repair Existing Culvert	habitat restoration	change to hydrology	
Restore Pond and Brook	aesthetics and water quality	increase tidal range	
	reduce upstream flooding	shift in species	
Central Street Culvert Option 2			
Remove Tidegate	improved hydraulic capacity	temporary water quality impacts	$ 1,910,000
Replace Existing Culvert	habitat restoration	change to hydrology	
Restore Pond and Brook	aesthetics and water quality	increase tidal range	
Restore Seawall and Railings	roadway safety	shift in species	
	reduce upstream flooding	historic aspects related to wall	
School Street Culvert			
Widen Culvert	improved hydraulic capacity	impacts to building foundation	$ 1,040,000
Widen Channel/Restore Brook	habitat restoration	temporary water quality impacts	
Restore Stone Walls	aesthetics and water quality	historic aspects related to wall	
	reduce downstream flooding		
Norwood Avenue Culvert			
Widen Culvert	improved hydraulic capacity	impacts to building foundation	$ 910,000
Widen Channel/ Restore Brook	habitat restoration	temporary water quality impacts	
Restore Stone Walls	aesthetics and water quality	historic aspects related to wall	
	reduce downstream flooding		
Lincoln Street Culvert			
Widen Culvert	improved hydraulic capacity	visual changes	$ 400,000
	reduce upstream flooding	increase downstream flooding	
Coach Field Parking Lot			
Install Porous Pavement	flood reduction	increased maintenance	$ 430,000
	water quality improvement	temporary water quality impacts	
	reduce upstream flooding	increase downstream flooding	
Essex County Golf Course Flood Storage			
Grade existing channel	flood attenuation	impacts to playability	$ 1,180,000
Flood plain restoration	aesthetics and water quality	ownership/maintenance	
	reduce downstream flooding	increase in wildlife attraction	
Old School Street Flood Storage			
Replace Culverts	flood attenuation	limited downstream benefit	$ 220,000
Raise roadway elevation	wildlife passage	increase upstream flooding	
	reduce downstream flooding	increase in wildlife (beavers)	
Hurricane Barrier			
Construct Dike	limit impact of storm surge	permitting	$ 26,000,000
Install Storm Surge Barrier	creation of safe refuge harbor	construction costs	
	limit backwater flooding	operation cost	

Central Street Tide Gate and Culvert Improvements – Option 1 Repair

Feasibility Level Opinion of Probable Cost [1]

- Construction: $670,000 Total cost = $860,000

- Total cost includes the following "soft costs":
  - Engineering and Design
  - Permits
  - Survey

Permits Likely Required

- Project Notification Form to Massachusetts Historical Commission
- 401 Water Quality Certificate
- MEPA Environmental Notification Form
- *NPDES Construction General Permit*
- Chapter 91 Waterways License
- Army Corps of Engineers General Permit (Section 10 and 404)
- Order of Conditions from Manchester Conservation Commission
- Excavation and Trench Permits

Bedrock configuration downstream of tide gate

Further Assessment Needs

- Evaluate and develop sediment management plan
- Further develop restoration concepts and cost
- Evaluate seawall hydrostatic surcharge and seepage
- Identify utilities

Central street view of road bed ahead and Elm Street on right

[1] +50% to -30%

Central Street Tide Gate and Culvert Improvements – Option 1 Repair

Project Need

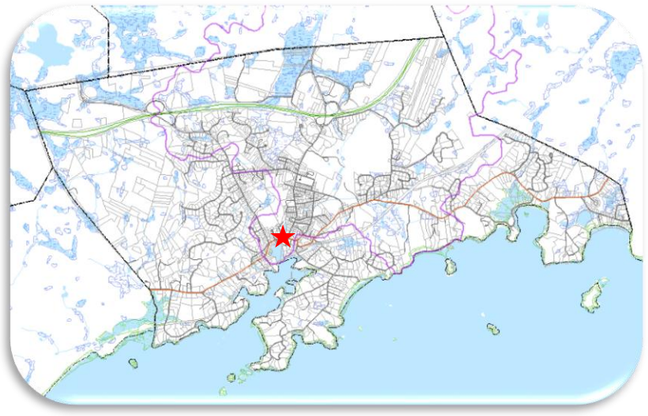
The Central Street tide gate, dam, and related structures are in need of modification to provide better functionality with respect to drainage and fish passage. The tide gate and culvert at Central Streets impedes drainage from Sawmill Brooks, especially during coastal storm events, resulting in localized flooding. The tide gate structure also overtops on spring high tides and storm surge tides. Discussions with the Massachusetts Division of Marine Fisheries indicate a preference to remove or modify the tide gate to improve fish passage conditions for Rainbow Smelt.

Evaluation Conducted

The Sawmill Brook culvert under Central Street was observed on June 11, 2015 as part of an in-water walk-through to view existing conditions of the seawall, tide gate structure, culvert and stream bed/weirs. The inspection report noted corrosion / erosion on the tide gate tracts and safety concerns due to the separation and settlement of culvert arch stones. Significant seepage was observed from the stone dam/sidewall supporting the south side of Central Street, particularly when the tide gate was closed. The seepage can cause a loss of soils under the street. Repairs made to the wall using pneumatically applied concrete and non-shrink grout repointing have failed, particularly in the tidal zone.

Impediments to fish passage include the current design of the bottom opening tide gate. The gate is typically set with a partial opening, which is not conducive for smelt migration due to the head pressure and high velocity of water exiting the gate. Even when the tide gate is fully open, smelt encounter two more weirs inside the stone arch culverts. Since smelt are not able to jump up weirs, the tide needs to rise to at least 2/3 of mean high tide to allow smelt to swim upstream.

Results from the HEC-RAS watershed modeling clearly demonstrate that removal of the tide gate results in significant upstream reduction in water levels. During an extreme storm event, Sawmill Brook would be lowered as much as 3 feet at Central Street by eliminating the hydraulic barrier at the tide gate.



Project location

Central Street Tide Gate and Culvert Improvements – Option 1 Repair

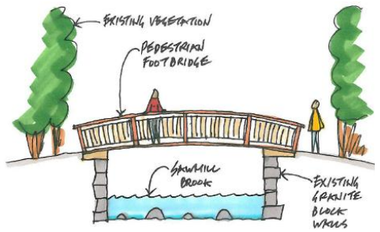
Conceptual Design

The conceptual design includes removing the existing tide gate and rehabilitating the existing stone arch culvert. Restoration of Central Pond to a stream channel and tidally influenced wetland system is included as part of the design. This may include sediment and organic debris removal and plantings. If the pond is desired to remain, dredging or adding a rock riffle at the mouth of the pond could be considered. However, the addition of a rock riffle will likely reduce some of the flood storage created by removing the tide gate. Consider repair and restoration of the Central Street seawall (not included in project costs). Project should be coordinated with intersection and street improvements, including widening Central Street to improve sidewalks, parking, travel lanes, and crosswalks.

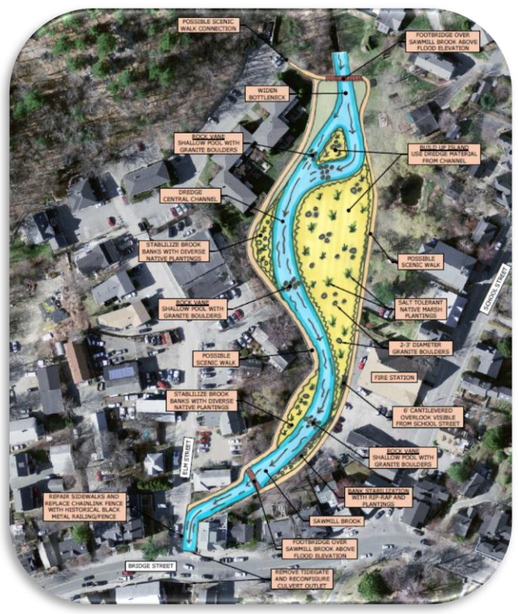
Project Impact

Removal of the tide gate will improve fish passage and the hydraulic capacity of Sawmill Brook, reducing upstream flooding. Removing the tide gate will alleviate the hydraulic pressure behind the seawall and reduce safety concerns. Stream restoration will improve habitat and aesthetics in the downtown area. The public location is ideal for educational signage about Sawmill Brook natural history.

