Central Street Bridge Replacement

Basis of Design Memorandum

MassDOT Bridge No. M-02-001, Bin. 8AM

Town of Manchester-by-the-Sea

August 23, 2019

Tighe&Bond

Engineers | Environmental Specialists

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Project Location and Background

Town: Manchester-by-the-Sea, Massachusetts

District: 4

Bridge Number: M-02-001

Bin: 8AM

Structure Number: M02001-8AM-MUN-BRI

Feature Carried: Central Street (Route 127)

Feature Intersected: Sawmill Brook

Background:

The Town of Manchester by the Sea (Manchester) has requested that Tighe & Bond provide engineering design services for replacement of the Central Street bridge over Sawmill Brook. This document describes alternatives for replacement of the structure based on evaluations previously performed by Tighe & Bond for the bridge, tide gate, and wingwall in 2015 that resulted in the development of a conceptual replacement design for the bridge using a precast concrete arch.

The existing bridge is a masonry block spandrel arch bridge with backfill supporting the highway above. In the past, the tide gate at the site impounded water within the bridge and backfill. This has led to seepage and loss of backfill material when large precipitation events and high tide elevations are concurrent. Multiple scenarios of prior hydrologic assessment of the bridge indicate that it is undersized to pass current design storm events without over-topping with concurrent tail water impacts due to storm surge. With the potential for future sea level rise, it is anticipated this area may flood more frequently.

The tide gate and weir design have been identified by the Massachusetts Division of Marine Fisheries (DMF) as an impediment to fish passage, notably impacting state-listed species including rainbow smelt (*Osmerus mordax*). It is proposed that the gate will be removed as part of this project.

Based on the planning and analytical work that has been completed to increase the profile of the project at the state level, MassDOT has awarded the Town of Manchester a $500,000 Small Bridge Grant to replace the significantly deteriorated bridge.

To support the basis of our design for the replacement, Tighe & Bond obtained detailed topographic survey, performed a subsurface exploration program and geotechnical evaluation, and expanded our hydrologic and hydraulic analysis for the site. This memorandum summarizes the results of the existing conditions data and describes our previously developed conceptual design for the crossing. Included in the document are refined recommendations based on this data.

Existing Conditions

Tighe & Bond requested available data on the existing structure including reports and plans from MassDOT at the State and District levels as well as the Manchester-By-The-Sea Department of Public Works. Existing plans are not available. However, MassDOT provided an inspection report dated November 9, 2016 that is included in Appendix A. Tighe & Bond also visited the site, met with Town officials on multiple occasions, attended public informational meetings associated with the closely related pond restoration project upstream of the site, obtained survey data, performed hydrologic & hydraulic analysis, obtained borings, and evaluated subsurface conditions to further define existing conditions.

During a site visit on August 13, 2018, existing conditions were observed and survey needs were further defined. The site visit also confirmed the conditions of the structure as described in the 2015 Sawmill Brook Central St Seawall, Tide Gate & Culvert Observations memorandum, included in Appendix B. The observations included water seepage paths, damming conditions caused by the tide gate, separation and settlement of culvert arch stones, and concrete degradation.

Tighe & Bond subcontracted with a licensed and qualified professional surveyor, Doucet Survey Inc., to conduct topographical field survey of the project area. The survey included an approximate 1.9-acre area surrounding the Central Street bridge location to identify features including existing structures, potential geotechnical exploration locations, observable utilities with inverts, channel walls, tide gate, and stream gages. Elevations were taken within the channel from 50 feet downstream to 10 feet upstream, to develop 1-foot contours. Records research was conducted that included review of current deeds from parcels within the survey limits referenced in the town assessors' records. The Existing Conditions Site Plan included in the 25% design is included in Appendix E.

Existing Bridge Structure

The Central Street Bridge spans Sawmill Brook at the mouth of Manchester Harbor on Central Street (Route 127). According to MassDOT records, the original bridge was constructed in 1850 and reconstructed in 1900. The crossing consists of the bridge, a tide gate, and coastal wingwalls. The bridge features a 16-foot span mortared stone masonry circular arch with stone masonry wingwalls and headwalls. The arch has a total opening height of 6.6 feet at the inlet, 10.0 feet at the outlet, and the height from the low chord to the roadway is approximately 4.5 feet. The structure bears directly on exposed bedrock. Timber cribs, functioning as weirs, are imbedded into the bottom of the stream bed. A concrete and iron tide gate abuts the bridge to the south.

The bridge was rebuilt around the mid 1900's and a tide gate was installed to control the Brook flows and created Central Pond just upstream. A stone masonry wingwall abuts the bridge in the southwest quadrant, functioning as a seawall.

The existing curb-to-curb width at the bridge is 34.5-feet with 6-inch granite curbs and 4-to-5-foot hot mix asphalt sidewalks for a total width of approximately 45-feet. The road carries two lanes of traffic, one in each direction, and has enough width to accommodate parking. However, there is no parking on the physical bridge structure as a majority of the span is covered by crosswalk that is generally situated above the channel. The curb cut ramps at the crosswalk are in poor condition and the grades do not meet current ADA requirements. The bridge has a 7-degree skew.

The property in the Northeast quadrant has a private porch structure that bears directly on the headwall of the bridge (see photo above). The tide gate structure abuts the southeast channel wall. Field observations indicate that the tide gate was designed as a standalone structure. However, it is unclear if the wall can function as a freestanding structure given its age.

The bridge is on the National Historic Registry as the site of historic water powered mill dating back to the 1600's and it marks the entrance to downtown Manchester-by-the-Sea. The design team and the DPW staff have been in consultation with the Manchester Historic District Commission (HDC) regarding the project, and expect the coordination efforts to continue during later stages of design development.

As described in MassDOT's inspection report, the bridge is in poor condition with deficiencies that should be addressed as soon as possible, Most notably, the arch is missing granite keystones along the northern portion of the bridge and a majority of the arch has concrete patches throughout. The northern headwall is covered with concrete patching and efflorescence over a majority of its surface. The headwall also has areas of spalling with exposed reinforcement. Chain link fence, which does not meet MassDOT standards for highway railing, exists for pedestrian and vehicular protection. Moderate cracking is evident throughout the roadway surface, which suggests loss of fill material around the structure. Previous site investigations revealed significant water seepage through joints between stones in the adjacent stone wingwall, indicating significant loss of fill material around the bridge and behind the wingwall.

The adjacent channel walls consist of granite masonry. Tighe & Bond excavated a test pit on November 27, 2018 behind the westerly upstream channel wall, approximately 70 feet north of the intersection of Elm Street and Central Street. The test pit revealed that the retaining wall consists entirely of granite blocks ranging from 31-inches wide at the base to 19-inches wide at the top, with longer staggered blocks keyed into the soil. Aside from the top course of blocks being 16-inches deep, the majority of the blocks are 24-inches deep. The test pit was excavated to a depth of 8-feet. Bottom of the wall was not encountered within the excavated depth. However, the bottom of wall is assumed to be at a depth of approximately 9.33-feet.

Existing Approach Roadway

Central Street (Route 127) is a Town-accepted layout in the downtown area of Manchester-by-the-Sea. The roadway is functionally classified as an urban minor arterial with a 25-mph speed limit and a 2016 AADT of 4,900[1]. The roadway within the project limits is not on the National Highway System (NHS). The roadway section to the east and west of the bridge is approximately 34.5 feet curb-to-curb with two travel lanes and a parking lane. The parking lane shifts from the south side of the road on the west of the bridge to the north side of the road on the east side of the bridge. Granite curbing and hot mix asphalt sidewalks of varying widths exists on both sides of the roadway.

Immediately west of the bridge site is the intersection of Central Street and Elm Street. Elm Street is a local road providing access to several residential and commercial properties. It is a dead-end road that is approximately 25 feet wide in the project area, with a 3-to-4-foot wide HMA sidewalk. Immediately east of the bridge site is the intersection of Central Street with Church Street. Church Street is a local road that provides access to the Municipal Building (including the Police Department), public parking, a boat launch, and the wastewater treatment plant. Church Street is a one-way with an exit farther east on Central Street, outside of the project area. The horizontal alignment of Central Street has minor deflections to the south and the north, with a tangent section across the bridge. The curb lines are not parallel to the centerline of the road. Overall functionality of the roadway is consistent with many older downtown urban corridors. However, there are opportunities to improve the overall geometry through the project area. The vertical grades are gentle, not exceeding 2% through the project area. There is a low point to the west of the existing bridge with a gentle upgrade through the crossing and continuing to the west.

There is no existing vehicular guardrail or barrier system. Existing concrete curbs and chain link fencing provide fall protection for pedestrians.

Existing Brook

The bridge crosses Sawmill Brook that is channelized between 12-foot-high granite walls with buildings abutting either side. A tide gate is located immediately downstream of the bridge separating the bridge from Manchester Harbor. Tidal flow from Manchester Harbor passes beneath the bridge depending on the setting of the tide gate and tide height. When the tide gate is closed and water is impounded underneath the bridge, the hydrostatic pressure of water forces seepage through the wingwall. The gate and bridge design have been identified as a contributing factor to upstream flooding, due to significant hydraulic restriction when large precipitation events and high tide elevations are concurrent. To minimize additional damage due to water impounding, the tide gate has been left in an open position.

The Massachusetts Division of Fisheries & Wildlife (Mass Wildlife) Division of Marine Fisheries (DMF) has monitored Rainbow Smelt habitat upstream of the bridge and found that the existing tide gate is a barrier to and limits fish passage.

[1] Roadway layout status, classification, speed, and volume data was queried from the MassDOT Roadway Inventory Portal (https://gis.massdot.state.ma.us/roadinventory/) on May 7. 2019.

Central Pond is approximately 150-feet upstream of the bridge and will be undergoing rehabilitation that is being coordinated with this bridge replacement project.

The channel walls that abut the bridge in two of the four bridge quadrants function as foundations for adjacent buildings. The channel is approximately 21-feet wide upstream of the bridge and approximately 45-feet wide immediately downstream of the bridge where the channel opens to Manchester Harbor. No marine traffic passage is currently feasible through the tide gate and culvert.

Existing Hydraulics

Tighe & Bond performed a hydraulic analysis for existing conditions using HEC-RAS, a 1-dimensional hydraulic modeling program available from the Army Corps of Engineers. HEC-RAS was used by Tighe & Bond to develop a model as part of the 2018 Sawmill Brook Feasibility Study[2], and was further refined as part of the current project design. The hydraulic performance under existing conditions was evaluated for the 2-, 10-, 25-, 50-, 100-, and 500-year return frequency storm events. The MassDOT Bridge Manual (2013) indicates that the hydraulic design flood return frequency for an Urban Minor Arterial or Rural Major Collector is the 25-year return frequency storm event with a recommended 2-feet of freeboard.

The hydraulic analysis presented herein is based on hydrologic analysis of the watershed of Sawmill Brook upstream of Central Street Bridge as part of 2016 Sawmill Brook and Green Infrastructure Analysis[3] that included the 25-, 50-, and 100-year frequency storm events using the U.S. Army Corps of Engineers HEC-HMS software. The 2-, 10-, and 500-year return frequency discharge peak flows were added to the existing HEC-HMS model. The 2016 Sawmill Brook and Green Infrastructure Analysis included climate change projections that predict stream flows in 2100 for the 25-, 50-, and 100-year frequency storm events. These projected values are not required as part of the MassDOT Chapter 85 guidelines but were considered as part of the design process. The drainage area upstream of the Central Street Bridge was determined to be approximately five square miles.

The hydraulic model was developed using the surveyed topographic data and LiDAR elevation data available from MassGIS. The hydraulic model was performed for Mean Higher High Water (MHHW) downstream tidal condition of 4.77 feet NAVD88 based on the NOAA Long Term Tide Water Level Monitoring Station ID: 8443970. MHHW is the technical term used by NOAA to describe the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch (19 year tidal cycle). The 25-year frequency storm event was also evaluated for Mean Sea Level (MSL) conditions and MHHW conditions in 2100 using the 0.012 feet/year increase recommended in the LFRD Bridge Manual to incorporate SLR. The existing conditions model results are presented in Table 1.

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[2] Tighe & Bond, 2018, "Task 2: Hydrologic Monitoring and Flushing Studies – Sawmill Brook Flood Mitigation and Restoration Projection".

[3] Tighe & Bond, 2016, Sawmill Brook Culvert and Green Infrastructure Analysis Task 4 Final Report: Evaluation of Locations for Flood Mitigation

A copy of the Hydrologic and Hydraulic Analysis Report is included in Appendix C. The analysis includes additional scenarios to incorporate future climate change conditions as well as storm surge.

Table 1
Hydrologic and Hydraulic Results Upstream of Existing Central Street Bridge (assuming tide gate is closed)

Storm Return Frequency[1]	Peak Discharge (Cubic Feet Per Second)	Upstream Peak Water Surface Elevation (feet, NAVD88)	Freeboard (feet)[2]	Distance to Top of Road (feet)	Average Velocity Inside Culvert (feet per second)
2-Year	254	6.4	-0.4	4.2	4.0
10-Year	924	11.2	-5.2	-0.6	12.1
25-Year	1,363	11.8	-5.8	-1.2	12.2
25-Year MHHW MassDOT SLR	1,363	11.9	-5.9	-1.3	12.3
25-year MSL MassDOT SLR	1,363	11.8	-5.8	-1.2	12.2
50-Year	1,772	12.4	-6.4	-1.8	8.5
100-Year	2,267	12.5	-6.5	-1.9	9.9
500-Year	3,078	12.6	-6.6	-2.0	9.5

[1] Tidal boundary condition is MHHW (Mean Higher High Water) unless stated otherwise. SLR = Sea Level Rise, MSL = Mean Sea Level.

[2] Freeboard measured as the vertical difference between the crown of the arch (low chord) and the Upstream Peak Water Surface Elevation.

The existing tide gate crest elevation is at 4.6 feet, which is below MHHW. The 2018 Sawmill Brook Feasibility Study found, through modeling and field measurements, that the tide gate increased water surface elevations upstream of Central Street during storm events, and water levels in the pond were found to exceed the tide levels during extreme high tides. As noted earlier, the tide gate will be removed due to hydraulic and fish passage considerations. Scour has not been observed at the Central Street Bridge for existing conditions.

Existing Utilities

There are numerous subgrade utilities beneath Central Street including sanitary sewer, storm drain, potable water, natural gas, electric, telephone, and cable. Tighe & Bond's survey subconsultant identified existing utilities in their existing conditions plan. The plan was developed based on the location of surface features, measure-downs in accessible manhole structures, record drawings, and utility locator data. Tighe & Bond developed a proposed utility plan for review and input by the Town and the various utility companies.

The following utilities are known to be present on site:

Utility	Company
Gas (unknown size)	National Grid
Electric (unknown size)	National Grid
Telephone (unknown size)	Verizon
Cable (unknown size)	Comcast
Sewer (8-inch main)	Department of Public Works
Storm Drain (12-inch main)	Department of Public Works
Water (12-inch main)	Department of Public Works

The top of the sanitary sewer has been observed in the bottom of the existing culvert structure. The vertical location of the sewer is fixed by the up- and downstream manhole inverts, but effort will be made as part of the next design submittal to adjust the pitch of the sewer to completely bury the pipe beneath the channel bed. The storm drain system is located on the west side of the bridge and does not cross the channel. The vertical profile of the road carries roadway runoff from east to west across the bridge to the drainage structures.

The water, gas, electric, and telecom utilities are presumed to cross above the bridge structure. The gas line is beneath the northerly sidewalk. Due to the uncertainty regarding vertical location of several existing utilities, test pits will be called out on the construction drawings. There is also an aerial power cable feeding power to one light pole across the bridge. We have assumed that the potable water and sanitary sewer will require temporary bypass during certain phases of construction. Tighe & Bond will continue to work with the DPW and individual utility companies regarding the appropriate handling of the various utilities both during construction and for their final configuration.

Refer to the Utility Plan included in Appendix E.

Wetland Resource Areas

Since the channel walls define the limits of the resource area, we have not conducted a separate wetland delineation for the project.

Cultural Resource Areas

The bridge is on the National Historic Registry as the site of historic water powered mills dating back to the 1600's and marks the entrance to the Downtown area of Manchester-by-the-Sea.

The DPW has preliminarily presented the general scope of the project and its aesthetic features to the Manchester Historic District Commission (HCD) and has obtained a letter of support from them (See Appendix H). The project team intends to continue working with the HDC during later stages of design development and permitting to address their design comments to the extent practicable.

Existing Hazardous Materials

While a Hazardous Building Material Assessment was not completed for the site, the Massachusetts Department of Environmental Protection database was reviewed and there are no known waste and reportable release sites identified within the project limits. Additionally, the Town does not have any knowledge of hazardous materials at the site.

Project Parameters and Constraints

Proposed Roadway Cross Section

This project is an isolated bridge replacement project and not part of larger corridor improvement project. Every effort was made to minimize the overall footprint. The existing horizontal and vertical alignments were matched to the extent practicable, roadway function was matched, and drainage patterns were preserved. Minor improvements were made to curb line geometry though to improve overall operation.

The following design parameters are proposed for the roadway approaches to the bridge:

- Curb-to-curb Roadway Width: 24-feet
- No. of Lanes: 2 @ 11-feet
- Parking Lanes: 1 @ 7-feet
- Shoulders: 2@ 1-foot
- Sidewalks: 2@ 5-feet minimum

The following design parameters are proposed for the bridge:

- Curb-to-curb Roadway Width: 24-feet
- No. of Lanes: 2 @ 11-feet
- Parking Lanes: none
- Shoulders: 2@ 1-foot
- Sidewalks: 1@ 5.5-feet and 1 @11.5 feet

Proposed Traffic Management – Central Street

During conceptual design, numerous methods of maintaining Central Street traffic have been considered, including a traffic detour, phased construction, a temporary bridge over the site, and a temporary bridge off-site. A description of each method is provided below.

Tighe & Bond met with the Town in December 2018 and discussed the pros and cons of the various methods, understanding that their desired method would influence our structural recommendations. The Town indicated they preferred the least-costly solution and would allow a full road closure of limited duration. It was discussed with the Town that a one-month closure would be challenging and is an aggressive schedule. To achieve this schedule, accelerated construction techniques would likely be required. Risks that could impact the construction schedule include unknown subsurface conditions that cannot be observed until demolition of the existing bridge and inclement weather at the site (in particular during the period of closure which is anticipated to be in late fall/ early winter).

If a one-month closure is utilized, a significant amount of preparation work will be required during the months leading up to the closure. All utilities and buried obstructions over the existing bridge would need to be removed or relocated in advance of the shutdown. Preparation work would require frequent lane shifts and lane closures restricted to a single-lane of traffic, leading up to the one-month full closure of the site for bridge demolition and replacement.

The one-month road closure would likely be scheduled for late fall or early winter to avoid impacts to tourism during the summer months and environmental restrictions during the spring. During the late fall and early winter, inclement weather such as snowfall, coastal storms ("Noreasters"), or tropical storms/hurricanes is more likely to occur and impact the schedule. Additionally, accelerated bridge construction techniques would require larger crews and work shifts outside of traditional hours, with potential for noise and vibration overnight, which may affect nearby residential areas.

Note: As an alternate approach to address the risks and challenges associated with a one-month closure restriction, the Town may consider evaluation of a structural design using precast concrete planks on concrete abutments. This type of structure can be constructed in phases and carry one-lane of traffic sooner than a buried arch can, and it can be constructed with reduced schedule and construction risks associated with weather, sequencing, or unanticipated site conditions.

Traffic Detour

A full bridge closure with a traffic detour is the preferred approach. This approach overall is considered to have lowest direct construction costs. A roadway closure will also provide for a safer work zone.

The shortest detour route would involve diversion of traffic from Central Street along Pine Street, Pleasant Street, and School Street. The full loop is approximately two miles long, which will take approximately five minutes to traverse in non-congested traffic conditions. Central Street, between Pine Street and School Street, would remain open to local traffic during detour periods. Regional traffic is likely to avoid Central street altogether and use Route 128 (Yankee Division Highway) to bypass the work zone. It is anticipated that detour signage would be installed in the detour loop supplemented by variable message signs posted in advance of the project prior to the start of construction.

Other staging approaches that have been considered but are not recommended, are described below.

Phased Construction

Phased construction would involve using half of the existing structure to maintain traffic while half of the new structure is constructed. Then, traffic would be shifted to the newly constructed half-structure while the remainder is constructed.

Since the existing structure consists of a spandrel wall arch, a temporary intermediate headwall would be required to retain the roadway fill over the usable-portion of the structure. Additionally, due to its poor condition, the existing structure would require substantial upgrades to maintain structural integrity. A detailed investigation of the bridge would be required to design such structural upgrades that would include removing portions of pavement and roadway fill to obtain structural information pertaining to the buried arch.

If the replacement structure is also a buried arch, a temporary intermediate headwall would also be required on the new structure to implement phase two of the phasing scheme. This approach would be non-standard and would require rework of placing roadway fill over the arch in order to remove the temporary intermediate headwall. Abandoning the intermediate headwall in place would be undesirable from the perspective of differential settlement and long-term performance of the roadway over the arch. Alternatively, if the new bridge structure consists of a traditional plank bridge (i.e. concrete abutments with concrete beams), phase two of this alternative would be simple as utilizing half the structure is commonly performed for non-buried structures.

Using phased construction will require a longer construction duration and invoke higher construction costs compared to a full road closure. The phased construction approach will likely reduce the bridge to an alternating one-way traffic pattern that would require a temporary signal to be installed for the duration of construction. Temporary signals can be costly depending on the duration they are deployed and the overall complexity of the system. A temporary signal for Central Street would likely need to include phasing for Elm Street, which would increase cost and decrease level of service through the work zone. Also, with the traveling public immediately adjacent to the active construction, the contractor will need to exercise additional safety precautions. A full road closure with a detour would still be required for short-period durations throughout the project. This option was therefore eliminated from further consideration.