Example rock riffle to maintain Central Pond

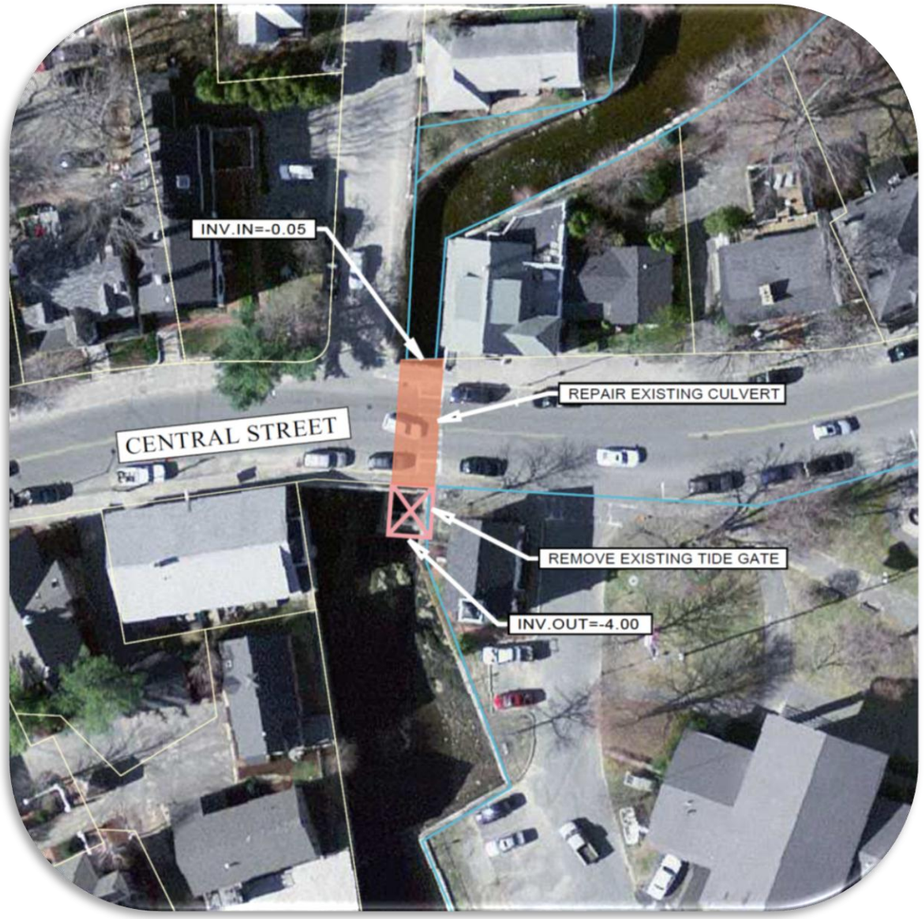


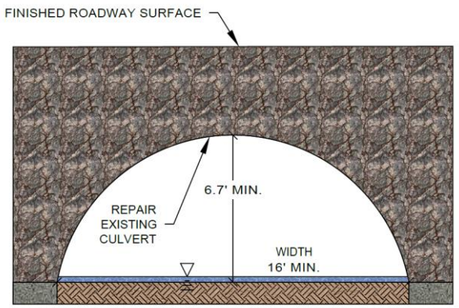
Footbridge over tidal brook



Conceptual restoration of Central Pond to stream channel and tidally influenced wetlands

Central Street Tide Gate and Culvert Improvements – Option 1 Repair





Central Street Tide Gate and Culvert Improvements - Option 2 Replace

Feasibility Level Opinion of Probable Cost [1]

- Construction: $1,700,000 Total cost = $1,910,000

- Total cost includes the following "soft costs":
  - Engineering and Design
  - Permits
  - Survey

Permits Likely Required

- Project Notification Form to Massachusetts Historical Commission
- 401 Water Quality Certificate
- MEPA Environmental Notification Form
- *NPDES Construction General Permit*
- Chapter 91 Waterways License
- Army Corps of Engineers General Permit (Section 10 and 404)
- Order of Conditions from Manchester Conservation Commission
- Excavation and Trench Permits

Bedrock configuration downstream of tide gate

Further Assessment Needs

- Evaluate and develop sediment management plan
- Further develop stream restoration concepts and cost
- Evaluate seawall hydrostatic surcharge and seepage
- Site-specific subsurface investigation including geotechnical evaluation and depth to groundwater
- Identification of utilities

Central Street view of road bed ahead and Elm Street on right

[1] +50% to -30%

Central Street Tide Gate and Culvert Improvements – Option 2 Replace

Project Need

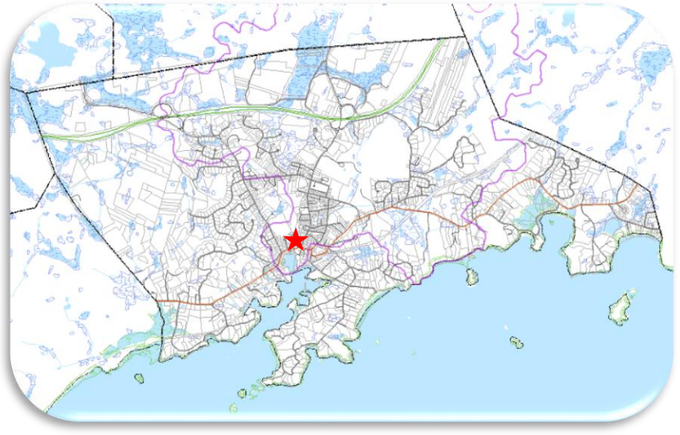
The Central Street tide gate, dam, and related structures are in need of modification to provide better functionality with respect to drainage and fish passage. The tide gate and culvert at Central Streets impedes drainage from Sawmill Brooks, especially during coastal storm events, resulting in localized flooding. The tide gate structure also overtops on spring high tides and storm surge tides. Discussions with the Massachusetts Division of Marine Fisheries indicate a preference to remove or modify the tide gate to improve fish passage conditions for Rainbow Smelt.

Evaluation Conducted

The Sawmill Brook culvert under Central Street was observed on June 11, 2015 as part of an in-water walk-through to view existing conditions of the seawall, tide gate structure, culvert and stream bed/weirs. The inspection report noted corrosion / erosion on the tide gate tracts and safety concerns due to the separation and settlement of culvert arch stones. Significant seepage was observed from the stone dam/sidewall supporting the south side of Central Street, particularly when the tide-gate was closed. The seepage can cause a loss of soils under the street. Repairs made to the wall using pneumatically applied concrete and non-shrink grout repointing have failed, particularly in the tidal zone.

Impediments to fish passage include the current design of the bottom opening tide gate. The gate is typically set with a partial opening, which is not conducive for smelt migration due to the head pressure and high velocity of water exiting the gate. Even when the tide gate is fully open, smelt encounter two more weirs inside the stone arch culverts. Since smelt are not able to jump up weirs, the tide needs to rise to at least 2/3 of mean high tide to allow smelt to swim upstream.

Results from the HECRAS watershed modeling clearly demonstrate that removal of the tide-gate results in significant upstream reduction in water levels. During an extreme storm event, Sawmill Brook would be lowered as much as three feet at Central Street by eliminating the hydraulic barrier at the tide-gate.



Project location

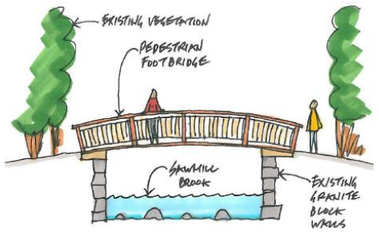
Central Street Tide Gate and Culvert Improvements - Option 2 Replace

Project Description

The conceptual design includes removing the existing tide gate and replacing the existing stone arch culvert with a concrete box culvert at the full stream width of the existing stream channel. Restoration of Central Pond to a stream channel and tidally influenced wetland system is included as part of the design. This may include sediment and organic debris removal, wetland plantings, stream bank stabilization and adding a rock riffle within the stream channel to improve aeration. Repair and restore the existing seawall including the guard rail (road widening is not included in project costs). Project should be coordinated with intersection and street improvements, including widening Central Street to improve sidewalks, parking, travel lanes, and crosswalks.

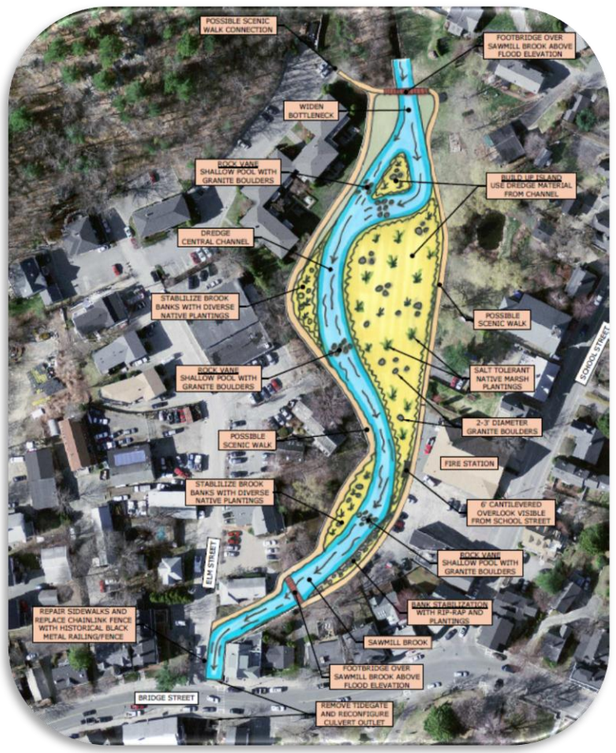
Project Impact

Removal of the tide gate and enlargement of the culvert will improve fish passage and increase the hydraulic capacity of Sawmill Brook reducing upstream flooding. Removing the tide gate will also limit the hydraulic pressure behind the seawall and reduce safety concerns. Restoration of the seawall and guard rail will improve traffic safety. Stream restoration will improve habitat and aesthetics in the downtown area. The public location is ideal for educational signage about Sawmill Brook natural history.