Temporary Bridge over Project Site

A temporary bridge over the project site would be one of the most expensive methods to maintain traffic during construction. Temporary abutments would be installed to support the temporary bridge after utilities are relocated. However, due to the proximity of bedrock, temporary abutments would have similar difficulty as installing permanent abutments. The temporary abutments would likely need to be placed behind a complex earth retaining wall braced with structs, tiebacks, keeper blocks, or socketed into ledge.

It is anticipated the temporary bridge would be used in two phases. The first phase would have the temporary bridge placed over the northern half of the bridge, allowing the southern half of the bridge and southwestern wingwall be constructed. The second phase would involve moving the temporary bridge over the southern half of the road so the northern half of the new bridge could be completed.

This alternative will require a longer construction duration and will cost more to construct compared to a full road closure. The contractor will also need to exercise safety precautions to maintain traffic through an active heavy construction site. This option was therefore eliminated from further consideration.

Temporary Bridge Off-Site

A temporary bridge located off-site would span over Central Pond or Sawmill Brook and traffic would be detoured away from the bridge. Temporary approach roads and Right-of-Way acquisition would be required. This alternative would result in significantly more traffic on local roads/accessways that normally would experience a handful of vehicles per day. One possible site includes a crossing from Elm Street to the Manchester Fire Department lot. This alternative would result in minimal traffic modifications required at the Central Street Bridge, therefore decreasing the duration of traffic impacts and improving safety at the site compared to other options. However, this would be one of the most expensive methods to implement. Furthermore, this option requires construction outside the project existing bridge footprint, and thus would require substantial additional permitting, as well as right-of-way impacts and takings, with related potential impacts to project advertisement. Also, this option requires routing of substantial traffic down Elm Street, which may not be suitable for this use. The Town dismissed this as a potential option for the above reasons, and it was therefore eliminated from further consideration.

Proposed Traffic Management – Elm Street

Elm Street must be considered in the traffic management strategy based on its proximity to the bridge. Elm Street is a dead-end street running along the Sawmill Brook Seawall. The proposed bridge and wall repair work will require closure of a least half of Elm Street. To maintain traffic during construction, a temporary road will need to be constructed immediately to the west of the current location. The temporary road site is on private property however, and an easement would be required to complete the work.

If property rights cannot be secured, a costlier option is to construct a temporary retaining wall beyond the limits of construction and reduce Elm Street to an alternating one-way road. The retaining wall will likely consist of modular blocks placed on compacted soil, which will require protection against erosion. A full closure of Elm Street would be required for approximately 24-hours to construct the temporary wall. An alternating one-way road would also require temporary signalization to ensure smooth traffic operations at the work site.

Impacts to Elm Street and potential mitigation alternatives are currently being further reviewed in consultation with the DPW. Future design submittals will reflect further refined solutions to handle access to Elm Street.

Proposed Clearances

The proposed span of the replacement bridge is 20 feet. The opening height is proposed to match the existing bridge, 6.6 feet at the inlet and 10.0 feet at the outlet.

Proposed Hydraulics

Tighe & Bond performed a hydraulic analysis for proposed conditions by updating the existing conditions HEC-RAS hydraulic model. A description of the methodology for the hydraulic and hydrologic models are described under the "Existing Hydraulics" section above. The tide gate will be removed during replacement of the Central Street Bridge.

The hydraulic performance under proposed conditions was evaluated for the 2-, 10-, 25-, 50-, 100-, and 500-year return frequency storm events. The MassDOT Bridge Manual (2013) indicates that the hydraulic design flood return frequency for an Urban Minor Arterial or Rural Major Collector is the 25-year return frequency storm event with a recommended two feet of freeboard. Based on prior coordination with Manchester-by-the-Sea, Tighe & Bond's hydraulic design exceeds MassDOT minimum requirements and was based on not overtopping Central Street during the 50-year return frequency storm event while incorporating projections for potential future sea level rise in flow and sea level rise.

Similar to existing conditions, the proposed conditions hydraulic modeling was performed for Mean Higher High Water (MHHW) downstream tidal condition of 4.77 feet NAVD88 based on the NOAA Long Term Tide Water Level Monitoring Station ID: 8443970. MHHW is the technical term used by NOAA to describe the average of the higher high-water height of each tidal day observed over the National Tidal Datum Epoch (19 year tidal cycle). The 25-year frequency storm event was also evaluated for Mean Sea Level (MSL) conditions and MHHW conditions in 2100 using the 0.012 feet/year increase recommended in the LFRD Bridge Manual to incorporate SLR. The proposed conditions assumed a low chord elevation of 6.0 feet and an arch with a clear span of 20 feet with an opening of 185 square feet. The upstream end of the culvert will be partially filled with stream bed material and/or limited by bedrock resulting in an effective opening of approximately 94 square feet. The model results are presented in Table 2.

Table 2
Hydrologic and Hydraulic Results Upstream of Proposed 20-foot Span Arch Bridge

Storm Return Frequency[1]	Peak Discharge (Cubic Feet Per Second)	Upstream Peak Water Surface Elevation (feet, NAVD88)	Freeboard (feet)[2]	Distance to Top of Road (feet)	Average Velocity Inside Culvert (feet per second)
2-Year	254	4.7	1.3	5.9	1.5
10-Year	924	4.8	1.2	5.8	5.4
25-Year	1,363	5.6	0.4	5.0	8.0
25-Year MHHW MassDOT SLR	1,363	5.7	0.3	4.9	7.5
25-year MSL MassDOT SLR	1,363	1.8	4.2	8.8	12.4
50-Year	1,772	6.6	-0.6	4.0	10.5
100-Year	2,267	7.7	-1.7	2.9	13.5
500-Year	3,078	10.9	-4.9	-0.3	16.9

[1] Tidal boundary condition is MHHW (Mean Higher High Water) unless stated otherwise. SLR = Sea Level Rise, MSL = Mean Sea Level.

[2] Freeboard measured as the vertical difference between the crown of the arch (low chord) and the Upstream Peak Water Surface Elevation.

Due to the elevation of the existing road and site constraints, the proposed low chord elevation of the replacement bridge is at 6.0 feet NAVD88. The MHHW tidal elevation is currently 4.77 feet NAVD88, so two feet of freeboard would not be feasible during MHHW design conditions. Using the MassDOT recommendation for potential sea level rise, it is anticipated that 0.3 feet of freeboard would be provided if the peak of the design 25-year frequency storm event in 2100 occurred during MHHW tidal conditions, and 4.2 feet of freeboard would be provided if the design 25-year frequency storm event occurred during MSL conditions.

A copy of the hydrologic and hydraulic analysis report is included in Appendix C. The analysis includes additional scenarios to incorporate future climate change conditions as well as storm surge.

Scour at the Central Street Bridge was evaluated in a manner consistent with the general guidelines set forth in the FHWA Hydraulic Engineering Circular Nos. 18 (HEC-18), HEC-20, and the MassDOT LRFD Bridge Manual section 1.3.3.4 Scour/Stability Analysis. The streambed material consists of mostly medium to fine grain sands underlain by sound bedrock with an average depth of 0 to 2 feet below the channel bottom. The bedrock was found to be very hard to hard granite and is therefore not anticipated to be susceptible to scour.

The computed scour depth extends beyond the sound bedrock depth. Therefore, concrete abutments are anticipated for design that will be cast-in place directly on bedrock. It is anticipated that the streambed will naturally fluctuate in depth ranging from the bedrock elevation to the culvert invert depending on storm frequency and tide cycles.

Open railings are recommended along Central Street Bridge to allow overtopping flow to travel over the roadway during low probability storm events (e.g., the 500-year frequency storm event). Closed parapets would likely cause overtopping flows to travel against adjacent buildings instead of the roadway. Storm events causing the roadway to overtop are significantly larger than the design storm.

Preliminary Geotechnical Data

Tighe & Bond subcontracted with New England Boring Contractors to obtain borings behind the proposed abutment and retaining wall locations. However, given the vast number of buried utilities within the roadway and the inability to close the road, and multiple attempts to find suitable boring locations, only one boring was obtained in the southwest quadrant of the bridge as shown in the Existing Conditions Site Plan, included in Appendix E. The boring was performed to a depth of 20.5-feet below the roadway surface. Bedrock was encountered at a depth of 9.9-feet and a rock core sample was obtained and analyzed in the lab. Blow counts and samples were obtained for the soils over the bedrock stratum. The soils comprised primarily of medium dense to very dense gravels and the bedrock consisted of very hard to hard, moderately to very slightly weathered, slightly fractured to sound, very coarse to coarse-grained granite.

Exposed bedrock elevations were determined from the survey data and used in combination with the boring data to create an assumed subsurface bedrock profile throughout the site. The exposed bedrock elevation range between -4.7 to +0.3 along the springlines of the existing bridge and -4.3 to +1.0 feet along the existing southwest wingwall location. Refer to the bedrock profiles provided in the geotechnical report (Appendix D).

Based on the proximity of sound bedrock, cast-in-place concrete footings bearing on bedrock are recommended. It is recommended that the footings be pinned to bedrock using galvanized or fiberglass dowels. The nominal bearing resistance of the bedrock was calculated as 200-ksf.

Tighe & Bond observed a test pit behind the existing channel wall located in the Northwest quadrant of the bridge, as shown in the Existing Conditions Site Plan included in Appendix E.

A copy of the geotechnical evaluation report, including boring log data and the subsurface profile, is included in Appendix D.

Constraints Imposed by Approach Roadway

Central Street is a downtown urban roadway on a coastal route with seasonal demand peaking during the summer months. The road carries a significant amount of traffic while simultaneously providing access to local businesses, residential areas, and municipal services, and the coast. Impacts to the roadway and the traffic patterns will have an adverse effect on the project abutters and the traveling public. The work site is further complicated by the intersection of Central Street and Elm Street. The intersection is immediately west of the bridge site and will be impacted by the proposed work. Elm Street is a dead-end street with both residential and commercial properties. To the east of the bridge site is the intersection with Church Street, which provides a one-way loop access to several public amenities. Church Street should not be directly impacted by the work limits.

Constraints Imposed by Brook

Since the stream is tidally-influenced, control of water during construction will impact the cost of construction as well as the schedule. Additionally, the preferred method of water control would likely influence our structural recommendations. Tighe & Bond evaluated the use of cofferdams for high tide conditions and limiting work during low tide only.

Based on discussions with the Town in an effort to minimize costs, allowing work during low tide only is preferred. It is possible that by constructing water control for low tide conditions, the construction schedule and quality may be impacted by high tide conditions and storm/ floods.

Working During Low Tide Only

This method involves the contractor working during low tide only. Cofferdams would still be required to allow the contractor to work out of the water during low tide and would likely consist of a combination of anchored wooden forms, concrete barriers, and sandbags. However, the cofferdam would need to be robust and capable of resisting flooding, as the work site would be inundated twice per day during high tide or more during storm events. The bottom of the cofferdam would need to be modified to account for the uneven bedrock bearing surface and the area with the cofferdam would need to be drained/pumped prior to the contractor working during low tide. Additionally, design modifications will be required for concrete and reinforcements to be exposed to salt water in such a manner that, for example, the concrete footings will need to be designed such that they can cure underwater. A non-standard mix-design may be required which could impact MassDOT Chapter 85 review. The contractor would be limited to a small window of working hours, which would vary on a daily basis, and a portion of each work session would be dedicated to preparing the site such so work can begin. Additionally, this method will still require shoring or erosion protection for open-cut excavation. It should be noted that inclement weather could cause formwork or the concrete placement to become susceptible to washout, which risks the ability to meet the one-month road closure restriction.

Cofferdams for High Tide

This method involves a full cofferdam that will allow site access for construction during low and hide tide. The cofferdam would cross the channel upstream and downstream of the bridge, and a large pipe would be constructed through the site such that streamflow would not be blocked. The cofferdam would be designed to flood in the event of a high-elevation storm event to avoid flooding in the downtown area. This type of cofferdam will be difficult to construct given the high bedrock elevation and would likely consist of braced sheet piles with tiebacks and walers. Installing a large cofferdam will have a high cost but will allow the contractor to work with minimal tidal shutdowns. This type of cofferdam could also function as the excavation shoring system assuming it extends the perimeter of the abutments.

An example of cofferdams for a small replacement bridge in Plymouth, MA is shown below. The site is adjacent to Cape Cod Bay in a stream that experiences tidal flow back and forth to the upstream pond. The cofferdams were designed by the contractor to remain dry during high tide, but not for flood conditions. The contractor's design assumed that in the case of infrequent flood conditions, the cofferdams would be "topped out" and after flood conditions receded, the base would be pumped out by the dewatering system.

Constraints Imposed by Utilities

As previously discussed, there are numerous utilities on the site. The design assumes that all utilities will require maintenance during construction. Potable water and sanitary sewer will likely require bypass systems for a portion of the work. Gas, electric, and telecom will require phased relocation and/or temporary servicing from alternate locations. Also, the sanitary sewer line is located vertically at the channel elevation. The proposed sanitary sewer will be in a similar vertical location and will require accommodation during structure and footing design.

The conceptual design is based on an assumed construction staging in which all utilities are relocated to a temporary utility bridge prior to demolition of the existing structure and installation of footings and the precast concrete arch. The temporary bridge may impose schedule and procedural limitations for demolition and bridge reconstruction. After installation of the precast arch, utilities will be relocated across the new bridge. The design team will continue to work closely to identify and refine methods to maintain service during construction, etc. that will work with both schedule and cost considerations.

Constraints Imposed by Wetland Resource Areas

The proposed bridge replacement will involve work in local, state, and federal jurisdictional resource areas. All replacement alternatives described above will require authorization under a number of regulatory programs. We understand that proposed work will occur within federally-regulated tidal waters, as well as within state and locally-regulated areas including Land Subject to Coastal Storm Flowage (LSCSF), Coastal Bank, Riverfront Area, and Land Under Waterbodies and Waterways (LUWW). Review and or approvals will be required from the Manchester-by-the-Sea Conservation Commission (MBTSCC), MassDEP, the Army Corps, and the Massachusetts Environmental Policy Act (MEPA) Office with the Executive Office of Energy and Environmental Affairs (EEA).

The MEPA review process provides for coordinated state agency and public review of projects that meet certain review thresholds defined at 301 CMR 11.03 and that require a state agency action (e.g., permit, financial assistance, or a land transfer). Through the MEPA process, relevant state agencies are required to identify any aspects of the proposed project that require additional analysis or mitigation prior to completion of the agency action. Single and complete projects must be considered for MEPA review; division of a project into elements for separate MEPA review is defined as segmentation and is not allowable.

The bridge replacement requires state approval (i.e., Agency Action), which, in this case, would be a Chapter 91 Waterways License for the bridge replacement with tide gate removal. Additionally, the project received state funding (i.e., Financial Assistance). Accordingly, MEPA jurisdiction will be broad and will review all portions of the project. We anticipate the proposed project will trigger one or more review thresholds related to wetlands, including impacts to coastal bank and new fill or structure in a regulatory floodway.

These triggers are review thresholds for an Environmental Notification Form (ENF) and other MEPA review if the Secretary so requires. Based on our current assumptions related to the combined project impacts (i.e., Central Street bridge replacement, tide gate removal and Central Pond restoration), the project does not trigger a mandatory Environmental Impact Report (EIR). The ENF will describe the project, its alternatives, and proposed mitigation. It will also describe how the project will comply with the performance standards of any required state permits. The ENF will also discuss compliance with the Office of Coastal Zone Management's (CZM) Federal Consistency Standards.

The proposed project likely meets the eligibility criteria to be permitted under an Ecological Restoration Notice of Intent (NOI) with the MBTSCC and MassDEP, as a result of the proposed tide gate removal. An NOI will be required for the proposed bridge replacement and tide gate removal within jurisdictional resource areas in accordance with the Massachusetts Wetlands Protection Act (WPA) M.G.L. Chapter 131 Section 40 and implementing regulations (310 CMR 10.00), along with the Manchester-by-the-Sea Wetlands Bylaw and regulations (Article 17). Work associated with the project is expected to occur within Land Under Water, Coastal Bank, Riverfront Area, Land Subject to Coastal Storm Flowage, and the 100-foot Buffer Zone, at a minimum.

The proposed project is subject to jurisdiction under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act due to work within tidal waters of the United States. Work within tidal waters generally do not meet Self-Verification review thresholds, and are subject to review under a Pre-Construction Notification (PCN) under the Massachusetts General Permit (MA GP).

Based upon a review of jurisdictional Tidelands provided by MassGIS, the project area is mapped as a jurisdictional contemporary high water. Replacement of the bridge at Central Street and removal of the tide gate will require authorization in the form of a Chapter 91 License.

Constraints Imposed by Cultural Resources Areas

As noted earlier, the bridge is on the National Historic Registry as the site of historic water powered mills dating back to the 1600's and marks the entrance to the Downtown Manchester-by-the-Sea.

The DPW has preliminarily presented the general scope of the project and its aesthetic features to the Manchester Historic District Commission (HCD) and has obtained a letter of support from them (See Appendix H). The project team intends to continue working with the HDC during later stages of design development and permitting to address their design comments to the extent practicable. MHC review (Section 106 Historic Review) will be coordinated as part of the MEPA ENF process.

Hazardous Material Disposition

There are no known hazardous building construction materials, waste sites, or reportable release sites identified within the project limits. This will be verified prior to construction by conducting a pre-demolition hazardous building materials assessment (HBMA) by licensed personnel.

In accordance with the United States Environmental Protection Agency (EPA) National Emissions Standard for Hazardous Air Pollutants (NESHAP) regulations (Title 40 CFR, Part 61, Subpart M); Massachusetts Department of Environmental Protection (MassDEP) regulations (310 CMR 7.15); and the Massachusetts Department of Labor Standards (MassDLS) regulations (453 CMR 6.00), any building or structure scheduled for renovation and/or demolition activities must undergo a thorough investigation to determine the presence or absence of asbestos in construction materials that may be impacted by the renovation / demolition activities. Further, the assessment should include an investigation of any other potential hazardous building materials or components which have potential to be disturbed.

Based on our site knowledge, understanding of construction and materials, and input from the Town, Tighe & Bond is not aware of suspect asbestos-containing construction materials (ACM), lead containing materials, polychlorinated biphenyls (PCBs) and/or any other potential hazardous sources potentially contained in the construction materials that may be impacted during the proposed bridge demolition. As the project design is advanced, if suspect hazardous materials are identified, Tighe & Bond will recommend to the Town that additional investigations be performed to identify/quantify the materials to reduce risk during construction and manage the materials. As part of the final design, Tighe & Bond will include the appropriate requirements in the Contract Documents to address any hazardous material handling in accordance with the applicable regulations.

Examples of suspect hazardous sources associated with a bridge demolition project are:

Suspect ACMs: waterproofing applications; gaskets; underlying roadway asphalt layers; mortar; mastics /coatings on steel; caulking; paint applications and utilities serving in and around the bridge which may be insulated or are constructed with transite (asbestos cement/conduit)

Suspect Lead Sources: paint applications; soldered joints

Suspect PCB sources: roadway marker paints; caulking; mastics; waterproofing applications

Suspect hazardous materials sources: oils within enclosed utilities and mercury sources such as switches or "Mercoid switches" around electrical / utility equipment

Personnel licensed by the Commonwealth, will be required to visit the site and investigate for these and any other suspect sources and sample as appropriate; quantify; assess condition and identify any specific needs which a contractor may use to access and abate the sources. Once laboratory data is assessed, and if determined to be necessary, the results of the field data will be incorporated into technical specification sections and designed for management, abatement and lawful disposal as part of the bridge demolition project. We often prepare inventory tables containing the site findings in a spreadsheet format and append these to our technical specification sections for use by the contractor.

Often, the same individuals who perform the assessment and are familiar with the project will also be retained during the construction phase to observe contractor abatement methodologies for compliance with applicable Massachusetts regulations and the project specifications. The level of construction phase observation is measured by project complexity; actual site findings and the awarding contractors experience and history. At the end of the project a remediation closeout report shall be prepared that includes waste shipment records, notifications, permits, air sample results, observation records and any other pertinent data generated during the project.

Adjacent Buildings

Northeast Quadrant – 21 Central Street

21 Central Street is occupied by Coldwell Banker Residential Brokerage. Determining access requirements from the building owner is recommended to coordinate demolition techniques for the bridge. The porch, which serves as an entryway to the building, currently bears directly on the existing bridge and upstream channel wall. Modifications will be needed to allow for bridge demolition without impacting the building and its access.

Excavation for the bridge is anticipated along the front of this property, which will likely expose the building foundation and could lead to undermining of the building and foundation in the absence of protective measures. Therefore, an advanced shoring system will likely be needed between the property and the proposed structure location, and structural monitoring of the building foundation will be required throughout construction. The construction documents will need to include requirements for supplemental action in case monitoring determines that excavation is resulting in impacts above pre-determined thresholds. Specifics of these pre-construction preparation activities will be coordinated with the Town as the design advances.

Southwest Quadrant – 26 Central Street

26 Central Street is currently occupied by Cuddlefish Gift Shop. The Southwest wingwall terminates at the corner of the building and the building foundation potentially bears directly on the channel wall.

Excavation for the wingwall is anticipated along the front of this property, which will likely expose the building foundation and could lead to undermining failures without protective measures. Therefore, it is assumed that an advanced shoring system will be constructed, and structural monitoring of the building foundation will be required throughout construction. Specifics of these pre-construction preparation activities will be coordinated with the Town as the design advances.

Southeast Quadrant – 14 Church Street

14 Church Street currently serves the Seaside No. 1 Museum. The building foundation appears to be offset behind the channel walls, but a walkway is retained at the top of the channel wall. Based on discussions with the Town, it is desired that if the existing walkway needs to be replaced, that it not be replaced in-kind but with an upgraded system that meets ADA requirements.

Excavation for the bridge is anticipated along the front of this property, which may expose the building foundation and potentially cause undermining failures in the absence of protective measures. Therefore, it is assumed that an advanced shoring system will be constructed between the property and the proposed structure location and structural monitoring of the building foundation will be required throughout construction.

Approach Guardrails

At this stage of the design, we are evaluating the available options for bridge rail types and configurations that will meet the Town Historic Commission's aesthetic needs while adhering to AASHTO Roadside Design Guide and the MassDOT Bridge Manual and highway standards. We are also evaluating the need for approach guardrails, given the low speed and heavily constrained environment of downtown Manchester.

Northwest Quadrant

Based on the results of the test pit, the Northwest channel wall does not have adequate capacity to support an anchored guardrail. As such, replacement of the channel wall would be required to support an anchored rail. If railing needs to be extended along Elm Street, additional borings are recommended to determine anticipated subsurface conditions.

We considered the possibility of upgrading the wall with post-tensioning anchors drilled vertically through the wall and socketed into ledge to increase its strength, but the test pit revealed this approach is not practicable for the granite blocks.

A moment-slab could be designed to carry anchored approach rail. However, there are many buried utilities below Elm Street that would conflict with this construction. Additionally, a moment slab may prevent future access to maintain these utilities.

An approach guardrail could be installed between the sidewalk and the roadway along Elm Street. However, the rail would require anchorage to a moment slab, deep anchored foundations, or a new wall.

Northeast Quadrant

Options to completely eliminate the approach guardrail may need to be considered in this quadrant due to the constrained location and low travel speeds on the roadway, similar to other locations where such a solution was adopted in MassDOT District 4.

Southeast Quadrant

Elimination of approach guardrail may need to be considered in this quadrant due to the constrained location and low travel speeds on the roadway, similar to other locations where such a solution was adopted in MassDOT District 4.

Alternatively, the rail can wrap around the corner, along the top of the channel wall, and terminate at the entrance ramp to the building. However, similar to the Northwest Quadrant, wall upgrades may be required if this is desired.

Southwest Quadrant

Anchored rail can be installed along the top of the new wingwall and terminated at the corner of the building.

Overall, we propose to continue to work with MassDOT during the design review process to identify an appropriate treatment given the low speed constrained environment of the bridge location.

Bridge Rail Alternatives

Bridge rail should be an approved, crash-tested rail. The MassDOT Bridge Manual provides several details that satisfy this requirement. The details have been independently tested for crash-worthiness. In general, the details include sufficient reinforcement to resist impact in the rail, and sufficient reinforcement to for anchorage to a bridge deck. In lieu of a bridge deck, anchorage can be provided by anchoring to a moment slab, or anchoring to a structural wall.

If a detail is proposed to be used that is not on the approved MassDOT list, it may be possible to submit calculations and other data showing that the proposed detail is suitable. In addition to requiring time and resources for evaluation, this approach may impact the schedule for MassDOT approval via the Chapter 85 review process.

Bridge Rail Alternative 1 – CT-TL2 Barrier

This alternative is a MassDOT standard rail type and can be used with pedestrians. It should be noted that the base of this concrete parapet would impound water in the event of a flood. As such, weep holes may be necessary which will require ongoing maintenance to prevent them from clogging with debris.

Bridge Rail Alternative 2 – S3-TL4 Steel Rail

This alternative is a MassDOT standard rail type and can be used with pedestrians. The steel may require occasional repainting to maintain its appearance given the salt environment of the bridge.

Bridge Rail Alternative 4 – BR-2 Bridge Rail (separated curb line & pedestrian rails)

The alternative of use of an approved curb line rail allows for use of a non-crash tested pedestrian rail on the edge of the sidewalk. This type of rail is more expensive than other alternatives since multiple rails would be provided. One drawback to providing this type of rail does not allow access to the sidewalk from the street. The Town has indicated that they would not be supportive of this type of a treatment.

Southwest Wingwall Façade

Based on discussions with the Town regarding their preference of surface treatment, and structural needs, one treatment alternative for the southwest wingwall involves the use of new large granite blocks integral with a concrete gravity retaining wall. By locating the new granite blocks on a concrete levelling slab in front of the existing wall, the new blocks could serve as a front-form and the existing wall could be abandoned in place and used as a rear form. As a result of this approach, the amount of excavation and associated shoring would be minimized.

Figure 1 – Rendering of Granite Façade using Large Stones

However, if the wall is replaced in its current location, it would be less expensive to use concrete formliners than large granite blocks. Formliners are available in a wide variety of patterns with different sizes, and are relatively simple since contractors need to construct forms anyways.

Figure 2 - Sample Concrete Formliner Appearance

Alternative to concrete formliners, small stone facing could be used if the wall is replaced in its current location. The facade would be supported by the concrete wall and would not contribute to the overall structural strength of the wall while providing a stone like finished look. It should be noted that small stone facing would be the least robust alternative as it would be more susceptible to being washed away given the harsh environment of the project site.

Figure 3 - Sample Stacked Stone Façade (Granite)

Appropriate Bridge Structure Types

In 2015, a 20-foot span precast concrete arch bridge was identified as a viable solution based on the MassDOT LRFD Bridge manual's recommendations for structure types by span range.

Given the various project parameters discussed in this report and based on additional site data obtained under the current phase of this project, Tighe & Bond has refined the arch design to better suit the site conditions. Alternative bridge types were also briefly considered previously, but were not pursued further at that time due to aesthetics, utility accommodations, and cost.

Refined Precast Concrete Arch Design

A precast concrete arch would be supported by cast-in-place concrete foundations to match the variable profile of the ledge. It is anticipated that minimal bedrock removal would be required to reach sound bedrock suitable of supporting foundations as well as areas with potentially high outcrops. Each footing would be constructed with a pedestal stem, where the top of the stem will create a uniform finished elevation to support the precast arch units and the footing portion would match the ledge profile. Thus, the stems would vary in height, which would provide the contractor flexibility to create a uniform top surface given the variable ledge profile.

Since the top of the foundation will be uniform, the concrete arch can be precast off-site and set on the foundation using a crane. Using precast components where possible will reduce the construction schedule on-site by avoiding lengthy set up and cure times. Precast concrete also provides a superior quality control compared to cast-in-place concrete since it is fabricated in a facility with regulated climate and ideal casting conditions. The joints between arch segments would be mechanically connected, grouted on site, and membraned. Headwalls would be placed to contain fill material, utilities would be relocated within the fill, and the road would be paved. The headwalls would also support anchored bridge rail, so the connections and supporting arch structure would require a non-standard design.

Due to the nature of the arch requiring confined backfill, half of the structure could not easily be used to phase a single lane of traffic. A one-month road shutdown will be difficult to achieve given the various work restrictions and a contractor would carry significant risk in attempting to do so. Supplementary weekend and overnight work shifts would likely be required to satisfy the project restrictions. Additionally, precast arch units traditionally come in square sections. However, non-standard end-units would be required to accommodate the skew of the road relative to the stream. As such, a precast concrete arch may not be the most-economical type of structure for the site given the project constraints.

The Engineer's Opinion of Probable Construction Costs is $3,700,000, not including ancillary costs such as shoring of buildings around the site, potential allowance to complete certain elements of the project during low tide conditions only and within a one-month road closure, ROW acquisition, etc.

Alternative Bridge Types

In addition to refining the precast concrete arch design, alternate structure types are briefly described below.

Structural plate pipes are not appropriate for the site given their limitations for structures less than 20' in span. Additionally, the material would not be durable in harsh salt environment. Lastly, plate pipes with bottoms would be difficult to place on an uneven bedrock surface.

A four-sided box culvert would have a bottom slab, which would be difficult to place as precast on an uneven bedrock surface. Additionally, the bottom slab would be ineffective compared to an open bottom structure pinned to ledge.

A precast concrete rigid frame could more-economically provide additional hydraulic capacity compared to an arch, however it would not resemble the historical aesthetics of the existing arch. Additionally, approach slabs would be required, further complicating utility installation and future access to utilities.

Steel beams on traditional concrete abutments would not be as durable or obtain as long of a service life compared to a concrete structure given the harsh salt water environment. Similar to a precast concrete rigid frame, this type of structure also would not resemble the historical aesthetics of the existing arch.

Precast planks on concrete abutments could potentially be a viable alternative compared to a precast concrete arch. The bottom of the abutments could be cast-in-place to match the ledge profile, and the upper portion could be precast to expedite construction in the field. The advantage that concrete planks provide over a precast concrete arch is that half of the structure could be constructed and used to phase one-lane of traffic. Non-structural aesthetic fascia arches could be constructed to mimic the historic arch appearance. Additionally, precast planks would allow for easier installation of bridge rail using standard MassDOT details compared to an arch structure.

Precast planks were not previously selected during previous conceptual phases of the project based on cost, aesthetics, and required utility accommodations. However, precast concrete planks may be more economical for the site given the current project restrictions and available site data.

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Appendix A
MassDOT Inspection Report (2016)

MASSACHUSETTS DEPARTMENT OF TRANSPORTATION
STRUCTURES INSPECTION FIELD REPORT
OTHER INSPECTION

2-DIST	B.I.N.	BR. DEPT. NO.
04	8AM	M-02-001

CITY/TOWN	8.-STRUCTURE NO.	11-Kilo. POINT	90-ROUTINE INSP. DATE	INSPECTION DATE
MANCHESTER	M02001-8AM-MUN-BRI	000.000	00/00/00	Nov 9, 2016

07-FACILITY CARRIED	MEMORIAL NAME/LOCAL NAME	27-YR BUILT	106-YR REBUILT	*YR REHAB'D (NON 106)
ST127 CENTRAL ST		1850	1900	0000

06-FEATURES INTERSECTED	26-FUNCTIONAL CLASS	DIST. BRIDGE INSPECTION ENGINEER
WATER SAW MILL BROOK	Urban Minor Arterial	T. G. Weil

43-STRUCTURE TYPE	22-OWNER	21-MAINTAINER	TEAM LEADER
811 : Masonry Arch - Deck	Town Agency	Town Agency	S. Shaw

107-DECK TYPE	WEATHER	TEMP. (air)	TEAM MEMBERS
N : Not applicable	CLOUDY	13°C	J. ROY

WEIGHT POSTING

Not Applicable: X

	H	3	3S2	Single
Actual Posting	N	N	N	N
Recommended Posting	N	N	N	N

Waived Date: 00/00/0000 EJDMT Date: 00/00/0000

Signs In Place (Y=Yes, N=No, NR=Not Required) / Legibility/Visibility

	At bridge E	At bridge W	Advance E	Advance W
Signs In Place				
Legibility/Visibility				

PLANS (Y/N): N

(V.C.R.) (Y/N): N

TAPE#:

RATING

Rating Report (Y/N): N Date: ----

Request for Rating or Rerating (Y/N): N

If YES please give priority: HIGH ( ) MEDIUM ( ) LOW ( )

REASON:

Inspection data at time of existing rating

I 58: - I 59: - I 60: - I 62: - Date :00/00/0000

MEMBER(S):

	MEMBER	CRACK (Y/N):	WELD'S CONDITION (0-9)	LOCATION OF CORROSION, SECTION LOSS (%), CRACKS, COLLISION DAMAGE, STRESS CONCENTRATION, ETC.	CONDITION PREVIOUS (0-9)	CONDITION PRESENT (0-9)	INV. RATING OF MEMBER FROM RATING ANALYSIS H-20	3	3S2	Deficiencies
A	Approaches a - Appr. pavement condition	N	N			7	0	0	0	-
B	Approaches b - Appr. Roadway Settlement	N	N			7	0	0	0	-
C	Approaches c - Appr. Sidewalk Settlement	N	N			7	0	0	0	-
D	Item 58.1 - Wearing surface	N	N	See remarks in comments section.		6	0	0	0	M-P
E	Item 58.3 - Spandrel Fill	N	N			7	0	0	0	-

List of field tests performed:

	I-58	I-59	I-60	I-61	I-62
(Overall Previous Condition)	7	7	7	7	7
(Overall Current Condition)	-	5	7	7	-

DEFICIENCY: A defect in a structure that requires corrective action.

CATEGORIES OF DEFICIENCIES:

M= Minor Deficiency - Deficiencies which are minor in nature, generally do not impact the structural integrity of the bridge and could easily be repaired. Examples include but are not limited to: Spalled concrete, Minor pot holes, Minor corrosion of steel, Minor scouring, Clogged drainage, etc.

S= Severe/Major Deficiency - Deficiencies which are more extensive in nature and need more planning and effort to repair. Examples include but are not limited to: Moderate to major deterioration in concrete, Exposed and corroded rebars, Considerable settlement, Considerable scouring or undermining, Moderate to extensive corrosion to structural steel with measurable loss of section, etc.

C-S= Critical Structural Deficiency - A deficiency in a structural element of a bridge that poses an extreme unsafe condition due to the failure or imminent failure of the element which will affect the structural integrity of the bridge.

C-H= Critical Hazard Deficiency - A deficiency in a component or element of a bridge that poses an extreme hazard or unsafe condition to the public, but does not impair the structural integrity of the bridge. Examples include but are not limited to: Loose concrete hanging down over traffic or pedestrians, A hole in a sidewalk that may cause injuries to pedestrians, Missing section of bridge railing, etc.

URGENCY OF REPAIR:

I = Immediate- (Inspector(s) immediately contact District Bridge Inspection Engineer (DBIE) to report the Deficiency and to receive further instruction from him/her).

A = ASAP- (Action/Repair should be initiated by District Maintenance Engineer or the Responsible Party (if not a State owned bridge) upon receipt of the Inspection Report].

P = Prioritize- (Shall be prioritized by District Maintenance Engineer or the Responsible Party (if not a State owned bridge) and repairs made when funds and/or manpower is available].

X=UNKNOWN N=NOT APPLICABLE H=HIDDEN/INACCESSIBLE R=REMOVED

CITY/TOWN	B.I.N.	BR. DEPT. NO.	8.-STRUCTURE NO.	INSPECTION DATE
MANCHESTER	8AM	M-02-001	M02001-8AM-MUN-BRI	NOV 9, 2016

MEMBER(S):

	MEMBER	CRACK (Y/N):	WELD'S CONDITION (0-9)	LOCATION AND DESCRIPTION OF DAMAGE	CONDITION PREVIOUS (0-9)	CONDITION PRESENT (0-9)	INV. RATING OF MEMBER FROM RATING ANALYSIS H-20	3	3S2	Deficiencies
F	58.4. Curbs	N	N			7	0	0	0	-
G	58.6. Sidewalks	N	N			7	0	0	0	-
H	58.8. Railing	N	N	See remarks in comments section.		6	0	0	0	M-P
I	59.1. Arch/Arch Ring	N	N	See remarks in comments section.		4	0	0	0	S-A
J	59.2. Keystone Area	N	N	See remarks in comments section.		4	0	0	0	S-A
K	59.5. Spandrel Walls	N	N	See remarks in comments section.		6	0	0	0	M-P
L	59.6. Spring Lines	N	N			7	0	0	0	-
M	59.10. Masonry Joints	N	N			7	0	0	0	-
N	59.13. Deformation/Flattening	N	N			8	0	0	0	-
O	60.1. Abutments	N	N			7	0	0	0	-
P	60.1. Abutments d.Breastwalls	N	N			7	0	0	0	-
Q	60.1. Abutments e.Wingwalls	N	N			7	0	0	0	-
R	60.1. Abutments g.Pointing	N	N			7	0	0	0	-
S	60.1. Abutments h.Footings	N	N			H	0	0	0	-
T	60.1. Abutments i.Piles	N	N			H	0	0	0	-
U	60.1. Abutments j.Scour	N	N			7	0	0	0	-
V	60.1. Abutments k.Settlement	N	N			8	0	0	0	-
W	61.1. Channel Scour	N	N			7	0	0	0	-
X	TRA.a. Bridge Railing	N	N	See remarks in comments section.		5	0	0	0	M-P

CITY/TOWN	B.I.N.	BR. DEPT. NO.	8.-STRUCTURE NO.	INSPECTION DATE
MANCHESTER	8AM	M-02-001	M02001-8AM-MUN-BRI	NOV 9, 2016

REMARKS

BRIDGE ORIENTATION
Single span granite arch with north and south elevations, east and west approaches. Saw Mill Brook is tidal.

GENERAL REMARKS
The arch has an adjacent concrete slab section on the south elevation, supporting the south sidewalk.

ITEM 58 - DECK

Item 58.1 - Wearing surface
Moderate sealed and unsealed cracking throughout. Minor potholes patched with asphalt in the eastbound travel lane, adjacent to catch basin drain and east pedestrian crossing. **(See Photo 1)**

Item 58.8 - Railing
Moderately corroded fence rails and posts on both the north and south rails. **(See Photo 2)**

ITEM 59 - SUPERSTRUCTURE

Item 59.1 - Arch/Arch Ring
Missing keystones - See Item 59.2 Keystone Area.

The majority of the arch interior has concrete patches and/or gunite applied throughout.

Item 59.2 - Keystone Area
Missing granite stones from keystone area, from inside the north ring to to mid-length. Gunite and other concrete patching has been applied over much of the interior of the arch. **(See photos 3-5)**

Item 59.5 - Spandrel Walls
The north spandrel granite wall is covered with gunite. There is minor vertical cracking with efflorescence throughout the north face.

There is spalling of the gunite, with exposed wire mesh, begining from the bottom of the relief pipe on the west side and ending at the arch spring line.

TRAFFIC SAFETY

Item 36a - Bridge Railing
See Item 58.8 Railing.

Chain link fence with steel posts and rails. Granite rail base.

Photo Log
Photo 1 : Moderate cracking throughout both lanes of wearing surface.
Photo 2 : Corroded north rail and fence posts.
Photo 3 : Keystone area with missing stones at north arch ring.
Photo 4 : Keystone area with missing stones at north end.
Photo 5 : Missing keystone near mid-length with shotcrete patching, looking south.

CITY/TOWN	B.I.N.	BR. DEPT. NO.	8.-STRUCTURE NO.	INSPECTION DATE
MANCHESTER	8AM	M-02-001	M02001-8AM-MUN-BRI	NOV 9, 2016

PHOTOS

Photo 1: Moderate cracking throughout both lanes of wearing surface.

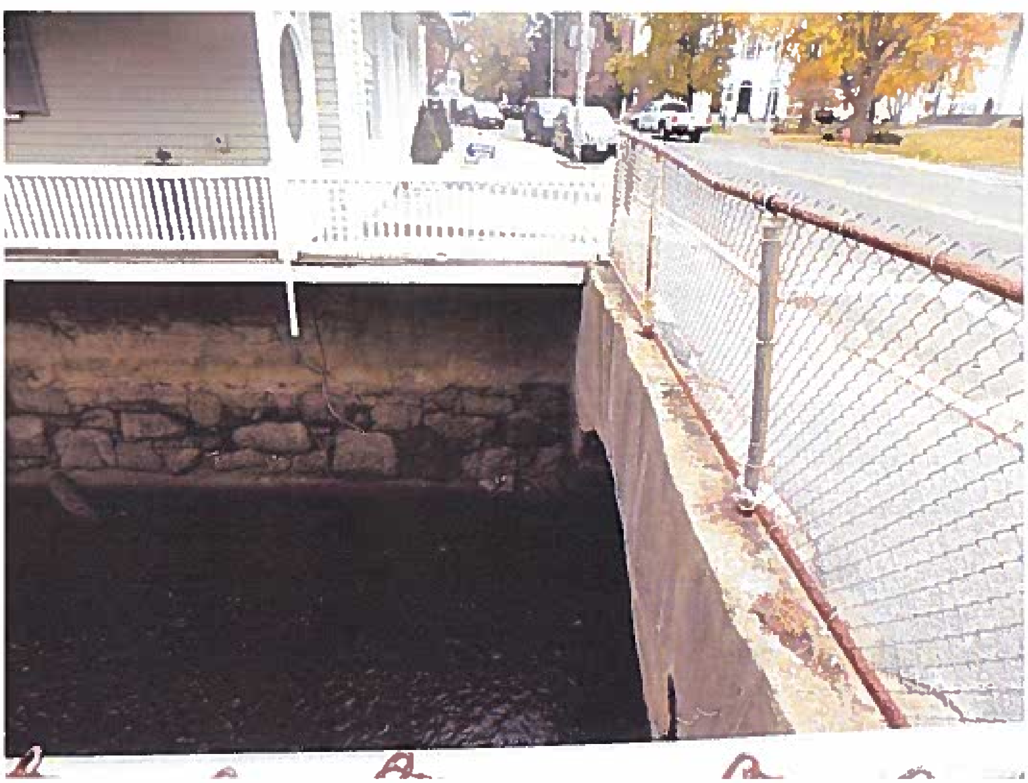

Photo 2: Corroded north rail and fence posts.

CITY/TOWN	B.I.N.	BR. DEPT. NO.	8.-STRUCTURE NO.	INSPECTION DATE
MANCHESTER	8AM	M-02-001	M02001-8AM-MUN-BRI	NOV 9, 2016

PHOTOS

Photo 3: **Keystone area with missing stones at north arch ring.**

Photo 4: **Keystone area with missing stones at north end.**

CITY/TOWN	B.I.N.	BR. DEPT. NO.	8.-STRUCTURE NO.	INSPECTION DATE
MANCHESTER	8AM	M-02-001	M02001-8AM-MUN-BRI	NOV 9, 2016

PHOTOS

Photo 5: **Missing keystone near mid-length with shotcrete patching, looking south.**

Appendix B

2015 Sawmill Brook Central St Seawall, Tide Gate & Culvert Observations Memorandum

Sawmill Brook Central St Seawall, Tide Gate & Culvert Observations

TO: Mary Reilly, Grants Administrator

FROM: Duncan Mellor, PE, Tighe & Bond

COPY: Dave Murphy, PE, Tighe & Bond

DATE: June 23, 2015

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. Discussions with the Massachusetts Division of Marine Fisheries just prior to the walk-through had indicated a preference to remove or modify the tide gate structure and perhaps the culvert weirs, to increase the times when Rainbow Smelt might have favorable tide conditions to pass these stream obstructions. The observations will be used to inform alternative designs that consider improvements to fish passage, stormwater drainage, and protection from storm surge. Based on a review of documents available from the Town, our understanding is that the tide gate was originally installed in the early 1900's for the purpose of creating a skating pond in the downtown area.

Observations

Fish coming from the harbor at low tide will encounter rock riffles and bedrock below the tide gate structure (Photo 1). As the tide rises these natural impediments will become submerged and no longer hinder fish passage at a water level about 2 feet above Mean Low Water (MLW), (CLE, 2000. Existing Conditions and Proposed Repairs to Tide Gate and Seawall).