Footbridge over tidal brook

Example rock riffle



Conceptual restoration of central pond to stream channel and tidally influenced wetlands

Central Street Tide Gate and Culvert Improvements - Option 2 Replace

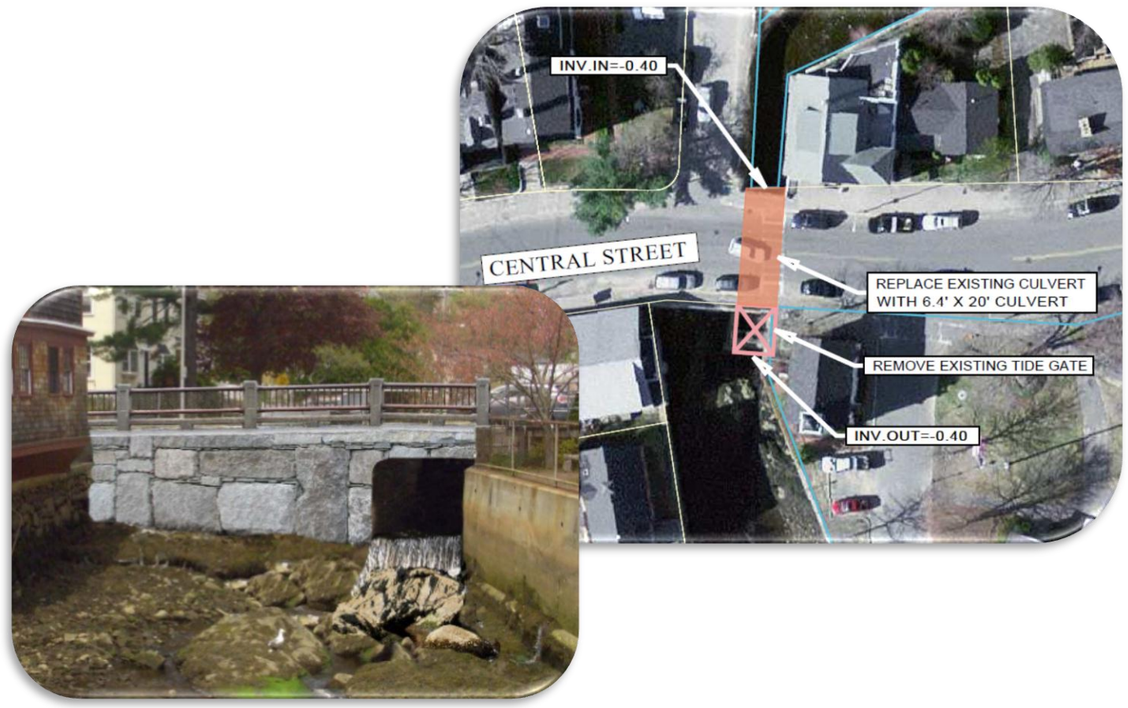
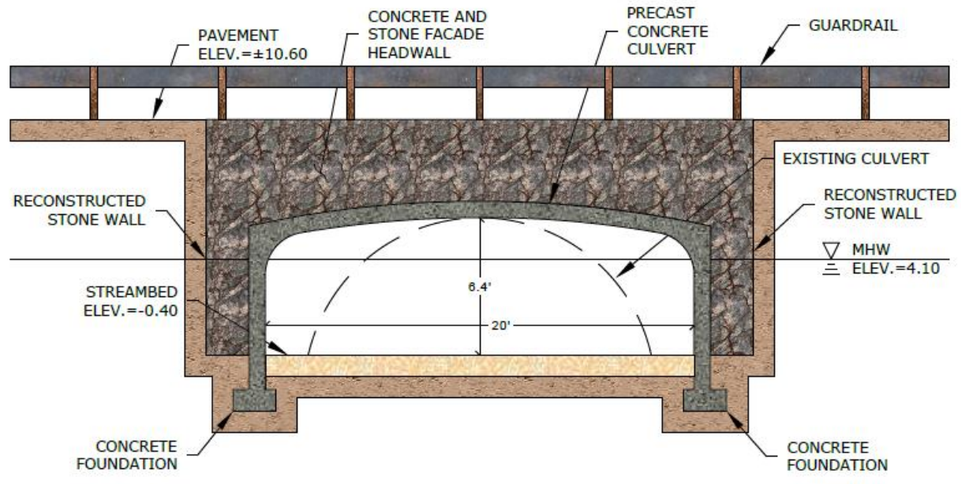


Photo rendering of tide gate removed, new culvert, new granite wall and guard rail



Culvert Improvement at School Street

Feasibility Level Opinion of Probable Cost[1]

- Construction: $920,000 Total cost = $1,040,000
- Total cost includes the following "soft costs":
  - Engineering and Design
  - Permits
  - Survey

Permits Likely Required

- Order of Conditions from Conservation Commission
- Massachusetts Historical Commission Project Notification Form
- Street Opening Permit
- *Massachusetts Environmental Policy Act (MEPA) Environmental Notification Form*
- *Department of the Army General Permit Commonwealth of Massachusetts*
- *Chapter 91 Waterways License*
- *401 Water Quality Certificate*

Further Assessment Needs

- Site-specific subsurface investigation including geotechnical evaluation and depth to groundwater
- Identification of utilities
- Consultation with local and state historical commissions
- Easements

Upstream inlet of Culvert 23

View upstream from inlet of Culvert 23

[1] +50% to -30%

Culvert Improvement at School Street

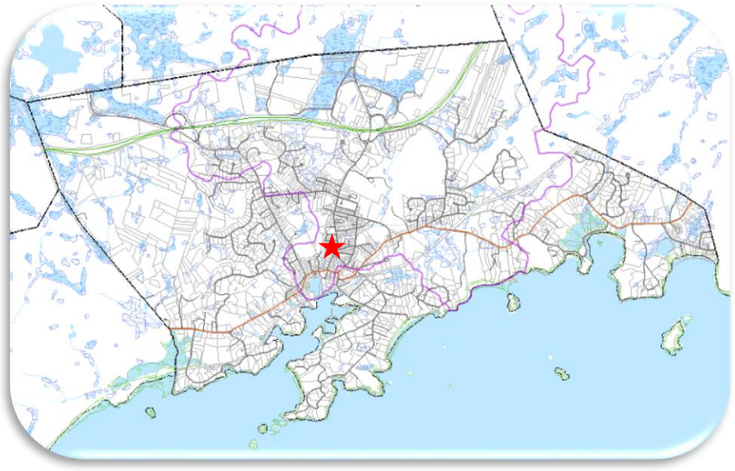
Project Need

Many areas of Manchester are subject to flooding during extreme storm events due to the combination of storm surge, hydraulic restrictions from culverts and the tide gate, stormwater runoff from impervious areas, the channelized stream system, and poor infiltration conditions. Impacts from climate change including increased precipitation and sea level rise will exacerbate flooding. The culvert under School Street is one of many hydraulic restrictions. This culvert is made of concrete and stone and has a natural channel bottom. This culvert is currently undersized and creates a flow impediment, resulting in maintenance concerns and safety hazards under flood conditions. Drainage in Sawmill Brook is also impeded by the undersized culvert combined with the low-gradient stream.

Evaluation Conducted

On May 30, 2015, sixteen volunteers completed a field effort to photograph and collect vital statistics on the culverts and stream crossings throughout Town. The volunteers were recruited from regional and local groups including Salem Sound Coast Watch, Stream Team, high-school environmental organizations, and Town committees including Conservation and Open Space. The field effort yielded an inventory of the culverts' condition and dimensions. In addition, a survey crew was deployed the week of July 20, 2015 to obtain additional culvert inlet and outlet elevations and road centerlines at specific locations throughout the watershed, including the School Street culvert.

Tighe & Bond modeled existing and future conditions within the Sawmill Brook Watershed based on anticipated climate change scenarios that considered impacts of increased precipitation, sea level rise, and storm surge in 2025, 2050, and 2100. This culvert was re-sized to accommodate the 50 year storm for the year 2050 under balanced energy use precipitation scenario and sea level rise.



Project Location

Culvert Improvement at School Street

Conceptual Design

- Remove existing School Street culvert and replace with 6.6 foot tall by 16 foot wide box culvert
- Emulate historic stone work in replacement facing
- Shore stone wall under existing building
- Full-depth roadway reconstruction including guardrail replacement
- Widen and lower limited segments of Sawmill Brook. At School Street, lower stream channel by approximately 1.2 feet. Downstream of School Street, widen by approximately 4 feet until Central Pond. Upstream of School Street to Norwood Avenue, widen by approximately 4 to 8 feet depending on location and conflicts with private property.
- Project should be coordinated with intersection and street improvements, including widening School Street to accommodate a full width sidewalk along the east side of the road, from Brook Street to the existing sidewalk north of the culvert on School Street, and adding a crosswalk to Bridge Street.

Project Impact

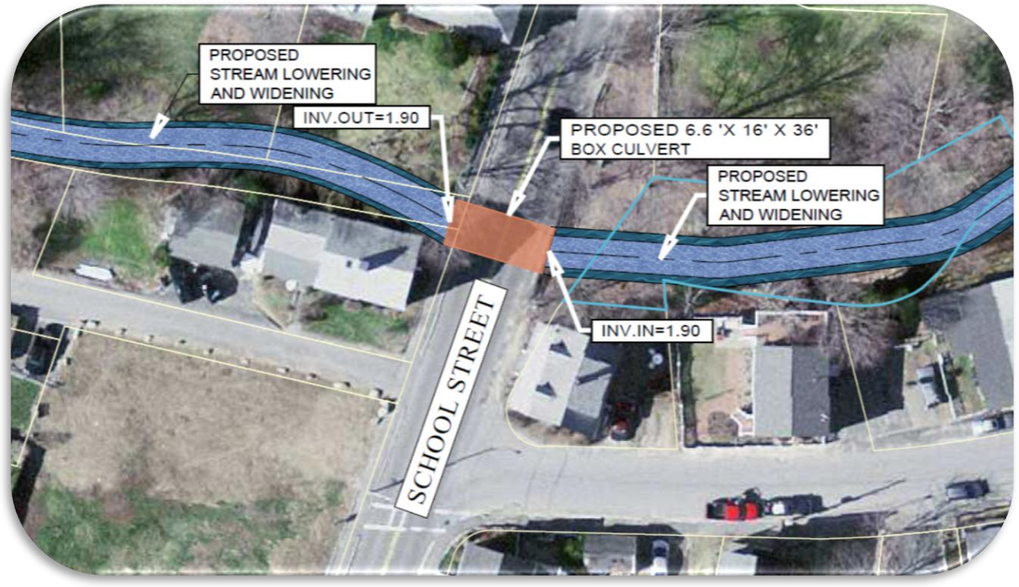
Enlargement of the School Street culvert and limited widening of Sawmill Brook stream channel will improve hydraulic capacity of the stream channel and limit backwater flooding to alleviate flooding of private properties adjacent to Sawmill Brook. Improvements to stormwater drainage will benefit water quality. Sediment removal and stabilization of the streambank as part of the stream widening will improve rainbow smelt habitat.