Photo 1 Looking upstream (low tide) toward tide gate and Central St culvert

The tide gate structure is comprised of two orthogonal concrete walls approximately 9 feet high, a bottom opening gate of cast iron or cast steel (gate and tracks), and an overhead actuator motor/controller galvanized steel platform (Photo 1). There is some corrosion/erosion metal loss at the bottom of the gate tracks, including the bottom seating wedge guides (Photo 2). The tide gate is operational and was opened to drain the impoundment for the culvert observation. The tide gate opening is 5.9 feet and the open height of the gate at the time of observations was 2.75 feet, with the invert 10 inches to 18 inches above the stream bed.

Photo 2 Corrosion/erosion of low tide gate tracks

The concrete walls of the tide gate structure appear to be gravity walls with indications of prior concrete repair and overlays, including the repairs circa 2000 (Photo3).

Photo 3 View of tide gate from inside culvert

During the walk-through it was noted that there is significant water seepage (flow) coming from the stone culvert side wall supporting the south side of Central Street when the tide gate is closed and ponding water in the culvert (Photo 4). This seepage flow in a dam structure is not desirable and can cause loss of soils under the street. Previously, a shotcrete surfacing (pneumatically applied concrete, previously referred to as "Gunite") was applied to this stone wall and the culvert; however it has failed, particularly in the tidal zone. The circa 2000 repairs indicated this wall was to be repointed with non-shrink grout. The shotcrete and repointing have not stopped the seepage problems and are not recommended here for seepage control.

Photo 4 Water seepage (flow) coming from the stone culvert side wall

The downstream end of the stone arch culvert is about 5 feet upstream from the south edge of the sidewalk. At this point there is a weir 2.7 feet high rising from the bedrock stream bed (Photo 5). This weir has a concrete face, but it appears to be just an overlay on rock filled timber cribs behind. The east side seawall from the harbor to the culvert has had a concrete overlay repair that restricts the culvert opening by about 2 feet on the eastern side at this weir, but it does not continue inside the arch culvert more than 2 to 3 feet. The typical base width of the stone arch culvert is about 16 feet.

Photo 5 Downstream culvert weir looking upstream

Proceeding upstream inside the culvert from the south weir is several feet of boulder rock riffles with horizontal transverse timbers that may be rock filled timber cribs (Photo 6). It is not known if these cribs support the arch culvert, or if they are inside the culvert from an earlier dam, or perhaps stream bed scour protection.

Photo 6 Apparent rock filled timber cribs forming stream bed at south end of arch culvert

At about half distance inside the arch culvert is a second weir with apparent bedrock outcrop at the western side of the culvert (Photo 7). This weir has a total height of about 4 feet (pool below) causing about a 17 inch rise in water level at the weir. The weir has a broad partially sloping crest of concrete (6.1 feet down from top of arch), which might be armor over a buried water and/or sewer main.

Photo 7 Mid length weir inside culvert, bedrock left

The upstream end of the arch culvert has a gate open pool depth of about 11 inches over a cobble, gravel with sand bed. The culvert height from stream bed is about 6.8 feet.

The stone arch culvert was observed to have two transverse open stone joints. The straight transverse joint about 6 feet inside from the south end appears to be a culvert extension, perhaps associated with a past road widening. The transverse joint 4 feet inside from the north end is not completely straight and appears to have been caused by movement of the outer 4 feet of culvert stonework resulting in separations between adjacent stones (Photo 8). The northwestern corner of the stone arch culvert is missing foundation support, likely caused by stream scour, and the stones above appear to be settling and separating.

Safety concerns related to the stone arch culvert were summarized in a separate memo to the Town dated June 18th, 2015 and located in Appendix E.

Photo 8 Separation and settlement of culvert arch stones, upstream, northwestern corner

Photo 9 Stream channel upstream from culvert looking south with dark staining on walls indicating normal gate closed high water level

Assessments

The existing tide gate structure has a top of wall elevation just above mean higher high water level, making this a significant obstruction to Rainbow Smelt passage on many high tides. Tidal water levels will rise over these walls on spring high tides (full moon or new moon) and during higher than predicted tides associated with atmospheric low pressure or wind setup, and such conditions will periodically allow smelt to swim over the walls when the tide gate is closed. This tide gate wall overtopping on spring high tides and storm surge tides does indicate that the tide gate is not effective in preventing seawater flooding. Recent preliminary topographic survey indicates Central Street at this location is within about 1 foot of tidal flooding, based on recorded high tides from the storm of 1978 (NOAA Boston tide record at 93% height correction for Manchester). The frequency of tidal flooding of the roadway will be increasing based on the current mean sea level rise relative to land (including land subsidence) of 0.92 feet per 100 years recorded in Boston (NOAA), and also based on forecast predictions of an increasing rate of relative sea level rise (IPCC).

This tide gate is a bottom opening gate, which is not suitable to partial opening for smelt passage due to the head pressure and high flow velocities associated with a limited the gate opening trying to maintain the impoundment pond. Full opening of the gate during smelt migration is feasible, though velocities during rainfall events would need to be checked relative to smelt swimming speeds.

Even with the tide gate open to allow for fish passage, there are two more weirs inside the stone arch culvert. Since the smelt are not able to jump up weirs, the tide will need to rise to at least 2/3 of mean high tide to allow smelt to swim upstream past these weirs.

As noted by the Massachusetts Division of Marine Fisheries experts, the bottom opening tide gate and culvert weirs are obstructions to smelt passage for most of the tide range, and delays in fish passage waiting for a rising tide makes them susceptible to predation. Fish passage can be improved if the tide gate and culvert weirs are removed, perhaps with a substitution using rock riffles in this area. The existing stone arch culvert does have some structural deterioration and the use of the roadway as a dam when the tide gate is closed also results in undesirable seepage. There are opportunities at this tide gate and culvert to improve fish passage while also addressing culvert deterioration and dam seepage. The stone filled timber cribs inside the culvert form a "natural" bottom to the culvert, which is desirable for fish and aquatic life, but they may also be hydraulically connected to the seepage from the dam face wall. Grouting of the crib voids would be one approach to reducing dam seepage, however this may not be desirable for habitat. Removal of the tide gate and the impoundment reduces dam hydrostatic surcharge and seepage as observed during the field investigation, so tide gate removal can offer fish passage improvements and resolution of dam seepage problems.

Next steps to define site constrains and opportunities

- Complete upstream culvert data collection and HECRAS stream modeling
- Obtain new survey elevation data
- Obtain FEMA 100-year flood revisions
- Consider further evaluation of dam hydrostatic surcharge and seepage issues

J:\M\M1476 Manchester MA Hydro Study\Task 2-Stream Crossing Survey\Task 2 deliverables\Appendix E\Sawmill Brook Central Tide Gate Evaluation Memo_Final.doc

Appendix C
Hydrologic and Hydraulic Report

Central Street Bridge Replacement Hydrologic and Hydraulic Analysis

TO: Massachusetts Department of Transportation (MassDOT)

FROM: David Azinheira, PE (Tighe & Bond)

COPY: Vinod Kalikiri, PE, PTOE; David Loring, PE, LEED AP (Tighe & Bond)

DATE: August 22, 2019

A hydrologic and hydraulic (H&H) analysis was performed by Tighe & Bond as part of the engineering design and permitting for the Central Street Bridge Reconstruction Project located on Sawmill Brook at the mouth of Manchester Harbor in Manchester-by-the-Sea. The primary reasons for performing the H&H analysis were to:

- Evaluate the hydraulics (e.g., capacity, freeboard, and velocities) for the existing culvert.
- Develop alternative design concepts for culvert.
- Provide recommendations based on the H&H analysis as to the preferred alternative replacement design approach.

The H&H analysis and subsequent recommendations are summarized in this report and builds on the "Task 2: Hydrologic Monitoring and Flushing Studies Sawmill Brook Flood Mitigation and Restoration Project" prepared for Manchester-by-the-Sea by Tighe & Bond in June 2018.

Based on the analysis we recommend the installation of a 20-foot span open bottom concrete arch culvert to meet the Massachusetts Department of Transportation (MassDOT) Municipal Bridge Projects MGL Chapter 85 Section 35 review requirements for the 25-year flood frequency hydraulic design. Note that the MassDOT Bridge Manual (2013) indicates that the hydraulic design flood return frequency for an Urban Minor Arterial or Rural Major Collector is the 25-year return frequency storm event. The proposed culvert has capacity to pass the 25-year frequency storm event with 0.4 feet of freeboard for MHHW conditions (compared to the low chord), and 4.2 of freeboard feet for MSL condition. Both of these scenarios assume MassDOT recommended increases in sea level due to climate change although the MHHW value is approximately the same with and without adding the MassDOT sea level rise. This alternative would also pass the 25-year flood frequency storm event during an annual storm surge with the water level 1.8 feet below the top of road at Central Street.

A Scour analysis for the preferred design alternative shows potential for scour up to existing bedrock located approximately 0 to 2 feet below the channel bottom upstream of Central Street Bridge. During the geotechnical boring investigation, the bedrock was found to be very hard to hard granite, and is therefore not anticipated to scour. Due to the tidal nature of Manchester Harbor and Central Pond it is anticipated that in general sediment aggradation will be anticipated when storms occur during higher tides (due to backwater) while sediment degradation will be anticipated when storms occur during lower tides.

Attachment A contains figures depicting an aerial overview of Central Street Bridge (Figure 1), a topographic map of the drainage-area (Figure 2), and the geometry used to define the cross-sections in the HEC-RAS model (Figure 3). Attachment B contains the 2016 Report with a description of the HEC-HMS model. Attachment C contains the HEC-RAS model output for the existing and proposed alterative conditions. Attachment D contains the scour analysis calculations.

A summary of the proposed geometry is provided below, with elevations referencing the North American Vertical Datum of 1988 (NAVD88):

Item	Description
Bridge Size and Type	20-foot wide open bottom Arch
Low Chord Elevation	6.0 feet NAVD88
Top of Road Elevation	10.6 feet NAVD88 (+/-)
Upstream Stream Bed Elevation	-0.2 feet NAVD88
Downstream Stream Bed Elevation	-5.3 feet NAVD88 (culvert invert at -4.0 feet NAVD88)
Skew	12 degrees*
Design Scour Elevation	-2 feet NAVD88 (+/-)

*The culvert will be installed at a 12-degree angle; however, since it will be a culvert and not a bridge the full width of the culvert will be available for flow. For traditional bridges the upstream and downstream cross sections control flow under a bridge deck so the skew must be incorporated; however, for an open bottom arch culvert tied into to the walls of an existing channel the geometry of the culvert limits flow and not the upstream cross section. A skew angle was therefore excluded from hydraulic modeling.

1 Project Site Description

The Central Street Bridge spans the Sawmill Brook at the mouth of Manchester Harbor on Central Street (Route 127). The Town-owned crossing is constructed of three integrated parts, a bridge, tide gate and coastal wingwall. The bridge consists of a 13-foot span mortared stone masonry circular arch tidal bridge with stone masonry wingwalls and headwalls. Timber cribs functioning as weirs are imbedded into the bottom of the stream bed. A concrete and iron tide gate abuts the bridge to the south. The bridge was rebuilt around the mid 1900’s and a tide gate was installed to control the Brook and create Central Pond just upstream. A stone and masonry wingwall abuts the bridge in the southwest quadrant, functioning as a seawall. The passage under the bridge discharges flow from Sawmill Brook via a narrow, channelized reach, with 12-foot- high granite walls and buildings abutting either side. Tidal flow from Manchester Harbor passes under the bridge, depending on the setting of the tide gate and tide height. When the tide gate is closed and water is impounded underneath the bridge, the hydrostatic pressure of water forces seepage through the wingwall. The gate and bridge design have been identified as contributing factor to upstream flooding, due to significant hydraulic restriction when large precipitation events and high tide elevations are concurrent.

The tide gate and weir design have been identified by the Massachusetts Division of Marine Fisheries (DMF) as an impediment to fish passage, notably impacting state-listed species, rainbow smelt (Osmerus mordax). The Town plans to remove the tide gate during the reconstruction of the Central Street Bridge.

2 Methodology

Tighe & Bond updated existing a hydrologic and hydraulic (H&H) models of the Central Street (Route 127) bridge watershed along Sawmill Brook as part of the bridge replacement alternatives analysis. The H&H model was developed by updating existing HEC-HMS (version 5.2.1) and HEC-RAS (version 5.0.3) models, both available from the U.S. Army Corps of Engineers. The hydrologic analysis was performed using HEC-HMS (version 5.2.1). The HEC-HMS model output was subsequently used to develop a steady-state HEC-RAS model to evaluate the hydraulic conditions for the existing and proposed structures. The methods used to develop both the hydrologic and hydraulic analysis are documented in the following sections.

2.1 Hydrologic Analysis

A detailed hydrologic analysis was performed using HEC-HMS as part of the February 2016 "Sawmill Brook Culvert and Green Infrastructure Analysis Task 4 Final Report: Evaluation of Locations for Flood Mitigation" prepared by Tighe & Bond. The 2016 study included 25-, 50-, and 100-year flow estimates for the present, 2025, 2050, and 2100 while incorporating multiple energy use climate change projections for rainfall, as well as sea level rise, and storm surge. The 2016 HEC-HMS model was developed using the runoff curve number and time of concentration methodologies outlined in the United States Department of Agriculture's (USDA) Technical Release 55 (TR-55)[1]. The drainage area upstream of Central Street (Route 127) was computed to be approximately 5 square miles, and was modeled using 23 sub-drainage areas. The computed runoff curve numbers ranged from 60 to 75, and the lag times (defined as 0.6 times the time of concentration) ranged from approximately 20 minutes to 70 minutes. The 2016 model developed inflow hydrographs using the 24-hour rainfall depths from the Northeast Regional Climate Center (NRCC) at Cornell University. Five storage areas were also included in the HEC-HMS model at culverts. The 2016 study is included as Attachment B of this memorandum.

Tighe & Bond updated the 2016 HEC-HMS model to include the 2-, 10-, and 500-year frequency storm event as recommended by the MassDOT LFRD Bridge Manual[2]. The 24-hour precipitation for the 2-, 10-, 25-, 50-, 100-, and 500-year frequency storms were estimated using the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 point precipitation frequency tool. Table 2-1 provides the precipitation amounts from NOAA Atlas 14, as well as the NRCC precipitation amounts used as part of the 2016 study. The NOAA Atlas 14 and NRCC values are approximately the same for the 25-year frequency storm event (the depths are within less than 1-percent), whereas the NRCC 24-hour rainfall depths are 4-percent and 10-percent larger than the NOAA Atlas 14 depths for the 50-year and 100-year frequency storm events, respectively. NOAA Atlas 14 was published after the 2016 study was performed and is more current than the NRCC values; however, the NRCC rainfall depths will be used at this time for the 25-, 50-, and 100-year frequency storm events for consistency with the previous recent hydrologic and hydraulic studies performed and because the NRCC depths are either similar to or more conservative than the NOAA Atlas 14 rainfall depths.

[1] Cronshey, R. G., R. T. Roberts, and N. Miller. "Urban hydrology for small watersheds (TR-55 Rev.)." *Hydraulics and Hydrology in the Small Computer Age*. ASCE, 1985.

[2] MassDOT (Massachusetts Dept. of Transportation. "LRFD bridge manual. Part I." (2013).

TABLE 2-1
24-hr Precipitation Values from the National Oceanic and Atmospheric Administration NOAA Atlas 14 and the Northeast Regional Climate Center (NRCC)

Storm Return Frequency	Precipitation Values from NOAA Atlas 14 (inches)	Precipitation Values from NRCC Used for Previous Modeling (inches)
2-year	3.20	
10-year	5.04	
25-year	6.20	6.16[1]
50-year	7.08	7.34[1]
100-year	7.97	8.77[1]
500-year	11.1	

[1]The NRCC rainfall depths will be used for the 25-, 50-, and 100-year frequency storm events for consistency with the previous recent hydrologic and hydraulic studies performed and because the NRCC depths are either similar to or more conservative than the NOAA Atlas 14 rainfall depths

Peak flows were also calculated through regression analysis using the Zarriello 2017[3] approach available in the USGS Streamstats program[4]. These flow estimates were used as a basis for comparison with the computed design storm flow rates.

2.2 Hydraulic Analysis

A hydraulic analysis of Sawmill Brook was prepared using HEC-RAS, a hydraulic modeling program available from the U.S. Army Corps of Engineers. This model updates the previous planning level modeling performed as part of the "Sawmill Brook Culvert and Green Infrastructure Analysis Task 4 Final Report: Evaluation of Locations for Flood Mitigation" prepared by Tighe & Bond in February 2016, with updates based on the November 2017 survey by Doucet Survey Inc., and surface water level monitoring. The updated model includes Sawmill Brook from approximately 50 feet upstream of Norwood Avenue to approximately 100 feet downstream of Central Street.

To update the model, Tighe & Bond first created a Triangular Irregular Network (TIN) elevation surface using the 2017 survey and MassGIS LiDAR topographic data for overbank areas beyond the extent of the surveyed cross sections. A geometric representation of the channel, banks, and cross-sections was created using the HEC-GeoRAS tool to extract cross sections from the TIN. Sawmill Brook was modeled using 30 cross sections, culverts at Norwood Avenue, School Street, and Central Street, as well as the existing tide gate structure immediately downstream of Central Street. The Manning's roughness coefficients were estimated to be 0.04 in the upstream area of the reach and 0.03 toward the downstream area based on the survey and orthographic imagery. The overbank area Manning's n varied from 0.035 (commercial/industrial land use) to 0.1 (forest cover). The overbank Manning's n varied horizontally along the cross sections and were calculated using the MassGIS 2015 land use dataset.

[3] Zarriello, P.J.,2017, Magnitude of flood flows at selected annual exceedance probabilities for streams in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2016–5156, 99 p.

[4] U.S. Geological Survey, 2016, The StreamStats program, online at http://streamstats.usgs.gov, accessed August 21, 2018.

Model geometry scenarios were developed for:

1. Existing Conditions with the Tide Gate Open/Closed
2. Proposed Alternatives

The downstream boundary conditions for the design storm hydraulic modeling were the Mean Higher High Water (MHHW) and the annual storm surge elevation. The modeled MHHW elevation was 4.77 feet NAVD88 based on the NOAA Long Term Tide Water Level Monitoring Station ID: 8443970. The annual storm surge elevation was provided in the February 2016 study as approximately 8.2 feet NAVD88. The 2016 study estimated that the annual storm surge elevation in 2100 would overtop Central Street so future storm surge scenarios were not modeled. For reference, the Mean Sea Level (MSL) is -0.3 feet NAVD88 at the NOAA Long Term Tide Water Level Monitoring Station ID: 8443970.

The sea level rise increase in 2100 used for this study is 2 feet. This value falls within the 66% probability range provided in the Northeast Climate Science Center (NECSC) sea level rise projections for the Boston area for the two emissions scenarios evaluated[5]. The MHHW elevation accounting for sea level rise was therefore 6.77 feet NAVD88. This sea level rise increase is more conservative than the 0.012 feet/year increase recommended in the LFRD Bridge Manual that corresponds with a 0.98-foot increase by 2100. This would correspond with a sea level rise MHHW of 5.75 feet NAVD88, and a MSL of 0.68 feet NAVD88.

Following the development of the geometric parameterization of the cross-sections along Sawmill Brook, flows from the updated HEC-HMS model were assigned by cross-section for both the existing and proposed condition. Water surface elevations and channel velocities were evaluated for the 2-, 10-, 25-, 50-, 100-, and 500-year storms.

MassDOT classifies Central Street (Route 127) as an Urban Minor Arterial or Rural Major Collector. The LRFD Bridge Manual suggests a hydraulic design storm as a 25-year frequency storm event, the scour design storm as the 50-year frequency storm event, and the scour design check storm as the 100-year frequency storm event. Freeboard is defined as the distance from the peak water surface elevation upstream of the culvert to the top of the culvert opening, which was evaluated across the range of storms.

2.3 Alternative Design Analysis

Three alternative designs were evaluated to replace the existing Central Street Bridge. All of the alternative designs included removing the existing tide gate. The first alternative (Alternative 1) was designed to pass the 50-year frequency storm event for predicted climate change rainfall and sea level rise conditions exceeding MassDOT requirements. The minimum hydraulic capacity structure was determined to be an open-bottomed concrete arch-culvert structure with a clear span width of 20-feet and a continuous low chord elevation at 6 feet NAVD88. The second alternative (Alternative 2) was sized to provide a span that could pass the 25-year frequency storm event with the MassDOT recommended sea level rise for 2100 using the tidal MHHW boundary condition, which was determined to be a structure with the geometry of Alternative 1 but with a span width of 12 feet. The third alternative (Alternative 3) is an in-kind replacement of the existing culvert.

1. Proposed Alternative 1 with 20-foot wide arch culvert with Tide Gate Removed
2. Proposed Alternative 2 with 12-foot wide arch culvert with Tide Gate Removed

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[5] Northeast Climate Science Center (NECSC) "Massachusetts Climate Change Projections - Statewide and for Major River Basins" for the Massachusetts Executive Office of Energy and Environmental Affairs, January 2018. Available from http://www. massclimatechange.org/.

3. Proposed Alternative 3 with Culvert Replaced in-kind with Tide Gate Removed

2.4 Scour Analysis

Scour at the Central Street Bridge was evaluated in a manner consistent with the general guidelines set forth in the FHWA Hydraulic Engineering Circular Nos. 18 (HEC-18), HEC-20, and the MassDOT LRFD Bridge Manual section 1.3.3.4 Scour/Stability Analysis. The HEC-RAS model was used to estimate the hydraulic parameters required to compute the total scour potential. The scour design and scour check flood return frequencies were the 50-year and 100-year frequency storm event, based on Table 1.3.4-1 in the LRFD Bridge Manual for an Urban Minor Arterial or Rural Major Collector.

Total scour consists of the summation of contraction scour, abutment scour, pier scour, and long-term aggregation and degradation. Contraction scour is calculated using the Modified Laursen's equation (1960) and the Laursen's equation (1963) as outlined in HEC-18. Abutment scour was calculated using the National Cooperative Highway Research Program (NCHRP) methodology as outlined in HEC-18 that provides a peaking factor to contraction scour to estimate the sum scour anticipated from contraction and abutment scour. Scour was also calculated using the Clear-Water Scour Equation for Open-Bottom Culverts that incorporate both contraction and abutment scour. There are no piers proposed, so pier scour was not evaluated. Long-term aggregation and degradation were evaluated based on qualitative approaches outlined in HEC-20. Scour calculations did not include any potential scour countermeasures. The sediment transport analysis performed in "Task 3: Sediment Characterization and Flushing Studies - Sawmill Brook Flood Mitigation and Restoration Project" completed in June 2018 by Tighe & Bond was also reviewed as part of the scour analysis.

3 Analysis Results and Alternatives Discussion

The H&H model was evaluated for the existing and proposed alternatives using the above described methodology. The model results for existing and proposed conditions are presented in the following sections.

3.1 Hydrologic Analysis

Table 3-1 shows the peak flow results from the HEC-HMS model as well as the prediction interval from the regression analysis.

TABLE 3-1

Design Storm Peak Flow Rates from HEC-HMS Hydrologic Model with associated Downstream Boundary Condition for HEC-RAS hydraulic model.

Model Scenario	Downstream Boundary Condition[1]	Flow to Norwood Avenue (ft^3/s)	Flow to Central Pond (ft^3/s)	Regression Analysis Prediction Interval at Central Pond[2] (ft^3/s)
Present (2018) 2-Year	MHHW	232	254	63 to 242
Present (2018) 10-Year	MHHW	845	924	129 to 535
Present (2018) 25-Year	MHHW	1,228	1,363	167 to 739
Present (2018) 50-year	MHHW	1,565	1,772	195 to 920
Present (2018) 100-year	MHHW	2,000	2,267	223 to 1,120
Present (2018) 500-year	MHHW	2,671	3,078	303 to 1,610
Present (2018) 25-year with MassDOT recommended SLR	MHHW + MassDOT SLR	1,228	1,363	167 to 739
Present (2018) 25-year MSL with MassDOT recommended SLR	MSL + SLR	1,228	1,363	167 to 739
Future (2100) 25-Year	MHHW + SLR	1,706	1,930	N/A
Future (2100) 50-Year	MHHW + SLR	1,717	1,946	N/A
Future (2100) 100-Year	MHHW + SLR	2,562	2,943	N/A
Present (2018) 25-Year with Storm Surge	Annual Storm Surge	1,228	1,363	N/A
Present (2018) 50-year with Storm Surge	Annual Storm Surge	1,565	1,772	N/A

[1] MHHW = Mean Higher High Water, SLR = Sea Level Rise, MSL = Mean Sea Level

[2] Regression analysis completed using Magnitude of flood flows at selected annual exceedance probabilities for streams in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2016–5156 (Zarriello 2017)

In general, the peak flows estimated using HEC-HMS are larger than the values predicted by the regression analysis though within the same order of magnitude. Based on this comparison, the HEC-HMS model was considered to provide reasonable conservative estimate for the storms of interest at the Central Street (Route 127) culvert and the values from this model were used as the peak inflow values for the steady-state HEC-RAS hydraulic model.

3.2 Hydraulic Analysis

Peak flows evaluated in the hydrologic analysis were subsequently used as input to the HEC-RAS model to evaluate hydraulics at Central Street Bridge for existing and proposed alternative conditions. Results from this analysis, which include peak water surface elevations, distance from the peak water surface elevation to the top of the road, freeboard to low chord, and velocities within the structure are included in Tables 3-2 through 3-5. HEC-RAS model output for the existing and proposed alterative conditions are provided in Attachment C.

TABLE 3-2
HEC-RAS Results for Existing Conditions at Central Street Bridge (assuming tide gate closed)

Model Scenario	Peak Water Surface Elevation (NAVD88)	Freeboard (feet)	Distance to Top of Road (feet)	Average Velocity Upstream Inside Culvert (ft/s)	Average Velocity Downstream Inside Culvert (ft/s)
Present (2018) 2-Year	6.4	-0.4	4.2	4.0	4.0
Present (2018) 10-Year	11.2	-5.2	-0.6	12.1	12.1
Present (2018) 25-Year	11.8	-5.8	-1.2	12.2	12.2
Present (2018) 50-year	12.4	-6.4	-1.8	8.5	8.5
Present (2018) 100-year	12.5	-6.5	-1.9	9.9	9.9
Present (2018) 500-year	12.6	-6.6	-2.0	9.5	9.5
Present (2018) 25-year with MassDOT recommended SLR	11.9	-5.9	-1.3	12.3	12.3
Present (2018) 25-year MSL with MassDOT recommended SLR	11.8	-5.8	-1.2	12.2	12.2
Future (2100) 25-Year	12.2	-6.2	-1.6	12.9	12.9
Future (2100) 50-Year	12.1	-6.1	-1.5	12.9	12.9
Future (2100) 100-Year	12.6	-6.6	-2.0	9.5	9.5
Present (2018) 25-Year with Storm Surge	11.9	-5.9	-1.3	12.2	12.2
Present (2018) 50-year with Storm Surge	12.4	-6.4	-1.8	8.5	8.5

TABLE 3-3
HEC-RAS Results for Alternative 1 at Central Street Bridge (replace culvert with 20-foot wide open-bottom arch culvert)

Model Scenario	Peak Water Surface Elevation (NAVD88)	Freeboard (feet)	Distance to Top of Road (feet)	Average Velocity Upstream Inside Culvert (ft/s)	Average Velocity Downstream Inside Culvert (ft/s)
Present (2018) 2-Year	4.7	1.3	5.9	1.5	1.5
Present (2018) 10-Year	4.8	1.2	5.8	5.4	5.4
Present (2018) 25-Year	5.6	0.4	5.0	8.0	8.0
Present (2018) 50-year	6.6	-0.6	4.0	10.4	10.5
Present (2018) 100-year	7.7	-1.7	2.9	13.4	13.6
Present (2018) 500-year	10.9	-4.9	-0.3	16.9	16.9
Present (2018) 25-year with MassDOT recommended SLR	5.7	0.3	4.94	7.4	7.5
Present (2018) 25-year MSL with MassDOT recommended SLR	1.8	4.2	8.8	11.7	13.0
Future (2100) 25-Year	6.9	-0.9	3.7	10.5	10.5
Future (2100) 50-Year	7.0	-1.0	3.6	10.5	10.5
Future (2100) 100-Year	10.6	-4.6	-0.01	13.8	13.8
Present (2018) 25-Year with Storm Surge	8.8	-2.8	1.8	7.4	7.4
Present (2018) 50-year with Storm Surge	10.6	-4.6	-0.01	9.6	9.6

TABLE 3-4
HEC-RAS Results for Alternative 2 at Central Street Bridge (replace culvert with 12-foot wide open-bottom arch culvert

Model Scenario	Peak Water Surface Elevation (NAVD88)	Freeboard (feet)	Distance to Top of Road (feet)	Average Velocity Upstream Inside Culvert (ft/s)	Average Velocity Downstream Inside Culvert (ft/s)
Present (2018) 2-Year	4.8	1.2	5.8	2.4	2.4
Present (2018) 10-Year	6.0	0.0	4.6	8.8	8.9
Present (2018) 25-Year	8.6	-2.6	2.0	12.9	13.2
Present (2018) 50-year	10.6	-4.6	-0.01	15.0	15.8
Present (2018) 100-year	10.6	-4.6	-0.03	15.7	16.9
Present (2018) 500-year	10.9	-4.9	-0.3	16.2	17.5
Present (2018) 25-year with MassDOT recommended SLR	9.0	-3.0	1.6	12.1	12.1
Present (2018) 25-year MSL with MassDOT recommended SLR	8.7	-2.7	1.9	14.0	15.4
Future (2100) 25-Year	10.9	-4.9	-0.3	13.5	13.5
Future (2100) 50-Year	10.9	-4.9	-0.3	13.5	13.5
Future (2100) 100-Year	10.6	-4.6	-0.01	14.8	14.8
Present (2018) 25-Year with Storm Surge	10.9	-4.9	-0.3	10.6	10.6
Present (2018) 50-year with Storm Surge	11.3	-5.3	-0.7	11.6	11.6

TABLE 3-5
HEC-RAS Results for Alternative 3 at Central Street Bridge (replace culvert in-kind)

Model Scenario	Peak Water Surface Elevation (NAVD88)	Freeboard (feet)	Distance to Top of Road (feet)	Average Velocity Upstream Inside Culvert (ft/s)	Average Velocity Downstream Inside Culvert (ft/s)
Present (2018) 2-Year	5.3	0.7	5.3	4.5	4.4
Present (2018) 10-Year	10.9	-4.9	-0.3	14.7	14.9
Present (2018) 25-Year	11.6	-5.6	-1.0	14.3	18.3
Present (2018) 50-year	11.9	-5.9	-1.4	14.7	18.8
Present (2018) 100-year	12.1	-6.1	-1.5	15.0	19.2
Present (2018) 500-year	11.9	-5.9	-1.3	15.5	19.7
Present (2018) 25-year with MassDOT recommended SLR	11.6	-5.6	-1.0	14.3	18.3
Present (2018) 25-year MSL with MassDOT recommended SLR	11.6	-5.6	-1.0	14.3	18.3
Future (2100) 25-Year	12.1	-6.1	-1.5	14.3	14.3
Future (2100) 50-Year	12.1	-6.1	-1.5	14.3	14.3
Future (2100) 100-Year	12.1	-6.1	-1.5	15.3	15.3
Present (2018) 25-Year with Storm Surge	11.9	-5.9	-1.3	11.7	11.7
Present (2018) 50-year with Storm Surge	12.1	-6.1	-1.5	12.3	12.3

3.3 Alternative Design Evaluation

Three alternative designs were evaluated to replace the existing culvert at Central Street. All alternatives are expected to result in increase hydraulic capacity compared to existing conditions with the tide gate in place. Alterative 1 and Alternative 2 would results in a more natural river alignment under the road by reducing the hydraulic restriction that currently exists. Also, all alternatives were limited in height by the existing road grade, which was assumed to remain the same from existing to proposed. The span width was also limited to 20 feet due to the upstream channel.

3.3.1 Preferred Alternative

Alternative 1 exceeds MassDOT hydraulic requirements by passing the 50-year frequency storm event for predicted climate change conditions without overtopping the road. This alternative also passes the 25-year frequency storm event with 0.4 feet of freeboard for MHHW conditions (compared to the low chord), and 4.2 of freeboard feet for MSL condition. Both of these scenarios assume MassDOT recommended increases in sea level due to climate change. Note that MHHW elevation is 5.75 NAVD88 when assuming MassDOT tidal increases due to sea level rise (0.25 feet lower than the maximum low chord based on site constraints). This alternative can also pass the 25-year frequency storm event during the annual storm surge without overtopping the road. While Alternative 2 met the MassDOT minimum hydraulic constraints for culvert design, it is not anticipated to meet predicted climate change conditions in 2100 for the 50-year frequency storm event. Alterative 3 does not meet the recommended MassDOT minimum hydraulic requirements, although it does offer an improvement to existing conditions due to removal of the tide gate. Alternative 1 was considered the preferred alternative.

3.4 Scour Analysis

Abutment, contraction, and long-term aggregation and degradation scour processes were evaluated in detail for the preferred alternative. Attachment D contains the calculations for this analysis.

Abutment scour was calculated for the 50-year scour design storm, and is anticipated to extend to the granite bedrock located approximately 0 to 2 feet below the channel bottom. If the bedrock had not been observed scour would be anticipated to a depth of 3.7 feet at the center of the channel and up to 10.8 feet toward the left and right abutment. Under the 100-year scour design check storm, scour is also anticipated to extend to the granite bedrock located approximately 0 to 2 feet below the channel bottom. If the bedrock had not been observed the scour would be anticipated to a depth of 4.1 feet at the center of the channel and up to 6.8 feet toward the left and right abutment. A contraction scour analysis shows that live-bed scour conditions are likely to dominate with sediment transport limiting the contraction scour depth rather than the size of the bed material.

The natural bed material of this stream is mostly comprised of medium to fine grain sands and silt, with average D50 and D85 values of approximately 0.011 inches and 0.05 inches, respectively. An incipient diameter analysis was performed and results indicate that the hydraulic forces are adequate to transport bed material up to 1 foot for a 50-year storm, which is greater than the average D85.

Based on this comparison between the incipient diameter particle size for the 50-year storm and the streambed material, it is anticipated that sediment will be mobilized from the upstream reach following the installation of an open-bottom culvert. The granite bedrock located 0 to 2 feet below the channel bottom will provide a vertical control for scour.

3.5 Stream-Crossing Standards

The preferred alternative of a 20-foot span open-bottom arch culvert was not designed to meet Stream-Crossing standards due to site constraints and coastal influence but does meet some of the recommendations. For replacement projects, stream simulation design approaches typically result in greater hydraulic capacity for passing flood flows than the existing bridge or culvert. This is true in this case, as the existing structure is an approximately 13 feet wide semi-circular arch culvert, which is proposed to be replaced with an open-bottom culvert with a clear span of 20 feet.

The proposed culvert is approximately the same width as the concrete wall lined channel located upstream of the bridge, so the opening width is not anticipated to limit flow. The concrete channel contains the 10-year frequency storm event, and is therefore anticipated to exceed the bankfull flow event (typically between the 1.5-, and 2-year frequency storm events).

The predicted opening area of the preferred replacement culvert is approximately 100 square feet. With a total length of approximately 45 feet, the openness ratio is approximately 2.2 feet, which exceeds the recommended openness ratio of 0.82 feet and approaches the recommended optimum standard. The height of the opening of the structure at this location is limited by the cover from the existing road grade, and a maximum low chord elevation of 6 feet NAVD88 is proposed for the preferred alternative.

3.6 Hydraulic Design Table

The H&H analysis is summarized in the design drawings in a hydraulic design data table. Table 3-6 provides the hydraulic design data table for Central Street Bridge.

TABLE 3-6
Hydraulic Design Data Table Included in Design Drawings for Central Street Bridge for a 20-foot span open-bottom arch culvert with low chord at 6 feet NAVD88.

HYDRAULIC DATA	
DRAINAGE AREA	5.0 SQ. MILES
WATER CONTROL FLOOD DISCHARGE (2 YR)	254 CFS
DESIGN FLOOD DISCHARGE (25 YR)	1,363 CFS
DESIGN FLOOD ANNUAL CHANCE (RETURN FREQUENCY)	4% (25-YEARS)
DESIGN FLOOD VELOCITY (25 YR)	7.5 FPS
DESIGN FLOOD ELEVATION (25 YR)	5.7 FEET
BASE 100-YR FLOOD DATA	
BASE FLOOD DISCHARGE (100 YR)	2,267 CFS
BASE FLOOD ELEVATION (100 YR)	7.7 FEET
DESIGN AND CHECK SCOUR DATA	
SCOUR DESIGN FLOOD ANNUAL CHANCE (RETURN FREQUENCY)	2% (50-YEARS)
DESIGN FLOOD ABUTMENT SCOUR DEPTH	LEFT: 2 FT RIGHT: 2 FT
SCOUR CHECK FLOOD ANNUAL CHANCE (RETURN FREQUENCY)	1% (100-YEARS)
CHECK FLOOD ABUTMENT SCOUR DEPTH	LEFT: 2 FT RIGHT: 2 FT
FLOOD OF RECORD	
DISCHARGE	UNKNOWN
FREQUENCY (IF KNOWN)	N/A
MAXIMUM ELEVATION	N/A
DATE	N/A
HISTORY OF ICE FLOWS	UNKNOWN
EVIDENCE OF SCOUR AND EROSION	NO

4 Summary

The H&H analysis methodology and results described above will be used as the basis of design of the Central Street Bridge along the Sawmill Brook in the Town of Manchester-by-the-Sea. The analysis confirms that the preferred alternative will provide both adequate hydraulic capacity for the design storm as well as will meet predicted future conditions due to climate change. Furthermore, scour is not anticipated to extend beyond the granite bedrock located between 0 to 2 feet below the channel bottom for the scour design storm (50-year storm) nor the scour check storm (100-year storm).

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ATTACHMENT A

Figures

FIGURE 1
SITE AERIAL OVERVIEW

Central Street Bridge Reconstruction
Manchester-by-the-Sea, Massachusetts

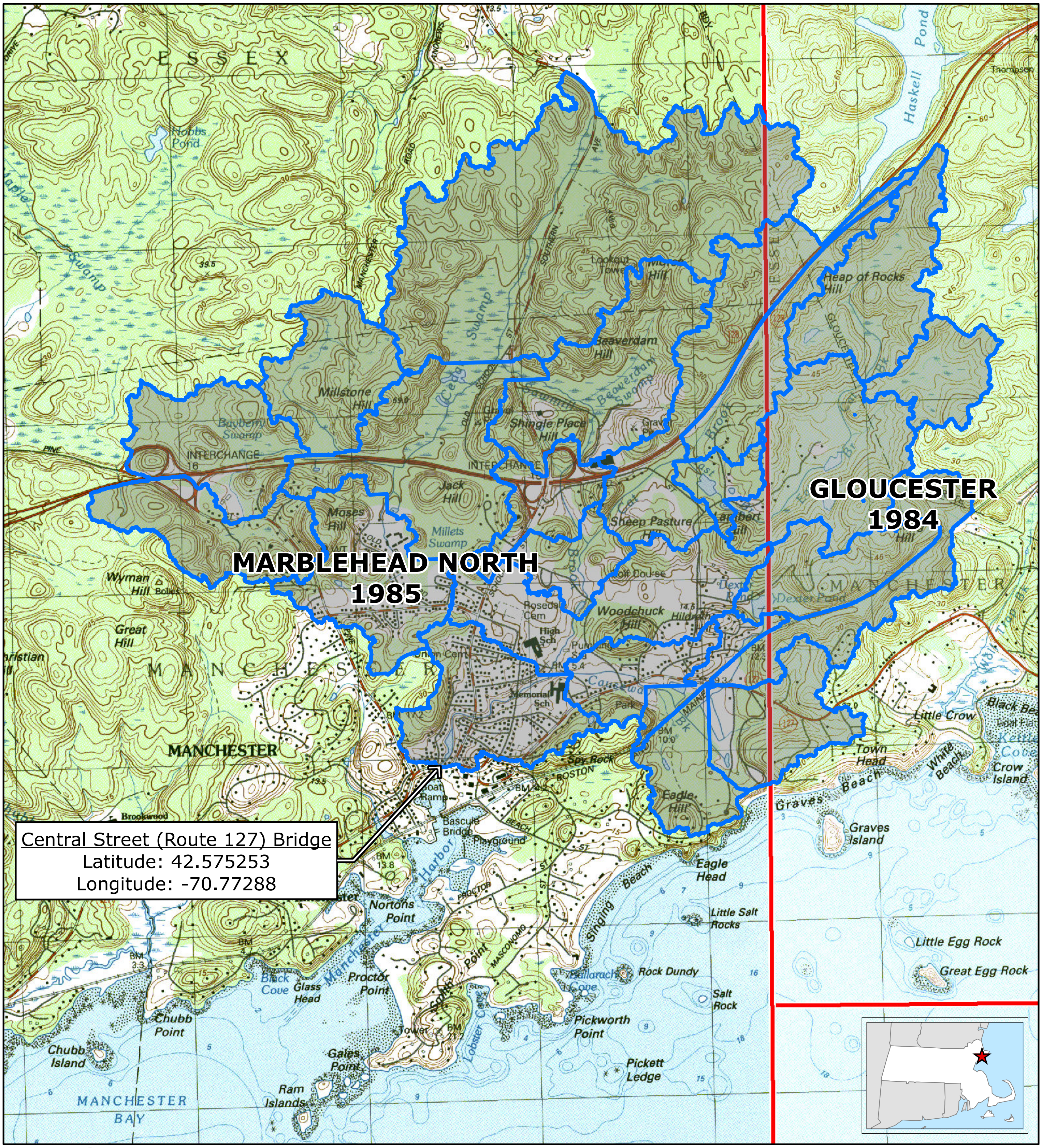
August 2018

Tighe&Bond
Engineers | Environmental Specialists

Based on MassGIS Color Orthophotography (2013)

J:\M\M1476 Manchester MA Hydro Study\011-Central Street Bridge\Drawings_Figures\GIS\MXD\01_Central Street MBTS Overview.mxd

S-1852



Legend

- Central Street Bridge Drainage Area
- HEC-HMS Sub-Drainage Areas
- USGS Quadrangle Sheet Boundary

Based on USGS Topographic Map for Marblehead, MA Revised 1985. Gloucester, MA Revised 1984.