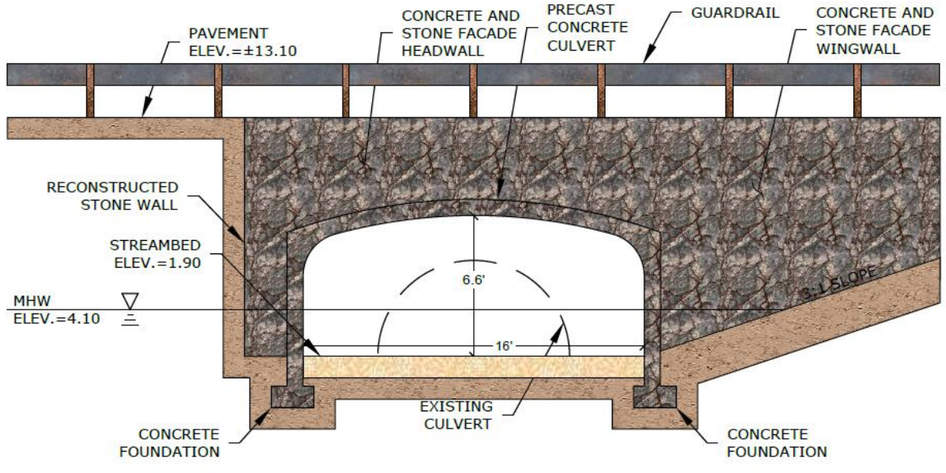
Based on the HEC-RAS modeling completed, increasing the size of this culvert along with widening and lowering of limited segments of Sawmill Brook, along with improving the downstream Central Street Culvert and upstream Norwood Avenue culvert, will decrease water surface elevations in flood conditions by approximately 5% upstream of School Street and approximately 13% downstream of School Street. Without making channel improvements, the downstream water surface elevations will only be reduced by only approximately 8%. In addition, some channel improvements are necessary for culvert widening.

Downstream face of School Street Culvert

View downstream from School Street Culvert

Culvert Improvement at School Street





Culvert Improvement at Norwood Avenue

Feasibility Level Opinion of Probable Cost[1]

- Construction: $800,000 Total cost = $910,000
- Total cost includes the following "soft costs"
  - Engineering and Design
  - Permits
  - Survey

Permits Likely Required

- Order of Conditions from Conservation Commission
- Massachusetts Historical Commission Project Notification Form
- Street Opening Permit
- *Massachusetts Environmental Policy Act (MEPA) Environmental Notification Form*
- *Department of the Army General Permit Commonwealth of Massachusetts*
- *Chapter 91 Waterways License*
- *401 Water Quality Certificate*

View upstream from Norwood Avenue Culvert

Further Assessment Needs

- Site-specific subsurface investigation including geotechnical evaluation and depth to groundwater
- Identification of utilities
- Easements

View upstream side of Norwood Avenue Culvert

[1] +50% to -30%

Culvert Improvement at Norwood Avenue

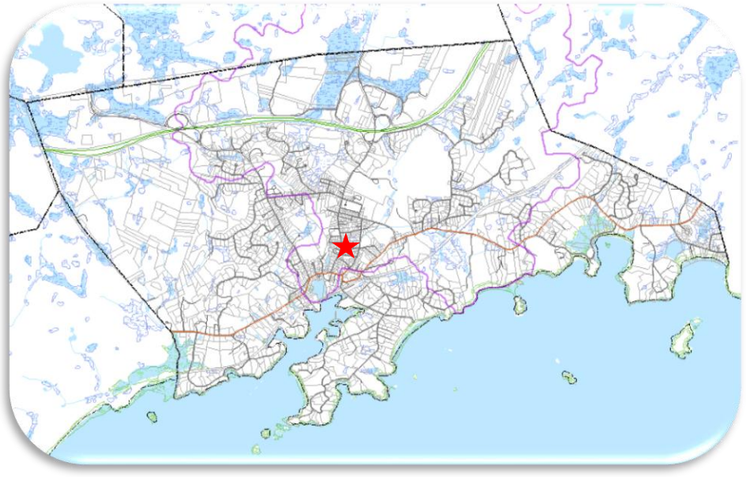
Project Need

Many areas of Manchester are subject to flooding during extreme storm events due to the combination of storm surge, hydraulic restrictions from culverts and the tide gate, stormwater runoff from impervious areas, the channelized stream system, and poor infiltration conditions. Impacts from climate change including increased precipitation and sea level rise will exacerbate flooding. The culvert under Norwood Avenue is one of many hydraulic restrictions. This culvert is made of metal girders and stone bridge abutments. This culvert is currently undersized and creates a flow impediment, resulting in maintenance concerns and safety hazards under flood conditions. Drainage in Sawmill Brook is also impeded by the undersized culvert combined with the low-gradient stream

Evaluation Conducted

On May 30, 2015, sixteen volunteers completed a field effort to photograph and collect vital statistics on the culverts and stream crossings throughout Town. The volunteers were recruited from regional and local groups including Salem Sound Coast Watch, Stream Team, high-school environmental organizations, and Town committees including Conservation and Open Space. The field effort yielded an inventory of the culverts' condition and dimensions. In addition, a survey crew was deployed the week of July 20, 2015 to obtain additional culvert inlet and outlet elevations and road centerlines at specific locations throughout the watershed, including the Norwood Avenue culvert

Tighe & Bond modeled existing and future conditions within the Sawmill Brook Watershed based on anticipated climate change scenarios that considered impacts of increased precipitation, sea level rise, and storm surge in 2025, 2050, and 2100. This culvert was re-sized to accommodate the 50 year storm for the year 2050 under balanced energy use precipitation scenario and sea level rise.



Project Location

Culvert Improvement at Norwood Avenue

Conceptual Design

- Remove existing Norwood Avenue culvert and replace with 7’ tall by 20’ wide box culvert
- Widen Sawmill Brook stream channel downstream of Norwood Avenue by approximately 4 to 8 feet depending on location and conflicts with private property.
- Lower Sawmill Brook channel by approximately 3.1 feet at Norwood Avenue Culvert
- Full-depth roadway reconstruction including guardrail replacement

Project Impact

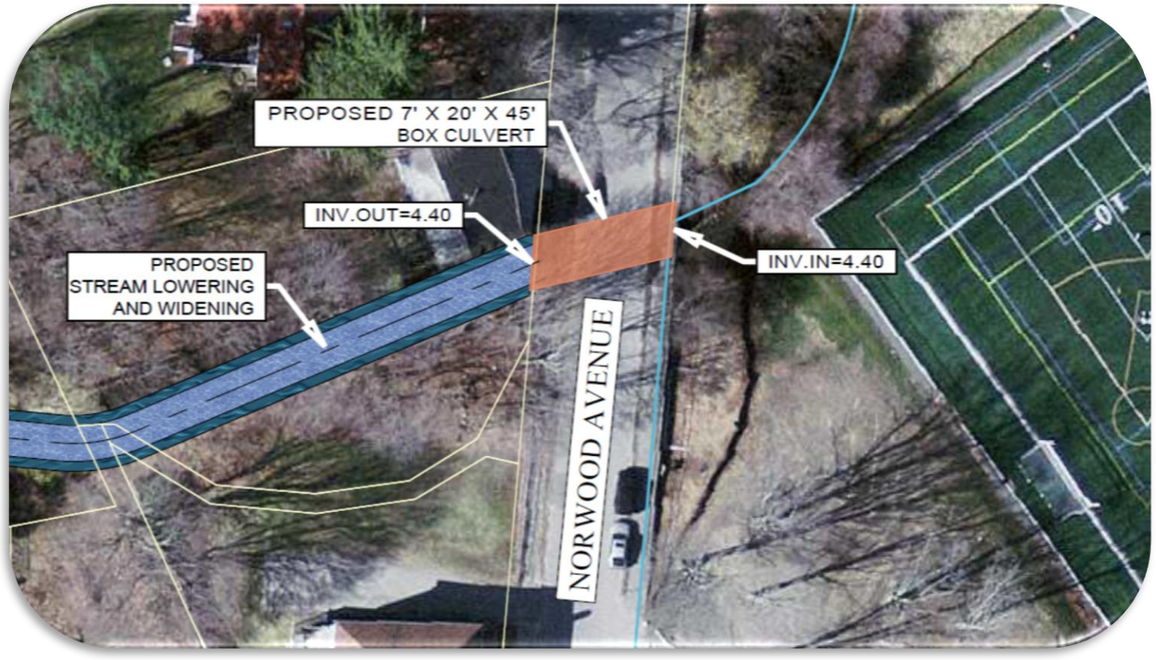
Enlargement of the Norwood Avenue culvert and limited widening of Sawmill Brook stream channel will improve hydraulic capacity of the stream channel and limit backwater flooding to alleviate flooding of private properties and municipal facilities adjacent to Sawmill Brook.