1:30,000

0 1,250 2,500
Feet

N

Tighe&Bond
Engineers | Environmental Specialists

FIGURE 1
DRAINAGE AREA MAP

Central Street Bridge Reconstruction
Manchester-by-the-Sea, Massachusetts

August 2018

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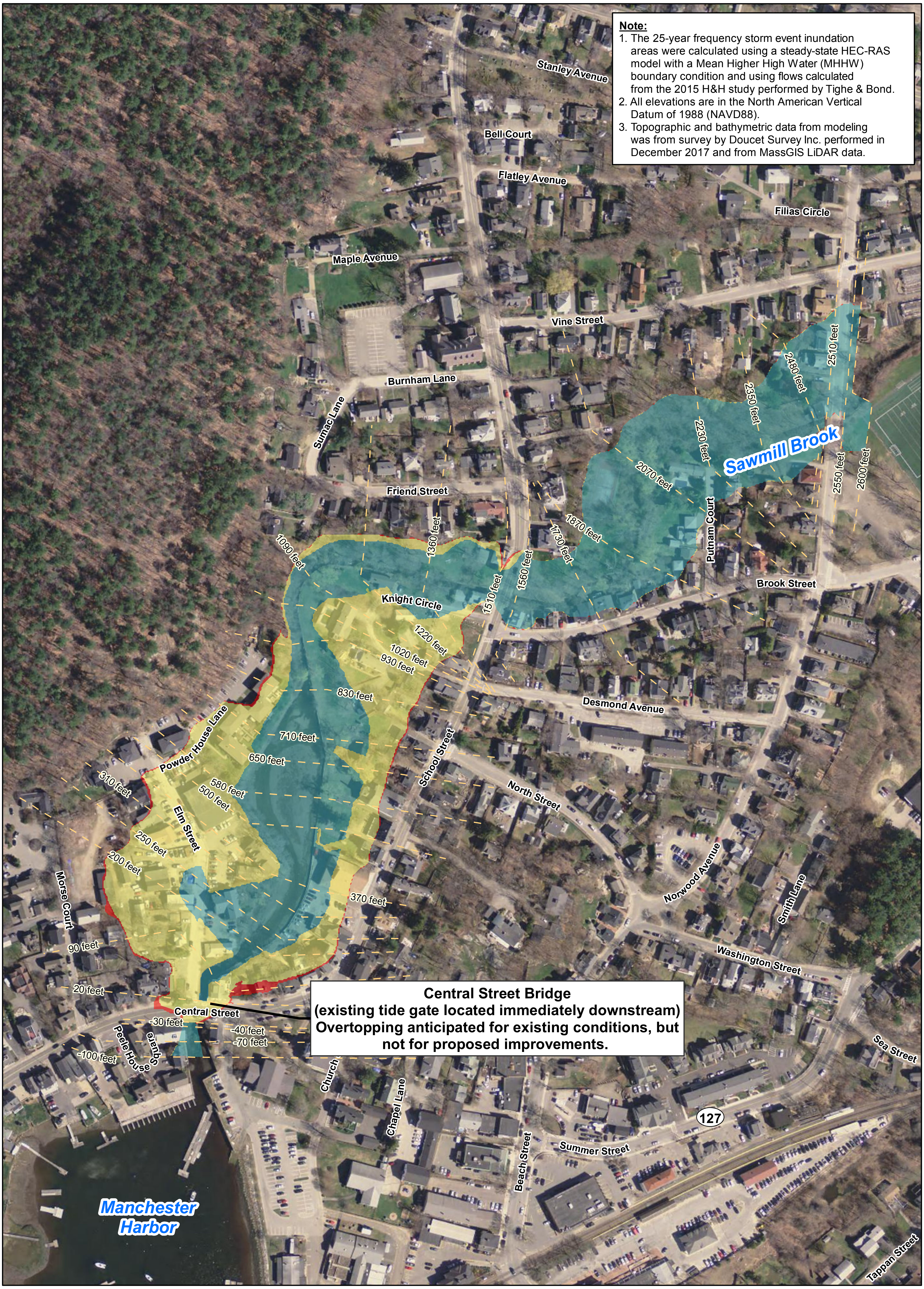

LEGEND

- Model Cross Section (label indicates feet upstream of Central Street)
- Proposed Conditions 25-year Storm Flow (Larger Culvert, and tidegate removed) Inundation Area
- Existing Conditions Tide Gate Open 25-year Storm Flow Inundation Area
- Existing Conditions Tide Gate Closed 25-year Storm Flow Inundation Area

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Based on MassGIS Color Orthophotography (2013).

1 in = 200 ft

0 100 200
Feet

N

FIGURE 3
25-YEAR FREQUENCY STORM EVENT INUNDATION AREA

Manchester-by-the-Sea
Sawmill Brook Feasibility Study

October 2018

V:\Projects\M\m1476\SawmillBrook_InundationFigures\SawmillBrook_MA_25Yr_StormEvent_Inundation.mxd

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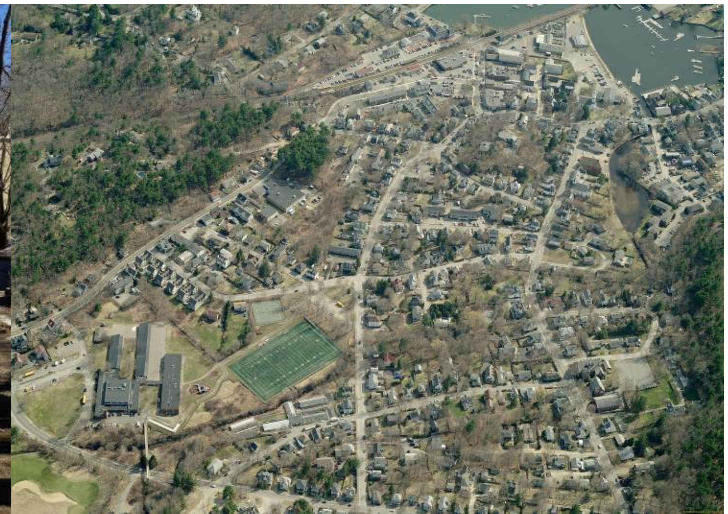
ATTACHMENT B

"Sawmill Brook Culvert and Green Infrastructure Analysis Task 4 Final Report: Evaluation of Locations for Flood Mitigation" (Tighe & Bond, 2016)

H&H Memo Attachment B

NOTE: The hydraulic modeling and sea level rise estimates have been updated since this study was performed and were not included in this Appendix.

Tighe&Bond

SELECTION FROM

Sawmill Brook Culvert and Green Infrastructure Analysis Task 4 Final Report: Evaluation of Locations for Flood Mitigation

Prepared For:

Town of Manchester-by-the-Sea
Manchester-by-the-Sea, Massachusetts

February 2016

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Appendices

Appendix D and E Excluded.

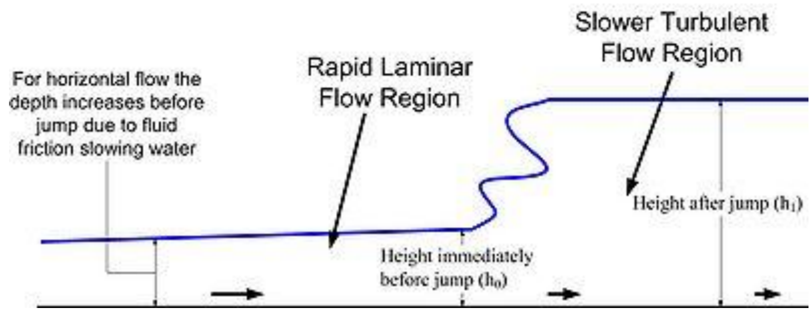
Figures

Tables

Definitions

GIS: acronym for Geographic Information Systems; a system designed to store, analyze, manage, and present all types of geographical data

Hydraulic Jump is a phenomenon in the science of hydraulics which is frequently observed in open channel flow such as rivers and spillways. When water at high velocity discharges into a zone of lower velocity water, a rather abrupt rise occurs in the water surface. The rapidly flowing water is abruptly slowed and increases in height, converting some of the flow's initial kinetic energy into an increase in potential energy, with some energy irreversibly lost through turbulence to heat. In open channel flow, this manifests as the fast flow rapidly slowing and piling up on top of itself similar to how a shockwave forms. The following figure illustrates the behavior in a hydraulic jump.



A hydraulic jump is a region of rapidly varied flow and is formed in a channel when a **supercritical flow** transitions into a **subcritical flow**. In general, supercritical flows are shallow and fast and subcritical flows are deep and slow.[1]

Hydrologic Soil Group is a designation by the Natural Resource Conservation Service (NRCS). The NRCS publishes a soil survey for most counties in the United States that classifies the soils into one of four hydrologic soil groups based upon how quickly the soil drains. Soils classified as "A" are the fastest draining (and have the smallest runoff potential) and soils classified as "D" are the slowest draining (and have the greatest runoff potential).

Hydrograph is a graph that shows the relationship of flow vs. time for a particular location within the watershed.

Hyetograph: A plot of cumulative rainfall or rainfall intensity versus time for a particular precipitation event

Inundation: to be covered with water

Lag time is the time between when the peak of a precipitation event occurs, and when that runoff makes it to the outlet of the watershed.

[1] Source: Wikipedia.org

LiDAR: Light Detection and Ranging, is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. It is a state-of-the-art method for collecting accurate elevation information for large areas.

NAVD88: North American Vertical Datum of 1988 is the vertical control datum established in 1991 for vertical control surveying. NAVD88 consists of a leveling network on the North American Continent, affixed to a single origin point. NAVD88 replaced NGVD29 as the official vertical datum.

Return Frequency: likelihood, or probability that a rainfall event (specific to the magnitude and duration) will be equaled or exceeded in any given year.

Riverine: Associated with a river

Sea Level Rise: An increase in sea level caused by a change in the volume of the world's oceans due to temperature increase, deglaciation (uncovering of glaciated land because of melting of the glacier), and ice melt (Source: NOAA).

Stage Storage Discharge Curves: define the relationship between the depth of water and the discharge or outflow for the flood storage areas behind a culvert or impoundment.

Stillwater Elevation: The projected elevation of floodwaters in the absence of waves resulting from wind or seismic effects. In coastal areas, stillwater elevations are determined when modeling coastal storm surge: the results of overland wave modeling are used in conjunction with the stillwater elevations to develop Base Flood Elevations (Source: FEMA).

Storm Surge: Storm surge is the water, combined with normal tides that push toward the shore by strong winds during a storm. This rise in water level can cause severe flooding in coastal areas, particularly when the storm coincides with the normal high tides. The height of the storm surge is affected by many variables, including storm intensity, storm track and speed, the presence of waves, offshore depths, and shoreline configuration (Source: FEMA).

Tributary: a stream or channel that joins with a larger stream

Tailwater: The elevation of the water surface downstream from a dam or culvert. In coastal areas, such as Manchester-by-the-Sea, the tailwater elevation downstream of a dam is affected by tides, storm surge and sea level rise.

Time of Travel: The time interval required for water to travel from one point to another through a part (reach) of a watershed

Weighted Runoff Curve Number (CN): is a parameter used for predicting direct runoff or infiltration. The CN characterizes the runoff properties for each particular soil and groundcover in modeling applications. The CN method was developed by the USDA Natural Resource Conservation Services, formerly the Soil Conservation Service or SCS.

10-year Storm: A storm event having a 10% probability of occurring in any given year

25-year Storm: A storm event having a 4% probability of occurring in any given year

50-year Storm: A storm event having a 2% probability of occurring in any given year

100-year Storm: A storm event having a 1% probability of occurring in any given year

H&H Memo Attachment B

SECTION 1

Section 1
Introduction

1.1 Purpose of Study

This report describes the Sawmill Brook watershed modeling that was completed as part of the Coastal Zone Management Grant, **Manchester-by-the-Sea Sawmill Brook Culvert and Green Infrastructure Analysis**: Task 4 "Evaluation of Locations for Flood Mitigation". As part of the study existing conditions within the Sawmill Brook watershed were modeled and flooding impacts due to climate change, including increased levels of precipitation in combination with corresponding projections for sea level rise, were evaluated.

The modeling provides the data needed to evaluate adequacy of culvert sizing within the Sawmill Brook Watershed under climate change conditions and the mitigation value of proposed stormwater best management practices at specific locations, including green stormwater infrastructure, conveyance projects and flood storage. Additionally, the model will help determine projected flooding impacts upon important community assets identified as part of the Hazard Mitigation Plan enhancement under a Federal Emergency Management Agency (FEMA) Pre-disaster Mitigation Grant.

1.2 Project Methodology Overview

Tighe & Bond evaluated the existing hydrology and hydraulics within the study area under varying climatic events.

- **Existing watershed conditions were modeled** with HydroCAD and HEC-HMS (US Army Corps of Engineers, 2015) using information about soils, topography, ground cover (impervious cover and land uses), existing wetlands and waterbodies, water travel times, and existing structures that control discharges (e.g. Central Street tide gate, culverts, etc.). Existing conditions considered rainfall depths developed by the Cornell University Northeast Regional Climate Center and tidal influences using data from Flood Insurance Study for Essex County (July 2014). The existing conditions model was calibrated against the May 2006 storm (Mother's Day storm) that represent 25-year single day and 100-year consecutive day storm conditions.

- Building off the existing conditions model, **future watershed conditions** were predicted considering anticipated impacts from climate change and sea level rise in 2025, 2050, and 2100. For this model, precipitation estimates in the existing conditions scenario were replaced with estimates of future rainfall depths for 2025, 2050, and 2100 from the Oyster River Culvert Analysis project completed in Durham, New Hampshire (UNH, 2010). In addition, sea level rise and storm surge was incorporated into the model using data from the Inundation Risk Model (IRM) outputs developed by Keil Schmid (Geoscience, 2015).

- Using the future conditions model, the **potential impacts on existing infrastructure** (e.g. tide gate at Central Street, culverts, crossings) from storm surge, sea level rise, and future precipitation conditions in 2025, 2050, and 2100 were identified. The future condition model was also used to evaluate culvert sizes and needed upgrades, and the mitigation value of proposed stormwater best management practices including green stormwater infrastructure, conveyance projects, and flood storage.

Tighe & Bond partnered with organizations to obtain data necessary to complete the evaluation. Tighe & Bond walked the river on May 30, 2015, along with the Town's Stream Team and other volunteers, to become familiar with the river and identify critical locations for survey cross sections. Measurements and inventories of culverts were taken during this visit.

Town Staff and Volunteers making observations at the Lincoln Street Culvert

Tighe & Bond coordinated with Keil Schmidt of Geoscience to obtain elevations from the Inundation Risk Model (IRM) outputs for sea level rise and storm surge for incorporation into our modeling.

Tighe & Bond subcontracted with Doucet Survey of Newmarket, New Hampshire to survey the upstream and downstream ends of critical culvert locations. Tighe & Bond also utilized MassGIS LiDAR topographic data for overbank areas beyond the extent of the surveyed cross sections. LiDAR, which stands for Light Detection and Ranging, is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. It is commonly used to make high-resolution contour mapping of large areas.

1.3 Sawmill Brook Watershed

Sawmill Brook is the longest watercourse that flows through Manchester-by-the-Sea, and drains a majority of the Town. Please refer to **Figure 1** for the watershed's approximate boundaries. The watershed comprises a total of 4.8 square miles, most of which lies within Manchester-by-the-Sea, although portions of the watershed extend into Essex and Gloucester.

Sawmill Brook upstream of School Street, near its interchange with Route 128.

Main Stem of Sawmill Brook

The main stem of Sawmill Brook drains a circuitous route, beginning in the residential area just south of Interchange 16 of Route 128 (Pine Street). The watercourse passes north, beneath Route 128, discharging into Bayberry Swamp, where the brook receives runoff from the undeveloped, forested hills to the north of the swamp, which are characterized by a large number of rock outcroppings.

Main Stem of Sawmill Brook

The main stem of Sawmill Brook drains a circuitous route, beginning in the residential area just south of Exit 16 of Route 128 (Pine Street). The watercourse passes north, beneath Route 128, discharging into Bayberry Swamp, where the brook receives runoff from the undeveloped, forested hills to the north of the swamp, which are characterized by a large number of rock outcroppings.

The brook flows easterly through the swamp, roughly paralleling the north side of Route 128, accepting runoff from a small tributary that drains the valley located west of Milestone Hill. The brook then meets another small watercourse carrying the discharge from Millet's Swamp, and then turns northeasterly, draining through Cedar Swamp. The area contributing to Cedar Swamp is forested and largely undeveloped, with steep slopes and a number of outcroppings.

The brook flows northeasterly for approximately 2,400 feet, before turning abruptly eastward, passing beneath Old School Street and School Street into Beaverdam Swamp. The brook then curves southeasterly, then southwesterly around the eastern side of Shingle Place Hill. The surrounding contributory area is largely steep, undeveloped forested hills.

Sawmill Brook then passes beneath Route 128 again, flowing southerly where it meets with Cat Brook at river left, approximately 1,300 feet downstream of Route 128.

Immediately downstream of the confluence with Cat Brook, Sawmill Brook passes through land of the Essex County Club golf course, where the overbanks are grassed to the edge of the watercourse, and also include small man-made impoundments. The brook gently begins an arc to the southwest where it passes Manchester-Essex Regional Middle-High School on river right, and property of the golf course on the left before passing beneath Lincoln Street.

Almost immediately below Lincoln Street, Sawmill Brook is joined by Causeway Brook, and enters an area of significantly increased residential development density, passing between the backyards of numerous residences. Sawmill Brook continues to flow along a gentle arc before flowing westerly at School Street, immediately north of Brook Street. Before this crossing, the river left side of the watercourse is channelized with a stone masonry wall with the adjacent residential structures located near the wall.

Sawmill Brook just upstream of its crossing of School Street near Brook Street.

Downstream of School Street, both sides of the brook are channelized by stone masonry walls. Approximately 425 feet downstream of School Street, the watercourse makes a sharp turn to the left, emptying into Central Pond, which is regulated by the existing tide gate and dam structure at Central Street. Once the flow passes through the structure, it discharges into Manchester Harbor.

Millet Swamp Brook

The area roughly bounded by Old Essex Road, School Street, and Route 128 drains toward Millet Swamp, which is located between these roadways. The edges of the development area include steep forested hills that drop down to residential development along the roadways to the low lying area where the swamp is located.

The stream has a number of crossings at residential roadways, including Blue Heron Lane, The Plains, Millet Lane, and Old Essex Road.

The stream in this area generally has flat topography and is slow-moving due to its low gradient. The swamp outlets to the north, where it joins Sawmill Brook just upstream of Route 128.

Cat Brook

The source of Cat Brook are the undeveloped and forested hills lying south and east of Route 128, extending into Gloucester. Cat Brook begins as two separate watercourses that converge east of Mill Street. The western branch runs generally parallel with Route 128, while the eastern branch flows southwesterly then northeasterly before joining the western branch 700 feet upstream of Mill Street.

Downstream of Mill Street, Cat Brook passes along property of the Essex County Club along river left before discharging into Sawmill Brook.

Causeway Brook

Causeway Brook begins as two separate watercourses that discharge from ponds on the eastern portion of the watershed, one of which is Dexter Pond. The two branches converge south of the MBTA railroad line, flowing westerly through a residential area along Summer Street, where it is briefly channelized, and passing through property of the Essex County Club before discharging beneath Lincoln Street. Causeway Brook discharges into Sawmill Brook just below Lincoln Street.

Causeway Brook downstream of Summer Street, showing the narrow channelized streambed

Culvert at Central Street

The Sawmill Brook culvert under Central Street consists of a seawall, tide gate structure, culvert and stream bed/weirs. Based on a review of documents available from the Town, it appears the tide gate was originally installed in the early 1900's for the purpose of creating a skating pond in the downtown area. This structure provides control for flooding caused by tides and maintains the elevation in Central Pond. The structure currently overtops during extreme storm events. Additionally, the tide gate design obstructs fish passage to upstream segments of Sawmill Brook that are known spawning habitat for Rainbow Smelt.

View of Tide Gate Structure from Harbor

View of Central Street tide gate towards the Harbor

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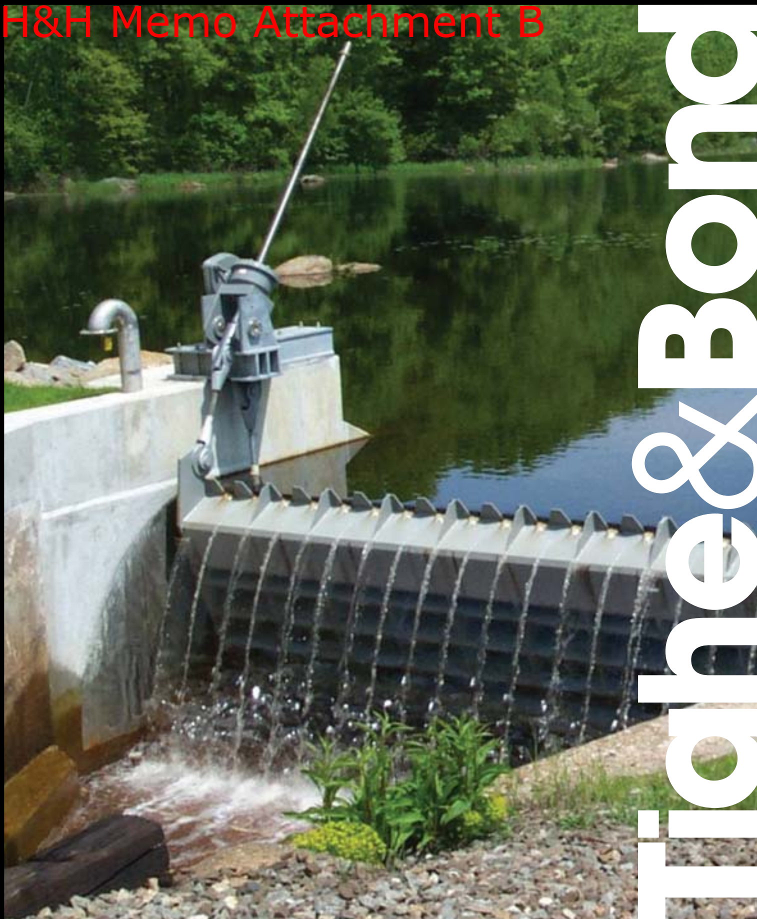
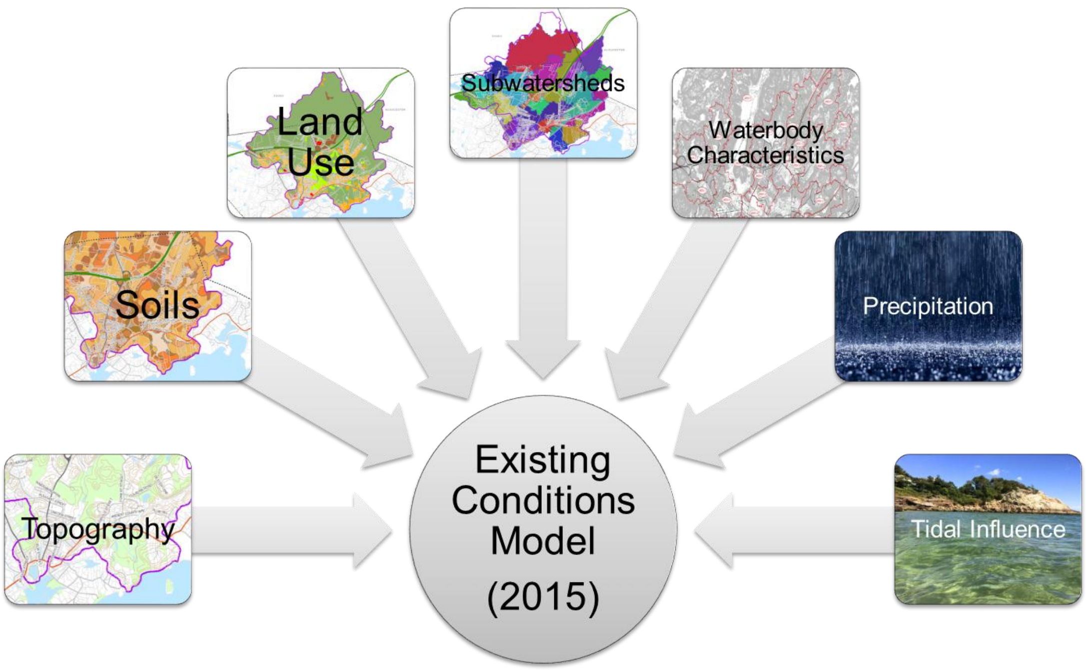


SECTION 2

Section 2
Modeling Existing Conditions

2.1 Overview

As part of the project, Tighe & Bond modeled existing conditions within the Sawmill Brook Watershed. The model considers information about soils, topography, ground cover (impervious cover and land uses), existing wetlands and waterbodies, water travel times, and existing structures that control discharges (e.g. Central Street tide gate, culverts, bridges, etc.). Existing conditions were based on rainfall depths developed by the Cornell University Northeast Regional Climate Center[2] and tidal influences using data from the Flood Insurance Study for Essex County (July 2014). The existing conditions model was calibrated against the largest storm in recent history, the May 2006 (aka "Mother's Day") storm.