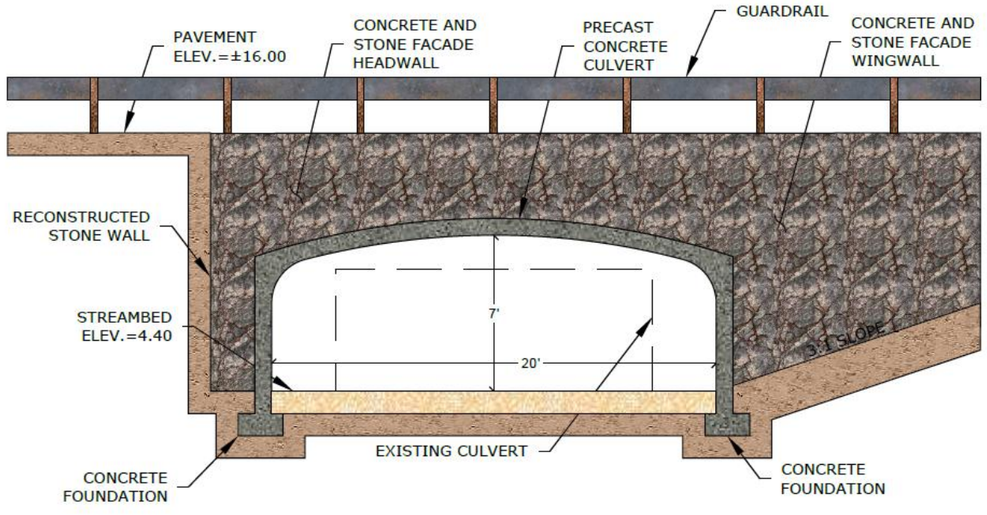
Based on the HEC-RAS modeling completed, increasing the size of this culvert along with widening and lowering of limited segments of Sawmill Brook, along with improving the downstream School Street and Central Street culverts, will decrease water surface elevations in flood conditions by approximately 6% downstream of Norwood Avenue and approximately 13% downstream of School Street. In addition, some channel improvements are necessary for culvert widening.

View downstream of Norwood Avenue

View of downstream face of Norwood Avenue Culvert during stream crossing survey

Culvert Improvement at Norwood Avenue





Culvert Improvement at Lincoln Street

Feasibility Level Opinion of Probable Cost[1]

- Construction: $315,000 Total cost = $400,000
- Total cost includes the following "soft costs"
  - Engineering and Design
  - Permits
  - Survey

Permits Likely Required

- Order of Conditions from Conservation Commission
- Massachusetts Historical Commission Project Notification Form
- Street Opening Permit
- *Massachusetts Environmental Policy Act (MEPA) Environmental Notification Form*
- *Department of the Army General Permit Commonwealth of Massachusetts*
- *Chapter 91 Waterways License*
- *401 Water Quality Certificate*

Further Assessment Needs

- Site-specific subsurface investigation including geotechnical evaluation and depth to groundwater
- Identification of utilities
- Easements
- Assessment of historic implications of replacing stonework

Volunteer in Culvert 17 during stream crossing survey

View of upstream Sawmill Brook from Culvert 17

[1] +50% to -30%

Culvert Improvement at Lincoln Street

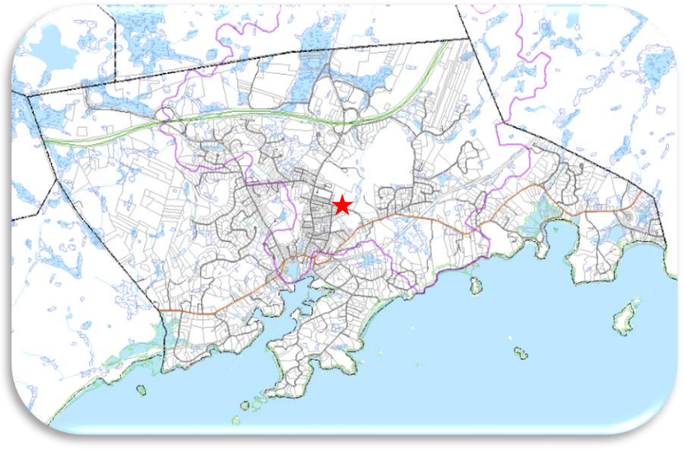
Project Need

Many areas of Manchester are subject to flooding during extreme storm events due to the combination of storm surge, hydraulic restrictions from culverts and the tide gate, stormwater runoff from impervious areas, the channelized stream system, and poor infiltration conditions. Impacts from climate change including increased precipitation and sea level rise will exacerbate flooding. The culvert under Lincoln Street is just upstream of the confluence with Causeway Brook and the location floods frequently. This culvert is made of stone and has a natural channel bottom. This culvert is currently undersized and creates a flow impediment, resulting in maintenance concerns and safety hazards under flood conditions. Drainage in Sawmill Brook is also impeded by the undersized culvert combined with the low-gradient stream.

Evaluation Conducted

On May 30, 2015, sixteen volunteers completed a field effort to photograph and collect vital statistics on the culverts and stream crossings throughout Town. The volunteers were recruited from regional and local groups including Salem Sound Coast Watch, Stream Team, high-school environmental organizations, and Town committees including Conservation and Open Space. The field effort yielded an inventory of the culverts' condition and dimensions. In addition, a survey crew was deployed the week of July 20, 2015 to obtain additional culvert inlet and outlet elevations and road centerlines at specific locations throughout the watershed, including the Lincoln Street culvert.

Tighe & Bond modeled existing and future conditions within the Sawmill Brook Watershed based on anticipated climate change scenarios that considered impacts of increased precipitation, sea level rise, and storm surge in 2025, 2050, and 2100. This culvert was re-sized to accommodate the 50 year storm for the year 2050 under balanced energy use precipitation scenario and sea level rise.



Project location

Culvert Improvement at Lincoln Street

Conceptual Design

- Remove existing Lincoln Street culvert and replace with 6.5 foot tall by 20 foot wide box culvert
- Full-depth roadway reconstruction including guardrail replacement.
- Sediment and organic debris removal in vicinity of culvert.

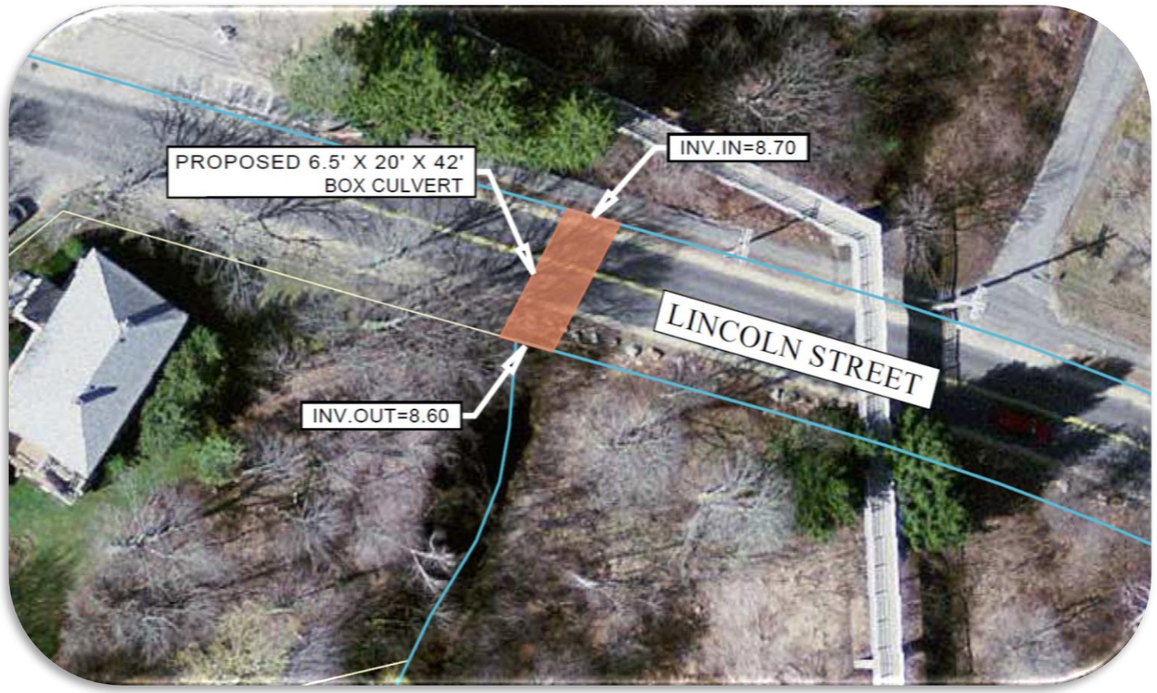
Project Impact

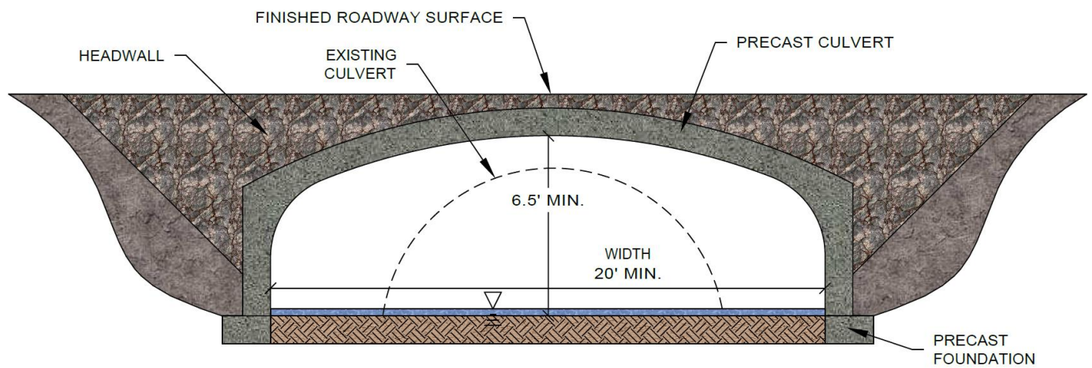
Enlargement of the Lincoln Street culvert will increase the hydraulic capacity of Sawmill Brook and reduce backwater flooding impacting the High School property and Lincoln Street Wellfield upgradient of the site, which has flooded in previous storm events. The stone culvert is aging, and replacement will eliminate safety concerns, especially during large flood events which are currently undercutting the banks at the culvert sidewalls.

Based on the HEC-RAS modeling completed, increasing the size of this culvert along with improving the downstream Norwood Avenue, School Street, and Central Street culverts, will decrease water surface elevations in flood conditions by up to 10% in the upstream segment, by approximately 3% directly downstream of Lincoln Street, almost 10% downstream of Norwood Avenue and School Street.

Downstream outlet of Culvert 17

Culvert Improvement at Lincoln Street





Porous Asphalt Parking Area at Coach Field Playground

Feasibility Level Opinion of Probable Cost[1]

- Construction: $360,000 Total cost = $430,000
- Total cost includes the following "soft" costs:
  - Engineering and Design
  - Permits
  - Survey
- Costs do not include maintenance of porous asphalt, which consists of vacuum sweeping two to four times each year.

Note that this project could potentially be funded through Community Preservation Act funds

Permits Likely Required

- Order of Conditions from Conservation Commission
- Local permits

Further Assessment Needs

- Site-specific subsurface investigation including geotechnical evaluation and depth to groundwater
- Identification of utilities

View of parking area from Norwood Avenue

[1] +50% to -30%

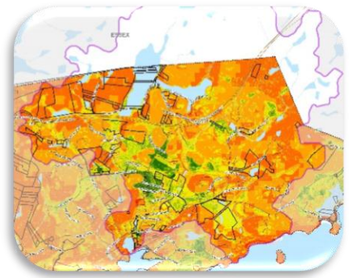
Porous Asphalt Parking Area at Coach Field Playground

Project Need

As part of the Town-wide assessment of opportunities to reduce runoff and manage floodwaters, including installing Green Infrastructure practices, Tighe & Bond identified the parking area for Coach Field Playground as a feasible location to replace the existing gravel/dirt parking area with porous asphalt. During a site visit, it was found that stormwater runoff causes erosion of the parking area and sediment migrates from the parking area along Norwood Avenue and enters Sawmill Brook through the Town's drainage system. Sediment loading decreases water quality, affects smelt habitats, and can alter the flow of water and stream depth. Installing porous pavement will eliminate the sediment migration from the parking area to Sawmill Brook.

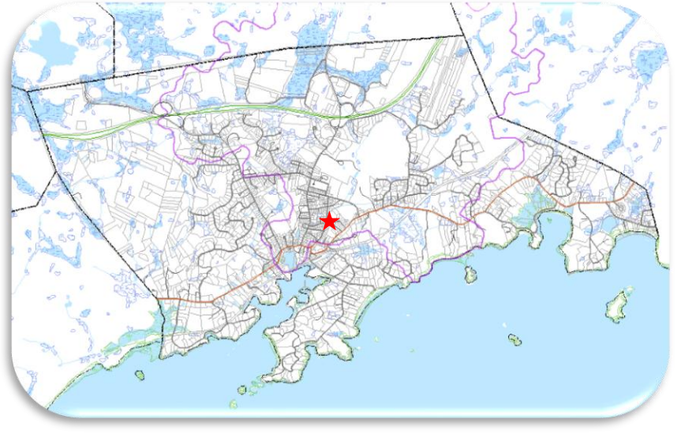
Evaluation Conducted

Tighe & Bond conducted a two step process to identify opportunities for flooding mitigation, including Green Infrastructure, within the Sawmill Brook watershed. The first step consisted of a desktop exercise using Geographic Information System (GIS) to identify and prioritize potentially feasible locations for Green Infrastructure based on subsurface conditions (including soil types and the depth to groundwater), parcel ownership, and environmental and permitting constraints. The second step consisted of a site visit to further assess the location for constructability, permitting needs, and further assessment required.



Initial desktop screening result

As part of modeling existing and future conditions in the Sawmill Brook Watershed, Tighe & Bond evaluated the potential water quantity benefit of installing porous asphalt in this parking lot. Because the parking area is small (approximately 0.4 acres) in comparison to the overall watershed (approximately 3,400 acres), this improvement will have limited benefit to reducing flows during larger precipitation events (e.g. the 25, 50, and 100 year storms in 2025, 2050, and 2100 that range from 6.3 inches to almost 11 inches in a 24-hour storm). However, it will have some benefit during small storm events. In addition, installing porous aspahlt on the parking area will improve the water quality of and reduce thermal loading to Sawmill Brook.



Project Location

Porous Asphalt Parking Area at Coach Field Playground

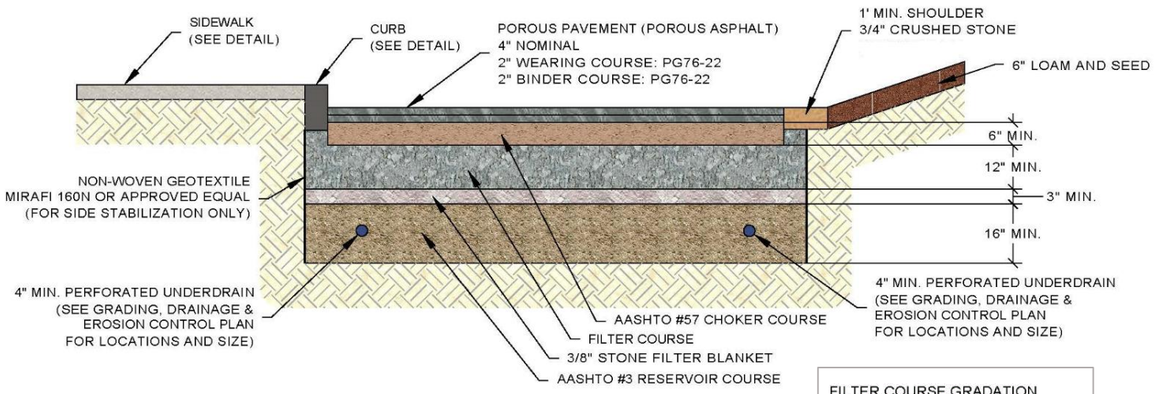
Conceptual Design

Porous asphalt, also known as pervious or permeable paving, is standard hot-mix asphalt with reduced fines (sand) that allows water to drain through it. The interconnected void space allows stormwater to flow through the asphalt, and enter a crushed stone aggregate bedding layer and base that supports the asphalt while providing storage and runoff treatment. When properly constructed, porous asphalt is a durable and cost competitive alternative to conventional asphalt. This project would consist of the following elements:

- Construction of a porous asphalt parking area to replace existing gravel parking, including excavation of existing parking lot and installation of sub-base.
- Installation of small bathroom facilities as part of project
- Project would include a public education component through signs and displays.

Project Impact

Water quality improvements would be attained with the implementation of this project. Sediment routinely migrates from the unpaved parking area to Sawmill Brook, negatively impacting smelt habitat. Porous asphalt, the green stormwater infrastructure recommended for the site, has the ability to reduce total suspended solids up to 80%. Porous asphalt will also help reduce runoff to Sawmill Brook during smaller storms. The public location of the parking area, and high use volume makes this an ideal spot for a public education kiosk, to inform the public about impacts of stormwater runoff on Sawmill Brook and the benefits of green stormwater infrastructure. As part of the improvement project, a restroom is also recommended (restroom building indicated in orange on page 3).



FILTER COURSE GRADATION

SEIVE SIZE	% PASSING
6"	100
#4	70-100
#40	10-60
#200	0-65

Porous Asphalt Parking Area at Coach Field Playground

Example of porous asphalt (shown in the parking stall) compared to traditional asphalt (remainder of parking lot) at Tighe & Bond's Portsmouth, New Hampshire Office.

Flood Storage Improvements at Essex County Club

Feasibility Level Opinion of Probable Cost[1]

- Construction: $1,020,000 Total cost = $1,180,000

- Total cost includes the following "soft" costs:
  - Engineering and Design
  - Permits
  - Survey

Permits Likely Required

- Order of Conditions from Conservation Commission
- 401 Water Quality Certificate
- Massachusetts Environmental Policy Act (MEPA) Environmental Notification Form
- *Department of the Army General Permit Commonwealth of Massachusetts*
- *Chapter 91 Waterways License*
- *401 Water Quality Certificate*
- Local Permits

Further Assessment Needs

The following items must be completed prior to the completion of this project:

- Coordination with Essex County Club
- Extensive survey (including wetlands flagging)
- Identification of existing utilities
- Easements needed, if any

Existing stream channel

[1] +50% to – 30%

Flood Storage Improvements at Essex County Club

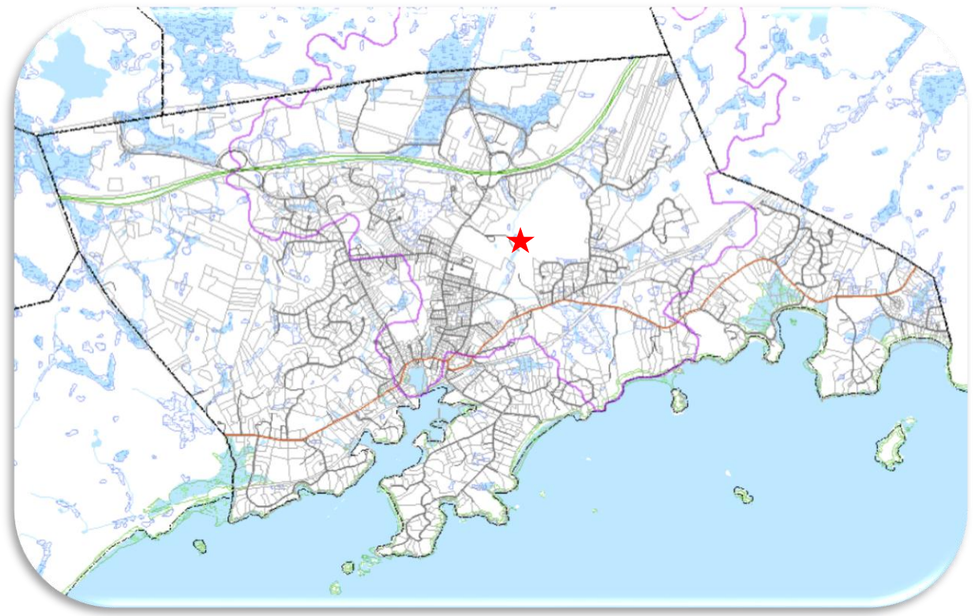
Project Need

The Essex County Club provides an opportunity to manage flooding in the municipally-owned or privately-owned portion of land by re-grading areas abutting the existing stream channel. The open space that the golf course provides could be utilized as temporary flood water storage. The golf course is the last opportunity to manage floodwaters before they reach the downstream segment of Sawmill Brook, which is within the more developed portion of Manchester-by-the-Sea and is channelized and hydraulically constrained. Completing this project would help mitigate downstream flooding.