2.2 Model Inputs

2.2.1 Watershed Conditions

The watershed contains steep topography in its upper reaches, which flattens out toward the main stem of the watershed as shown in **Figure 2.** Contours were developed using the LiDAR terrain and Digital Elevation Model (DEM) data available on the Massachusetts Geographic Information Systems (GIS) website.

[2] http://precip.eas.cornell.edu/

Soils within the watershed are classified by their Natural Resources Conservation Service (NRCS) Hydrologic Soil Group. Most of the soils within the swampy and steep areas of the watershed are slow draining, while the balance of the soils within the developed portion of the watershed are moderate to moderately well-drained. Please refer to **Figure 3** for the NRCS Hydrologic Soil Group (HSG) classifications of the watershed soils. **Appendix A-1** includes an NRCS Web Soil Survey report that provides further detail on the classifications.

Land uses within the watershed primarily consist of wetlands, forest, open space, and residential areas, along with small areas of industrial and commercial uses. Please refer to **Figure 4** for the distribution of land uses within the watershed and table describing the aggregation of categories from the MassGIS Land Use data for input into the model.

To facilitate the analysis of the stream, Tighe & Bond divided the watershed into 24 subwatershed areas to obtain a better understanding of the timing relationships between the numerous tributaries within the watershed. Please refer to **Figure 5** for the subwatershed mapping. Within each subwatershed, the land cover and underlying hydrologic soils group were evaluated and a lag time was developed in order to estimate the contribution of each subwatershed to Sawmill Brook.

In a complex watershed with a number of tributaries, such as Sawmill Brook, the time it takes various tributaries in the watershed to have peak flow can vary greatly from tributary to tributary depending on a number of factors, such as topography, impervious coverage, soil types and storage areas (reservoirs). Therefore, the timing of the peak flow from the tributaries could be different enough that they do not impact the receiving river simultaneously.

Tighe & Bond utilized available GIS mapping and data to develop the data inputs for the hydrologic analysis. Using the Soil Conservation Service (SCS) methodology in the HydroCAD software package, each subwatershed was routed through downstream subwatersheds and combined as necessary to develop a hydrograph of the main channel flow. The hydrographs were routed through the riverine network all the way to Manchester Harbor.

The weighted runoff curve number (CN) values for each of the subwatersheds were calculated based upon the land uses and hydrologic soil groups within the watershed. The lag time was computed based upon land cover, flow regime and basin topography. Please refer to **Appendix A-2** for the computation worksheets for both the weighted CN value and the lag time for each subwatershed.

2.2.1 Watershed Storage

The hydrologic model accounts for areas of flood storage within the watershed. Typically, these areas of storage can be found behind dams or behind culverts. As part of the hydrologic analysis, Tighe & bond developed stage-storage-discharge curves using Autodesk's Hydraflow for Hydrographs software program. The curves define the relationship between the depth of water and the discharge or outflow for the flood storage areas behind the existing culverts.

Appendix A-3 provides a summary table of the culverts within the watershed. More detail on these culverts can be found in the Tighe & Bond report titled "Manchester-by-the-Sea, Massachusetts, Stream Crossing Evaluation, Sawmill Brook Watershed" dated July 30, 2015. Please refer to **Figure 6** for the culvert locations.

In addition, the following locations in the watershed were modeled as storage areas:

- Pine Street (Pond 1)
- School Street north of Route 128 (Pond 2)
- Atwater Avenue (Pond 3)
- Mill Street (Cat Brook) (Pond 4)
- Lincoln Street (Causeway Brook) (Pond 5)

Please refer to **Appendix A-4** for the stage-storage-discharge computations for the storage areas.

2.2.2 Precipitation

The hydrologic model uses rainfall totals from the Northeast Regional Climate Center (NRCC) at Cornell University to develop the hydrographs. In the recent past, many flood studies historically used the climatic data published by the U.S. Weather Bureau in Publication TP-40, issued in 1961. The NRCC data is a more current data set and incorporates the increase in annual precipitation and storm intensity that has been documented by a number of studies since the 1961 publication of TP-40. **Table 2-1** lists the rainfall depths from a 24-hour duration storm that were used in the model.

Table 2-1
2015 Rainfall Depths for the Sawmill Brook Watershed (24 hour storm)

Frequency Storm	Annual Probability	Rainfall Depth (inches)
25-year	4%	6.16
50-year	2%	7.36
100-year	1%	8.76

This report refers to storm events by their return frequency, such as a 25-year storm, 50-year storm, and 100-year storm. The return frequency is the likelihood, or probability, that a rainfall event (specific to the magnitude and duration) will be equaled or exceeded in any given year. The reference will help the general public better understand the typical probability associated with a storm event. However, it is possible to have multiple 100-year storms in consecutive years, and it is also possible to have 50 years pass without a 25-year storm. Notable storm events for Manchester-by the Sea measured at the Town's Wastewater Treatment Facility include a near 100-year storm event of 8.27 inches recorded on October 20, 1996, and a 25-year storm event of 6.56 inches recorded on May 13, 2006, during the Mother's Day Storm.

Please refer to the Extreme Precipitation Tables in **Appendix B-1** for the completed data set for Manchester-by-the-Sea.

2.2.3 Surge and Tidal Influence

There is a tide gate structure that regulates the mouth of Sawmill Brook at Central Street. The structure normally limits the tidal influence of Manchester Harbor on the Sawmill Brook. Based on the current effective Flood Insurance Study (FIS) for Essex County, Massachusetts, dated July 16, 2014, the tidal stillwater surface elevations (that include storm surge) at the mouth of Sawmill Brook just downstream (ocean side) of Central Street are outlined in **Table 2-2** for existing conditions. Values presented in Table 2-2 are elevations associated with an annual probability (e.g. for the 1% annual probability, there is a 1% annual chance of the high tide influenced by storm surge to reach an elevation of 9.90 feet NAVD88 at the mouth of Sawmill Brook) shown in the

FIS.[3] The Base Flood elevation at this location is 10.6 ft NAVD 88, which includes the stillwater elevation and the effects of wave setup.

Table 2-2
2015 Stillwater Elevations at Central Street

Frequency Storm	Annual Probability	Elevation (NAVD88) (feet)
25-year	4%	9.15
50-year	2%	9.40
100-year	1%	9.90

The values in Table 2-2 were used as starting water surface elevations in the hydraulic (HEC-RAS) model to account for tidal influence and storm surge on Sawmill Brook. Based on the Inundation Risk Model (IRM) outputs for 2015, Sawmill Brook is tidally influenced to the School Street culvert under existing conditions. See Section 3.2.2 for additional detail on the IRM model.

The town is currently in the process of requesting a revision of the July 16, 2014 FEMA FIS based on an August evaluation by the Woods Hole Group. A Letter of Map Revision has been submitted by the Town. The revised 100-year still water level is 9.00 ft NAVD, and the Revised Flood Zone and Base Flood Elevation for the Central Street location is AE 10, one foot lower than the current effective FIRM. As the planning progresses, this information should be taken into consideration.

2.3 Modeling Approach

2.3.1 Hydrologic Modeling

Hydrologic analysis of existing and post-development conditions was carried out by generating a computer model using the HEC-HMS Computer Program developed by the U.S. Army Corps of Engineers at the Hydrologic Engineering Center in Davis, California.

The hydrologic equations used in the computer model are described in the U.S. Army Corps of Engineering publication "Hydrologic Modeling System, HEC-HMS User's Manual, Version 3.5", dated August 2010. The data requirements for the HEC-HMS computer model include the following categories:

1. Soil Cover
2. Ground Cover
3. Ground Slopes
4. Degree, Density and Type of Development
5. Location and extent of wetlands, including swamps and ponds
6. Time of concentration, travel time, lag time
7. Controlled discharge structures, pipes and channel

[3] See Table 11 – Transect Data. Transect 38 was used to represent Manchester Harbor.

The results of the HEC-HMS for existing conditions are included in **Appendix B-2.**

2.3.1 Hydraulic Modeling

Once hydrographs had been developed for the various watersheds, the next step was to build a model using the U.S. Army Corps of Engineers Hydraulic Engineering Center's HEC-RAS software to analyze the resultant water surface elevations. The HEC-RAS model evaluates stream gradient, cross section, and land cover within the channel and overbanks. It also accounts for energy losses through friction, and expansion and contraction at hydraulic structures, such as bridges and culverts.

The geometry of the HEC-RAS model was based upon a digital terrain model extracted from MassGIS LiDAR data, and then extrapolated cross sections from that data. The LiDAR data was supplemented by survey from third-party culvert surveys.

2.4 Model Calibration

In developing the existing conditions model, past storm events were examined to confirm if channel geometries, land use coverages and lag times used in the model can duplicate observations recorded during past rainfall events. Calibration efforts were focused on a historic storm in May 2006. The storm lasted over a 4-day period and dropped nearly 11 inches of rain on the area.

Table 2-3
May 2006 Rainfall Event recorded at Beverly Municipal Airport

Date	Precipitation (inches)
May 13, 2006	4.32
May 14, 2006	4.95
May 15, 2006	1.15
May 16, 2006	0.56
Total	**10.98**

Based on information provided by the NRCC, 11.29 inches of rain over a 4-day period is equivalent to a 100-year storm event, while 4.95 inches of rain in a 24 hour period is equivalent to a 25-year storm event.

Please refer to **Appendix C-1** for the precipitation data from Beverly Municipal Airport.

The May 2006 event was preceded by a wetter than normal weather pattern, which increased the moisture conditions in the ground. Therefore, the weighted runoff curve number (CN) values were adjusted in the calibration model to reflect the higher level of moisture in the soil at the time of the May 2006 rainfall event. The calculations for the CN values appear in **Appendix C-2.**

In order to calibrate the hydrology, observations of flooding elevations reported by the Town during the May 2006 flood event were compared to the elevations calculated by the HEC-HMS model for the storm event.

Please refer to **Table 2-4** for a comparison of observations and model predictions for the May 2006 flood event. The observations for the storm event come from the document titled "Hydrologic Study, Millets Brook and Sawmill Brook Watersheds" (Metcalf & Eddy, February 2008).

Table 2-4
May 2006 Flood Observations Compared to HEC-RAS Model Output

Location	Cross Section Number	Observed Elevation (NAVD 88) (feet)	HEC-RAS Model Prediction (NAVD 88) (feet)
School Street north of Route 128	11191	45.1	43.04
Mill Street at Cat Brook	2359	39.6	38.03

Note: Observed elevations presented in Table 2-4 are from Table 5 in the 2008 Metcalf & Eddy report. The survey from the 2008 report used vertical datum reference NGVD 29 (FT). They have been converted to NAVD 88 in Table 2-4 for consistency. An error was identified in Table 5 of the 2008 Metcalf & Eddy report. Table 5 indicates the observed elevation at School Street north of Route 128 was 48.75 feet (downstream) and 45.8 feet at Old School Street (upstream). To correct this error, the two points were swapped, and Table 2-4 includes the Metcalf & Eddy value for Old School Street, adjusted for NAVD88.

2.5 Model Output

After calibrating the model, existing conditions were simulated for the 25-year, 50-year and 100-year storm events. **Appendix D** provides the data outputs from the existing conditions modeling runs. To assist in interpretation of the results Table 2-5 provides a cross reference for each culverts and bridges in the model including identifying culvert number from the Task 2 culvert inventory, and their cross section number in the HEC-RAS model. Cross section numbering is based upon distance from the mouth of Sawmill Brook at Manchester Harbor for the main stem of Sawmill Brook, and from the distance with the confluence of the main stem of Sawmill Brook for the tributaries. **Figure 7** shows the existing conditions model results, where culvert overtopping may occur.

For the 2015 25-year storm, the existing conditions models indicate that 48% of the culverts overtop the roadway. For the 50-year storm, this number increases to 52%, and with a 100-year storm, 59% of culverts overtop.

Comparing the model existing conditions to the historic experience of culvert overtopping gives the reader an idea of where the model may be conservative. The model is consistently predicting the areas of historic flooding from the intersection of Causeway Brook to the Harbor, but may be conservative for culverts along Route 128 (culverts 33 and 35) and in the area of Old School Street at the Cedar Swamp, and Conservation Area on Winchester Drive. There are additional areas outside of Sawmill Brook that flood, so it is important to realize the limitations of the model extent and accuracy. The model can continue to be refined with observed flood elevations. It is an excellent screening tool to evaluate the impact of future flood conditions as discussed in Section 4 and the combined effect of flood mitigation projects, discussed in Section 5.

Table 2-6
Cross Reference for Hydraulic Structure Identification in HEC-RAS Model

Stream	Culvert Inventory Identification Number	Street Crossing	HEC-RAS Section Number
Sawmill Brook	25	Central Street	199
	23	School Street	1629
	22	Norwood Avenue	2653
	17	Lincoln Street	3686
	16	Golf Course Driveway	5192
	27	Mill Street	7533.5
	26	Route 128	7686
	36	Route 128 Ramp	8131.5
	4	Atwater Avenue	9168
	3	School Street	11161
	2	Old School Street	11479.5
	5	Old Essex Road	13499
	34	Route 128	14218
	31, 33	Route 128	15106
	32, 35	Route 128	16328
	28, 29	Route 128	17648
Causeway Brook	18	Lincoln Street	378
	19	Golf Course Driveway	1280
	20	Summer Street	1757
Cat Brook	11	Mill Street	1869
Millet Brook	12	Millet Lane	1777
	13	The Plains	1570
	15	Blue Heron Lane	1111

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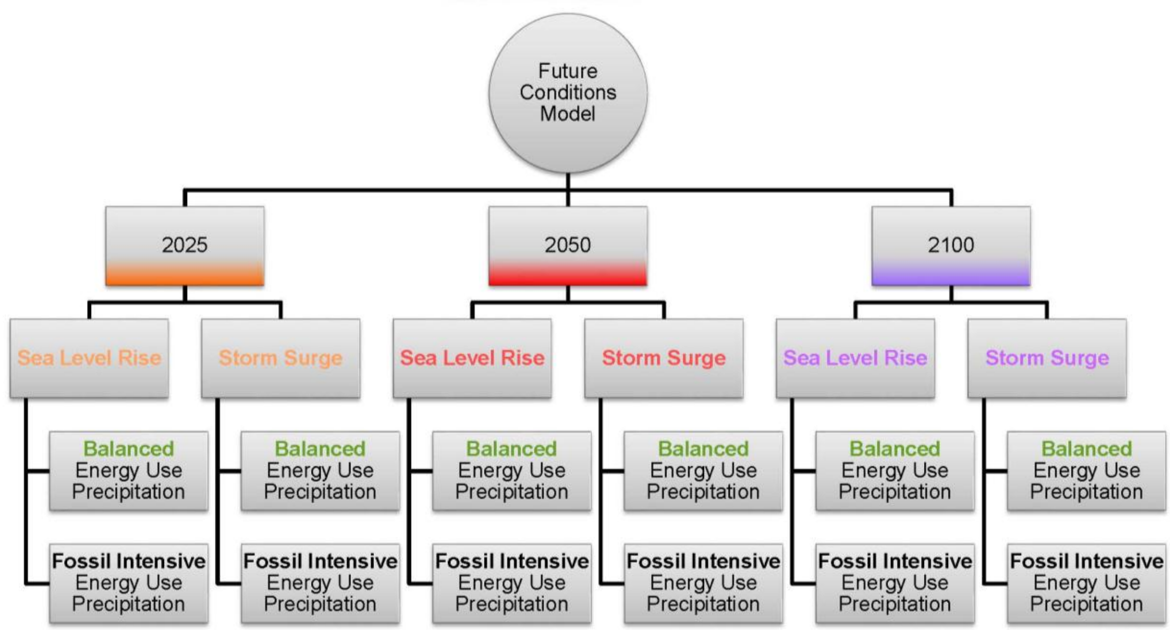
SECTION 3

Section 3
Modeling Future Conditions

3.1 Overview

As part of the project, future flooding conditions within the Town were projected as a result of anticipated climate change and sea level rise at three different points in the future: 2025, 2050 and 2100. Data on climate change was obtained from two sources. Future conditions precipitation relied upon the Oyster River Culvert (UNH, 2010) analysis, while the future conditions sea level utilized projections along the Manchester-by-the Sea coastline prepared by Kiel Schmid (GeoScience, 2015).



3.2 Inputs for Future Conditions Model

3.2.1 Precipitation

The Oyster River Culvert Analysis University of New Hampshire (2010) was utilized to project precipitation depths for future conditions. The Oyster River Culvert Analysis extreme precipitation model was developed based upon recent peer-reviewed studies for statistical analysis of climate change effects. The model focuses on fall precipitation events (September, October, November) since 25-year events for this time period were consistently greater than events for late spring (April, May, June)

The Oyster River watershed is located in Durham, New Hampshire, approximately 60 miles north of Manchester-by-the-Sea along the New Hampshire coast. The two areas have a similar climate and elevation, and therefore would experience similar precipitation patterns.

The rate of increase in future precipitation events is anticipated to be dependent upon the use of fossil fuels and the corresponding impacts on greenhouse gases. If a transition to a more balanced use of renewable and fossil fuel energy sources is used, the expectation is that the rate of increase in precipitation would be less than it would if fossil fuels continue to be a primary source of energy.

The Oyster River study model predicts a range of possible climate change outcomes by considering two peer-reviewed greenhouse gas emission scenarios [4]:

1. One scenario assumes a "balanced" global energy mix; i.e. an equal ratio of fossil fuel use to less greenhouse gas intensive sources of energy. This balanced scenario can be viewed as the more optimistic view of climate change's potential impacts in which the atmosphere has approximately 700 ppm of carbon dioxide equivalents by the year 2100.

2. The second scenario assumes a "fossil intensive" global energy mix; i.e. fossil fuels continue to be the primary fuel source. The fossil intensive scenario is the more pessimistic view of climate change's potential impacts in which the atmosphere has approximately 970 ppm of carbon dioxide equivalents by the year 2100.

The data in the Oyster River Culvert Analysis was utilized to project future precipitation in 2025, 2050, and 2100 for the balanced and fossil intensive scenarios, with the results shown in **Tables 3-1a** and **3-1b**. Data points from the 1964 U.S. Weather Bureau, the 2015 NRCC data, and the mid-century (2050) Oyster River Study precipitation estimates were plotted, and a logarithmic trend line was used to establish data points for balanced and fossil intensive energy use conditions in 2025 and 2100.