Evaluation Conducted

Tighe & Bond modeled existing conditions within the Sawmill Brook Watershed for the 25-, 50- and 100-year storms, and projected future flooding conditions within the Town as a result of anticipated climate change scenarios (balanced energy use and fossil intensive use) and sea level rise during 2025, 2050, and 2100. Areas along the County Club stream channel were evaluated using the 50 year storm for the year 2050 under balanced energy use and sea level rise to determine whether they would overtop and flood.

Tighe & Bond evaluated increasing the floodplain through the golf club. In the model, the existing stream channel stayed the same but the adjacent flood plain was expanded to over 6.5 acre-ft.



Project Location

Flood Storage Improvements at Essex County Club

Conceptual Design

- Increasing flood storage areas by re-grading area abutting the stream channel to create approximately 6.6 acre-feet of storage.
- Total area of disturbance is approximately 13.8 acres

Project Impact

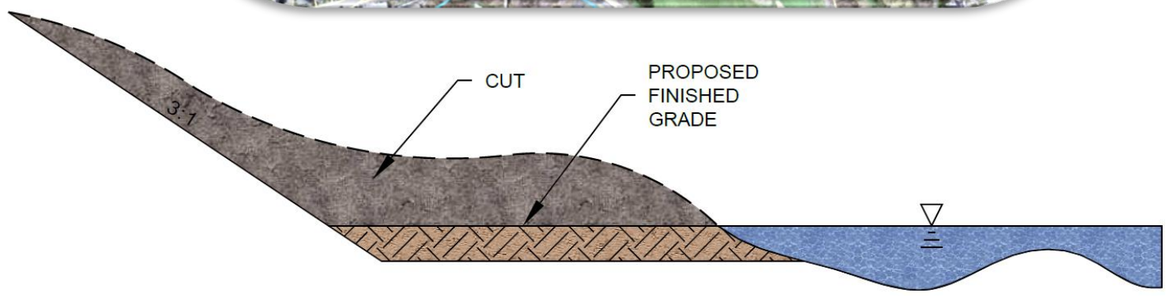
Providing flood storage within the golf course by increasing the cross sectional area of the existing stream channel will attenuate flood waters below Route 128, reducing downstream flooding severity.

Restoring the channel to a more natural orientation would improve aesthetics. This public location presents an excellent opportunity for a public education kiosk describing how open space parcels can help flood attenuation.

Based on the HEC-RAS watershed modeling completed, this project has limited potential to reduce water surface elevations and water flows during the 50 year storm in 2050, due to the extensive size of the watershed.

Aerial view of part of the existing stream channel

Flood Storage Improvements at Essex County Club



Old School Street Flood Mitigation

Feasibility Level Opinion of Probable Cost[1]

- Construction: $165,000 Total cost = $220,000
- Total cost includes the following "soft costs":
  - Engineering and Design
  - Permits
  - Survey

Permits Likely Required

- Order of Conditions from Conservation Commission
- Massachusetts Historical Commission Project Notification Form
- Street Opening Permit
- Massachusetts Environmental Policy Act (MEPA) Environmental Notification Form
- Department of the Army General Permit Commonwealth of Massachusetts
- Chapter 91 Waterways License
- 401 Water Quality Certificate

Further Assessment Needs

- Identification of utilities
- Full survey and extensive wetlands flagging
- Potential need for easements, if any

Inlet of one of Old School Street Culverts

[1] +50% to -30%

Old School Street Flood Mitigation

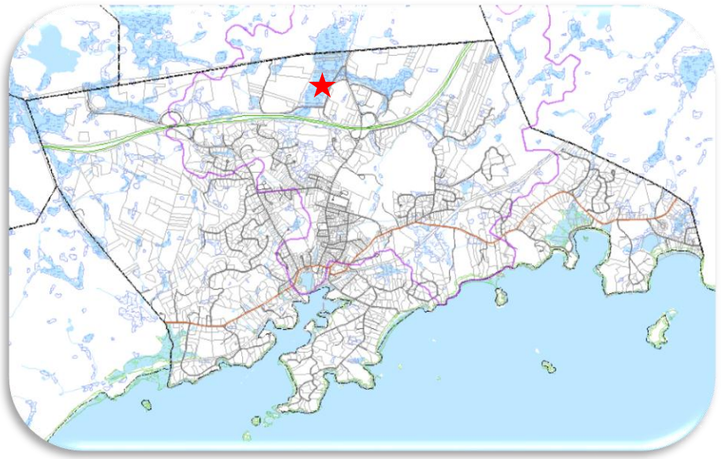
Project Need

As part of the Town-wide assessment of opportunities to reduce runoff and manage floodwaters, Tighe & Bond identified Old School Street as a feasible location to raise the elevation of the road which will allow additional storage of flood water upstream of the road. Many areas of Manchester are subject to flooding during extreme storm events due to the combination of storm surge, hydraulic restrictions from culverts and the tide gate, stormwater runoff from impervious areas, the channelized stream system, and poor infiltration conditions. Impacts from climate change including increased precipitation and sea level rise will exacerbate flooding. This project provides an opportunity to manage floodwaters in the upper watershed, before water migrates downstream into the more channelized, hydraulicly restricted, and low-gradient segments that are within the developed portion of Town.

Evaluation Conducted

Tighe & Bond conducted a two step process to identifiy opportunities for flooding mitigation within the Sawmill Brook watershed. The first step consisted of a desktop exercise using Geographic Information System (GIS) to identify and prioritize potentially feasible locations for flood managemenet based on subsurface conditions, parcel ownership, and environmental and permitting constraints. The second step consisted of a site visit to further assess the location for constructability, permitting needs, and further assessment required.

As part of modeling existing and future conditions in the Sawmill Brook Watershed, Tighe & Bond evaluated the potential flood storage benefit of raising the elevation of Old School Street. Tighe & Bond modeled existing and future conditions within the Sawmill Brook Watershed based on anticipated climate change scenarios that considered impacts of increased precipitation, sea level rise, and storm surge in 2025, 2050, and 2100.



Project Location

Old School Street Flood Mitigation

Conceptual Design

- Replace three existing culverts with two reinforced concrete box culvert with natural bottoms and one reinforced concrete pipe culvert.
- Raise the road elevation of Old School Street by approximately 4 feet

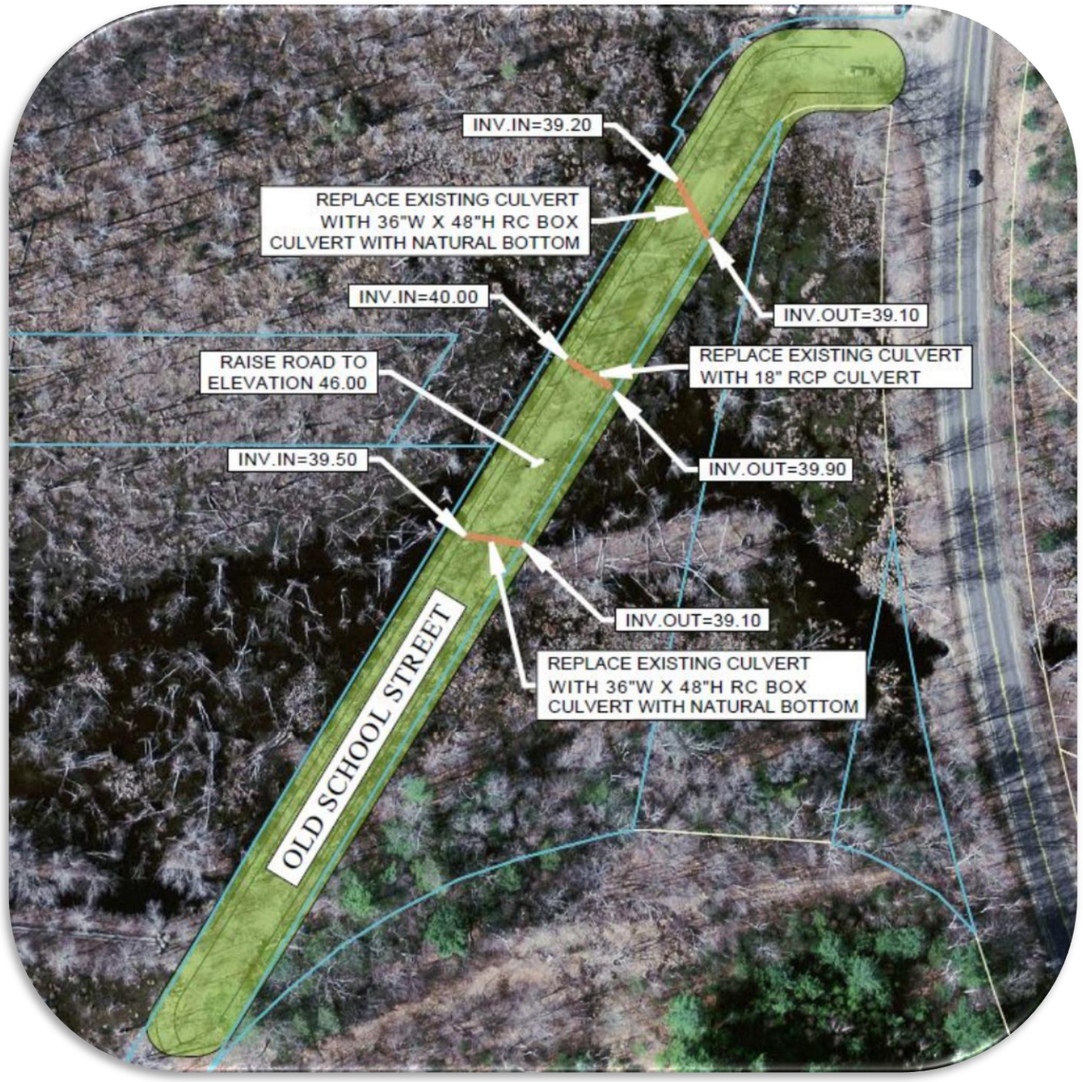
Project Impact

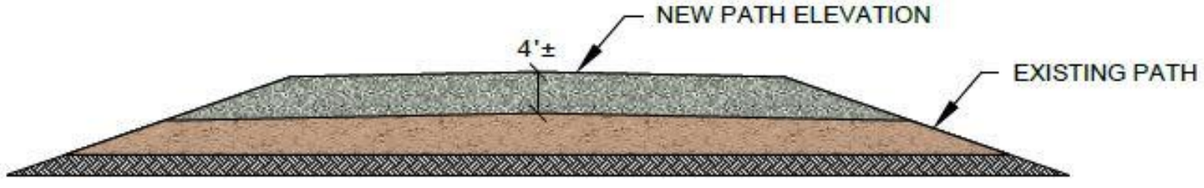
Increasing the storage behind Old School Street attenuates storm discharge and reduces the frequency and amount of instances where culverts overtop downstream. Providing flood storage at the top of the Sawmill Brook Watershed would provide greatest benefit for locations immediately downstream of Route 128, where flooding occurs frequently. The roadway and culverts are old and replacement of the dry stone box culverts with natural bottom structures would improve passage for a number of wildlife species.

Based on the HEC-RAS watershed modeling completed, increasing the flood storage behind Old School Street has the potential to reduce total flows by between 16% and 85% in the area south of Old School Street before the Essex County Club, but by 1% or less downstream from the County Club particularly in the downtown area.

Outlet of one of Old School Street culvverts

Old School Street Flood Mitigation





Storm Surge Barrier

Feasibility Level Opinion of Probable Cost[1]

- Total cost = $26,000,000

- Assumptions:
  - Stone dike type structure
  - 60’ wide navigation opening with gate
  - Crest height for existing 100 year flood

- Construction cost includes:
  - Engineering
  - Permits
  - Survey
  - Contingency (20%)

View of the Manchester-by-the-Sea harbor

Permits Likely Required

- Order of Conditions under the Wetlands Protection Act
- Massachusetts Environmental Policy Act (MEPA) ENF and EIR
- Chapter 91 Waterways License
- Individual Permit from the Army Corps of Engineers
- Section 106 / State Historic Preservation Office
- 401 Water Quality Certificate
- If federally funded:
  - National Environmental Policy Act (NEPA)
  - Environmental Impact Statement

Further Assessment Needs

- Feasibility study
- Bathymetry and survey
- Benthic study
- Underwater archeology evaluation
- Wave analysis and flushing analysis
- Subsurface soil & bedrock data
- Stakeholder buy-in

[1] +50% to -30%

Storm Surge Barrier

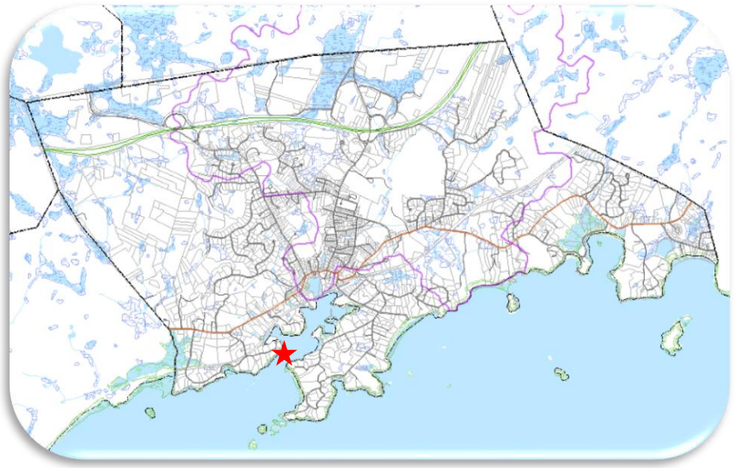
Project Need

A storm surge barrier would be an option to protect Manchester Harbor and vicinity from moderate storm surge, some sea level rise, wave action and if closed during low tide, a way to hold a low tail-water condition to minimize back-watered river flooding. These types of structures can range from large structures, such as the New Bedford Hurricane Barrier (right), to smaller tidal dikes, lower right. From the existing topographic land height limitations in Manchester Harbor, a surge barrier would likely be a structure size in between these two example photographs.

Hurricane barrier in New Bedford, MA

Evaluation Conducted

The site of the conceptual surge barrier illustrated in Figure 1 was selected as a balance between vicinity protected (most of the harbor area) and finding an area with adjacent high shoreline and relative shallow water depths to minimize structure costs. Several sites were considered, including the railroad bridge that benefits from the existing railroad fill, and were viewed and discussed with town officials. The preferred site from a technical perspective is the harbor entrance between Tucks Point and Proctor Point. This site is just inshore of mapped/historical eelgrass beds, thus avoiding sensitive benthic habitat.

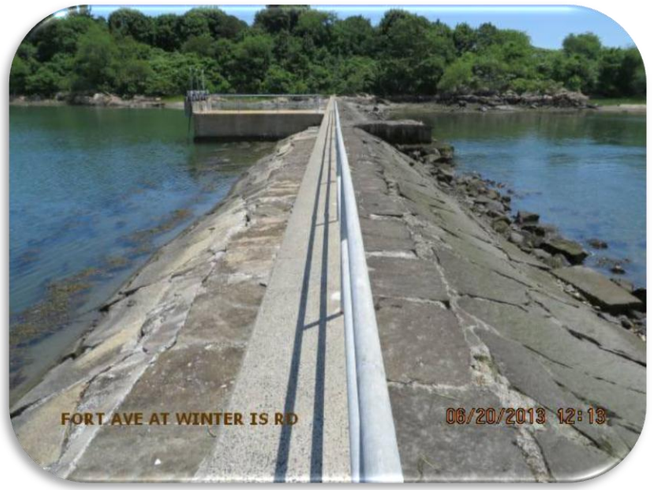


Project Location

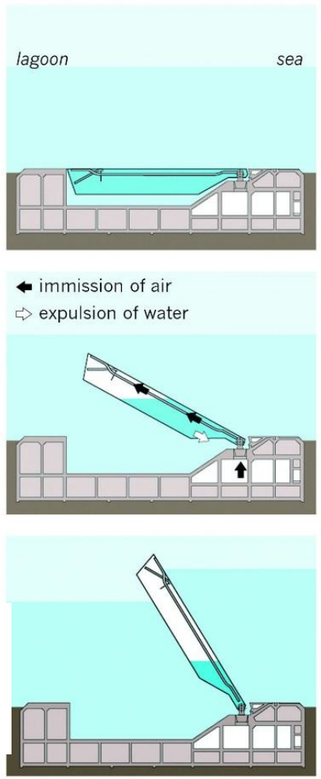
Storm Surge Barrier

Conceptual Design

The conceptual design of the surge barrier is a traditional stone armored dike/breakwater with a navigation opening aligned with the harbor entrance channel. A boat navigation opening at least 60 feet wide would be provided in the barrier, aligned with the channel, formed by side walls and a hinged steel gate, typically open, lying on the seabed. The opening end walls might consist of steel sheet pile cells, or concrete structures. The concept layout is based on a 12 foot wide crest path that would likely be needed for periodic maintenance and a crest elevation about 21 feet above mean lower low water, based on the present FEMA 100 year velocity zone elevation. The barrier structure might also need to include submerged tunnels with gates, normally open, to maintain good tidal water exchange and water quality in the harbor. The existing town sewer outfall pipe is buried along the edge of the existing navigation channel and this would need to be investigated to see if modifications including armoring and a back flooding prevention valve might be needed.



Tidal dike



Example of gate movement from Venice MOSE project (Wikipedia.org). Under normal conditions (top graphic), the gates are completely full of water and rest on the seabed. When needed to address tidal impacts, gates are emptied of water with compressed air to rise up to create a barrier that temporarily isolates the sea from the lagoon (middle and bottom graphics)

Storm Surge Barrier

Project Impact

Installation of a surge barrier will augment protection of Manchester Harbor in the event of a hurricane or tsunami by controlling storm surge entering the harbor. The barrier may assist in prevention of upland flooding by closing it at low tide, to control backwater hydraulic restrictions during period of high stream discharge.