Table 3-1a
"Balanced Energy Use" Rainfall Depths for the Sawmill Brook Watershed
(inches, 24-hour storm)

Frequency Storm	2025	2050	2100
25-year	6.36	6.86	7.84
50-year	7.42	7.58	7.88
100-year	8.85	9.31	10.69

Table 3-1b
"Fossil Intensive Energy Use" Rainfall Depths for the Sawmill Brook Watershed
(inches, 24-hour storm)

Frequency Storm	2025	2050	2100
25-year	6.77	8.35	11.39
50-year	8.19	10.34	14.48
100-year	10.82	12.58	16.82

[4] Intergovernmental Panel on Climate Change's (IPCC) 4th Report developed in 2007

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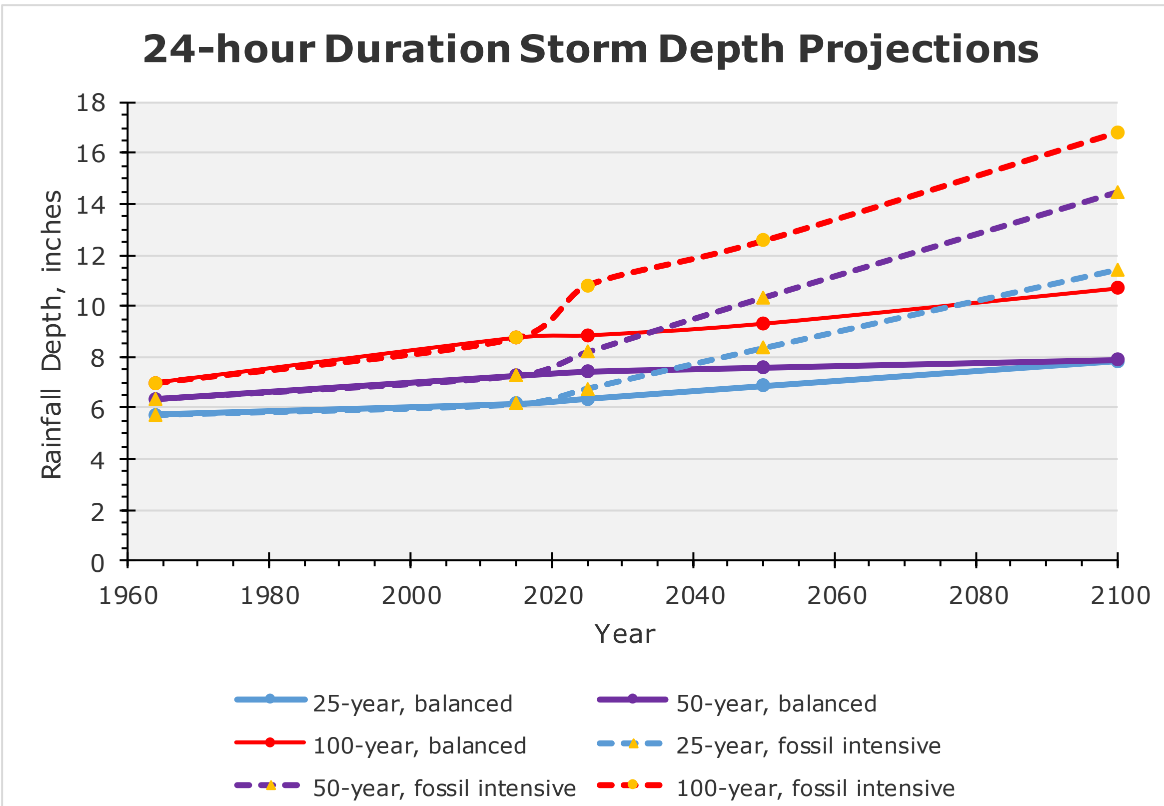
Chart 3-1 offers a graphic representation of the changing rainfall depths for a 24-hour duration storm over time, beginning with the U.S. Weather Bureau Technical Paper-40 data from 1964, through the 2015 Northeast Regional Climate Center data, and also the balanced and fossil intensive energy use projections for 2025, 2050, and 2100. Please refer to **Appendix C-3** for the calculations of the precipitation values in 2025, 2050 and 2100.

Chart 3-1
Precipitation Depths Over Time, 24-hour Duration Storm



3.2.2 Coastal Climate Change Model

Potential sea level rise and future storm surge predictions for Manchester-by–the-Sea were obtained from the Inundation Risk Model (IRM). The IRM model was developed by Keil Schmidt of Geoscience Consultants in 2015 for the Salem Sound Coast Watch communities in Northeast Massachusetts, including Manchester-by-the-Sea. Tighe & Bond reviewed a number of coastal models with the Town and the Town's Coastal Resilience Advisory Group (CRAG) and elected to use the IRM model because of its balance of simplicity and detail. More information on the model selection may be found in a Tighe & Bond Technical Memorandum "Potential Climate Change Impacts to Manchester-by-the-Sea", September 30, 2015. Tighe & Bond worked with the model developer to refine data specific for Manchester-by-the-Sea.

The IRM is an expanded version of the National Oceanic and Atmospheric Administration (NOAA) Sea Level Rise (SLR) viewer, which considers present and future inundation from SLR at mean higher high water (MHHW), shallow coastal flooding, Category 1 hurricanes and stillwater annual storm surge (including coastal storms other than hurricanes, i.e. Nor'easters). The goal of the model is to provide easily understandable

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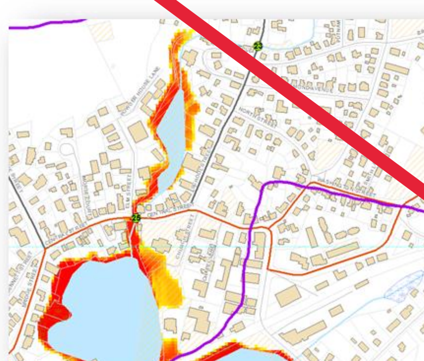
and self-contained information for decision makers and citizens that incorporates a probabilistic handling of the uncertainties involved in documenting future coastal hazards.

Model outputs are shown as risk of inundation presented in percent risk of occurrence ranging from 1% highly unlikely to 99% certain risk. The model outputs do not show water levels or depth of inundation. Data sets include sea level rise at mean high high water, shallow coastal flooding, Category 1 hurricanes and still-water annual storm surge for selected timeframes (2015, 2025, 2050 and 2100). The output, description of risk and data sources are included in **Table 3-2.**

Table 3-2
IRM Model Outputs, Descriptions and Data Sources

Output	Description of Risk	Data Sources
Sea Level Change	Level is mean higher high water (MHHW). Risk describes chance of being inundated at least once per day.	Sea Level Change NOAA curves are source for future water levels.
Shallow Coastal Flooding	Risk describes chance of area being flooded several times a year, where inundation becomes a deterrent to development.	
Storm Surge	Risk describes the chance of an area being inundated once a year from coastal storms other than hurricanes (i.e. Nor'easters).	Historic still water surge data (Boston gauge) is used to define surge height.
Hurricane/ Category 1	Risk describes chance of area being inundated if a Category 1 hurricane is predicted to strike in the area. Rare occurrence.	Data from SLOSH model defines hurricane surge height for grid cells.

Keil Schmidt of Geoscience Consultants provided elevation values for use as model inputs to the HEC RAS software for future coastal tailwater conditions. The image on the left, below, shows the output of all probability values for areas impacted by sea level rise for a particular time period, from 1% in dark green as the least likely to occur to 99% in red as the most likely to occur. The right image shows the area covered by the 50 percent probability output, defined by the IRM author "flooding that is as likely to occur as not". Elevations provided by Keil Schmidt are based on the 50 percent output.

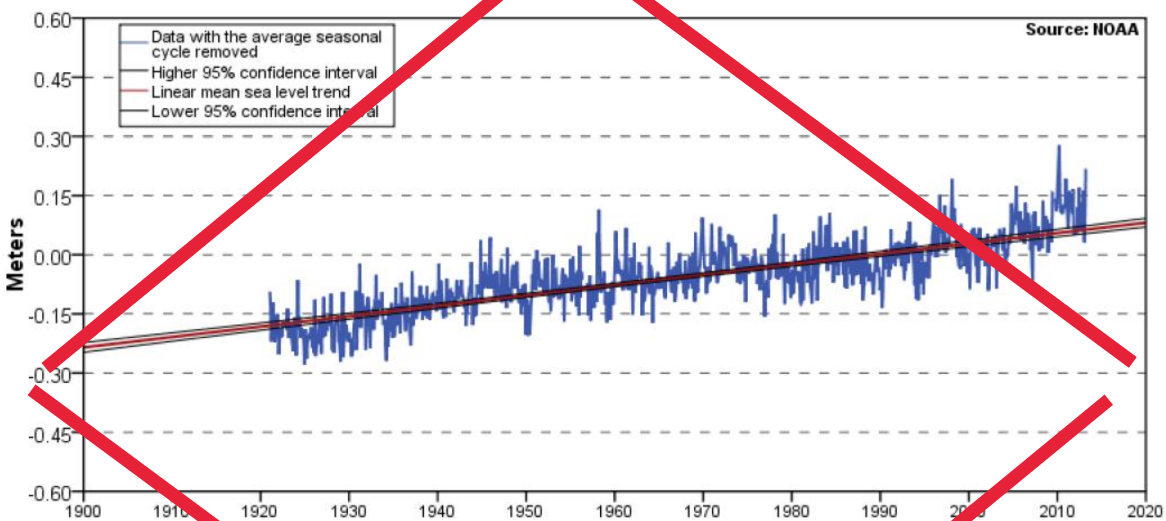


3.2.3 Sea Level Rise

Climate scientists are predicting a rise in sea level caused by a change in the volume of the world's oceans due to temperature increase, deglaciation (uncovering of glaciated land because of melting of the glacier), and ice melt. It is anticipated that as a result of sea level rise, the tidal influence of Manchester Harbor will exert a greater effect than it does today, and the boundary of tidal influence will shift further up Sawmill Brook.

NOAA has documented that the average sea level has been slowly increasing in Boston Harbor, and has increased by approximately 2 millimeters on average per year since 1920, for a cumulative increase of 0.67 feet (**Chart 3-2**) to the present.

Chart 3-2
Observed Mean Sea Level, Boston, MA
Source: NOAA



Keil Schmidt of Geoscience Consultants extracted the tidal elevations just downstream of the existing tide gate from the 50% probability of the IRM MHHW model output for sea level rise in 2025, 2050 and 2100 (**Table 3-3**). These elevations were utilized to evaluate tailwater impacts on the watershed flood model due only to sea level rise. The sea level rise flood elevations would impact affected properties on a daily basis, likely twice each day corresponding to the high tides.

Table 3-3
IRM Mean High High Water (Sea Level Rise) Tailwater Conditions for HEC-RAS Modeling
50% probability, approximate location 42° 34' 30.6664" N, 70° 46' 22.4346" W

Year	MHHW (Sea Level Rise) Feet Above Sea Level (NAVD88)
2025	5.1
2050	5.8
2100	8.0

3.2.4 Storm Surge Influence

Keil Schmidt of Geoscience Consultants provided elevation data interpreted from the 50% probability contours of IRM model just outside of the existing tide gate for annual stillwater flood scenarios, which include annual storm surge, as the governing elevation for the tailwater impact of coastal flooding. The annual stillwater scenarios were used because the stillwater methodology is consistent with what FEMA uses for determining backwater for riverine analyses. The annual flood elevation would impact affected properties on an annual basis.

Table 3-4 shows tidal elevations extracted from the 50% probability of the IRM stillwater output for storm surge in 2025, 2050 and 2100. It is interesting to note that these model outputs bracket the 25-, 50- and 100-year FIRM stillwater elevations presented in Table 2-2.

Table 3-4
IRM Mean Storm Surge Tailwater Conditions for HEC-RAS Modeling
50% probability, approximate location 42° 34' 30.6664" N, 70° 46' 22.4346" W

Year	Annual Stillwater Storm Surge Feet Above Sea Level (NAVD88)
2025	8.2
2050	8.9
2100	11.1

3.3 Future Conditions Modeling Approach

3.3.1 Hydrology

The rainfall depths presented in Section 3.2.1 were entered into the HEC-HMS model of the watershed to determine flow rates (discharge) along the river. The results of the HEC-HMS under future conditions is included in **Appendix B-3**. **Table 3-5** summarizes the discharge at Central Street comparing balanced energy use (A1b) and fossil intensive use (A1fi) greenhouse gas emissions scenarios as described previously in Section 3.2.1. for present and future time periods. Table 3-5 illustrates that the flow rates increase dramatically under the fossil intensive uses and by 2100, under the fossil intensive scenario, flow rates will be nearly 2.5 times greater than they are today

Table 3-5
Summary of Flow Rates (cubic feet per second) at Central Street

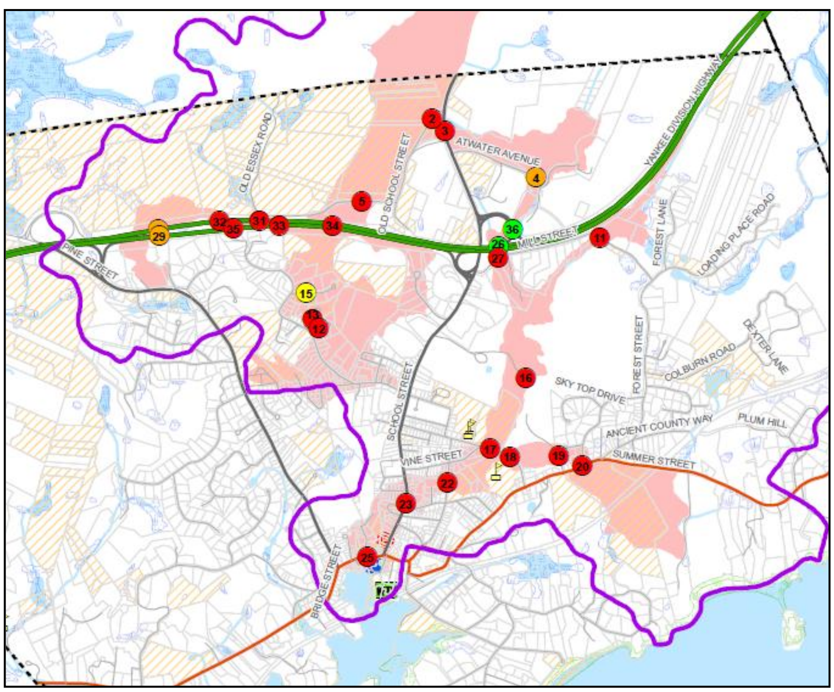
Frequency (years)	2015	2025		2050		2100	
		Bal.	Intensive	Bal.	Intensive	Bal.	Intensive
25	1,437	1,513	1,674	1,706	2,261	2,073	3,437
50	1,897	1,919	2,202	1,978	3,039	2,088	4,642
100	2,427	2,450	3,222	2,630	3,868	3,174	5,924

3.3.2 Future Conditions Hydraulics

The riverine flow data obtained from the hydrologic analysis was entered and combined with two different tailwater elevations (storm surge and sea level rise) to model the watershed under future climate change scenarios in 2025, 2050, and 2100 for the balanced and fossil intensive energy use precipitation projections. As anticipated, the floodplain expands considerably, especially under the fossil intensive energy use scenarios. HEC-RAS model data for future conditions appears in **Appendix D**.

3.4 Impact on Existing Infrastructure

Based upon the results of the HEC-RAS model, the impact on the existing culverts and bridges in the watershed was assessed based on the 50% probability for both stillwater (annual storm surge) and sea level rise. By 2100 almost all of the culverts in the watershed will be overtopped for storms more frequent than the 100-year event due to either tailwater condition (see inset below). **Table 3-6** shows where, when and how culverts in the Sawmill Watershed will be impacted with climate change conditions. For example, using the Balanced Energy Use projection, the culvert at Mill Street on Sawmill Brook will overtop under the Balanced Energy Use in the years 2025 and 2050 during a 50-year storm; and under both Balanced and Fossil Intense Energy Use, it will overtop in the year 2100 during a 25-year storm. Overtopping results with sea level rise tailwater conditions alone versus storm surge conditions does have overall lower surface elevations. For project specific applications, the data provided in Appendix D should be referenced.



Shown above are culverts that will overtop during specific flood events in the year 2100 with a fossil intensive precipitation scenario and storm surge. Culverts shown in red will overtop during a 25 year storm, orange will over top during a 50 year storm, yellow will overtop during a 100 year event and culverts in green will not overtop even with a 100 year storm event. Areas of surficial flooding are shown in pink.

Table 3-6
Storm Frequency at which Hydraulic Structures Overtop-
Storm Surge or Sea Level Rise

Stream	Culvert Crossing		Balanced Energy Use			Fossil Intense Energy Use		
	Location	Number	2025	2050	2100	2025	2050	2100
Sawmill Brook	Central Street	25	25-year	25-year	25-year	25-year	25-year	25-year
	School Street	23	25-year	25-year	25-year	25-year	25-year	25-year
	Norwood Avenue	22	25-year	25-year	25-year	25-year	25-year	25-year
	Lincoln Street	17	25-year	25-year	25-year	25-year	25-year	25-year
	Golf Course Driveway	16	50-year	50-year	25-year	50-year	25-year	25-year
	Mill Street	27	50-year	50-year	25-year	50-year	25-year	25-year
	Route 128	26	>100-year	>100-year	>100-year	>100-year	>100-year	>100-year
	Route 128 Ramp	36	>100-year	>100-year	>100-year	>100-year	>100-year	>100-year
	Atwater Avenue	4	>100-year	>100-year	>100-year	>100-year	100-year	50-year
	School Street	3	>100-year	>100-year	100-year	100-year	100-year	25-year
	Old School Street	2	25-year	25-year	25-year	25-year	25-year	25-year
	Old Essex Road	5	25-year	25-year	25-year	25-year	25-year	25-year
	Route 128	34	100-year	100-year	100-year	50-year	25-year	25-year
	Route 128	31, 33	25-year	25-year	25-year	25-year	25-year	25-year
	Route 128	32, 35	>100-year	100-year	100-year	100-year	50-year	25-year
	Route 128	28, 29	>100-year	>100-year	>100-year	>100-year	>100-year	50-year
Causeway Brook	Lincoln Street	18	25-year	25-year	25-year	25-year	25-year	25-year
	Golf Course Driveway	19	25-year	25-year	25-year	25-year	25-year	25-year
	Summer Street	20	25-year	25-year	25-year	25-year	25-year	25-year
Cat Brook	Mill Street	11	>100-year	>100-year	100-year	100-year	50-year	25-year
Millet Brook	Millet Lane	12	25-year	25-year	25-year	25-year	25-year	25-year
	The Plains	13	>100-year	>100-year	>100-year	>100-year	>100-year	25-year
	Blue Heron Lane	15	>100-year	>100-year	>100-year	>100-year	>100-year	100-year

Precipitation Storm Event Frequency

25-year	dark red
50-year	orange
100-year	light yellow
>100-year	light green

Another way of examining the model output is to look at flood profiles created by the HEC RAS model. The profiles across the Sawmill Brook Watershed are shown in Chart 3-3 for existing conditions. The chart shows the graphic output directly from the HEC-RAS model including the elevation profile of the land surface, the water table elevation resulting from a 100 year storm event in 2015, and the location of the 27 culverts that were included in the model. Locations are highlighted for Central Street, School Street, Norwood Avenue and Lincoln Street where culvert projects are proposed. The County Golf Course and Old School Street are highlighted where flood storage projects are proposed. These mitigation projects are further described in Section 4- Modeling Improvements for Flood Mitigation.

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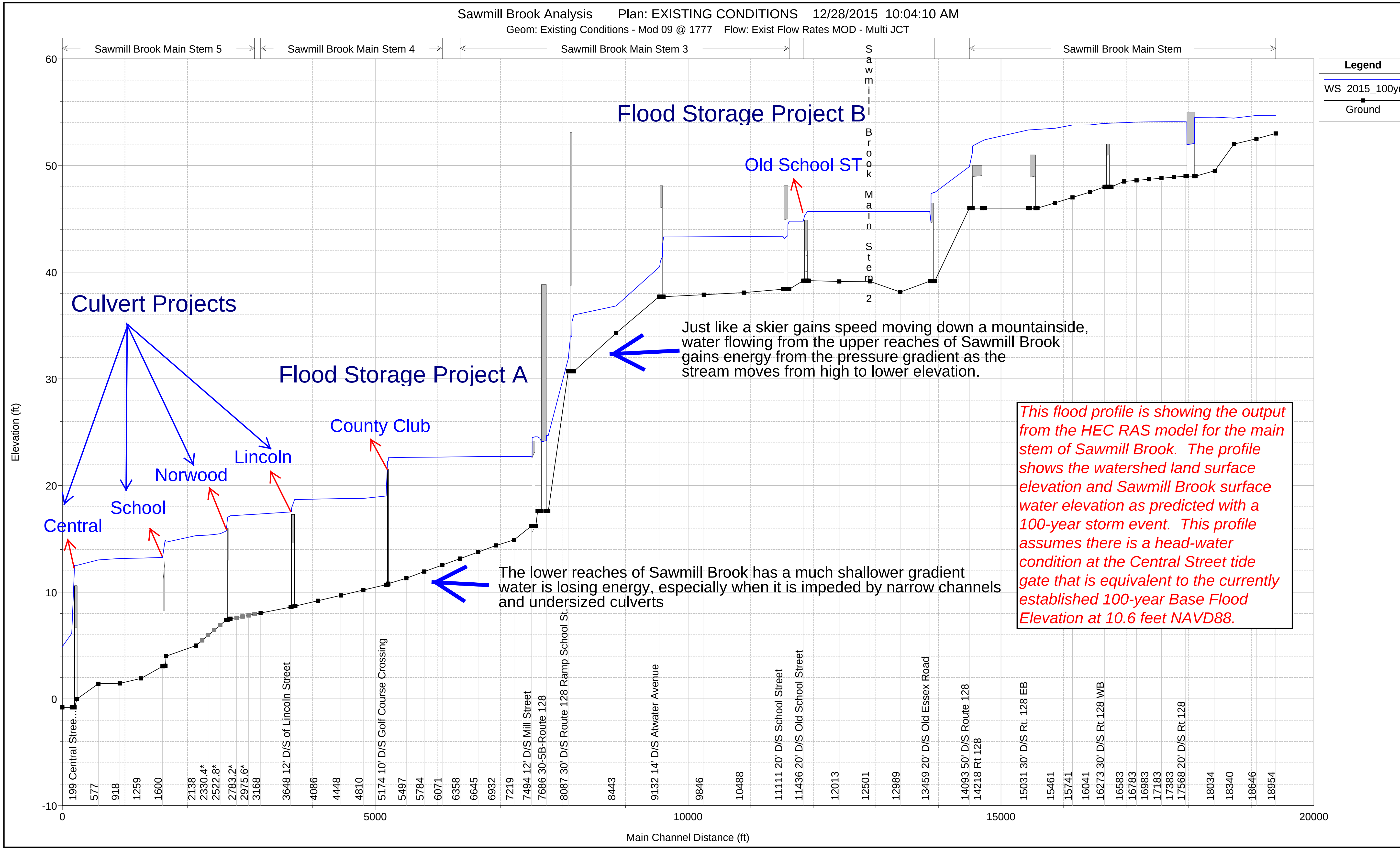
CHART 3-3 FLOOD PROFILE FOR EXISTING CONDITIONS SAWMILL BROOK MAIN STEM 2015 100-YEAR FLOOD



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SECTION 4

Section 4 Modeling Improvements for Flood Mitigation

The watershed modeling was expanded to look at potential improvements to flooding by relieving channel restrictions at Central Street, providing additional flood storage north of Route 128, managing flooding through culvert rightsizing, and utilizing green infrastructure best management practices at a variety of pre-screened locations. Modeling for the flood mitigation scenarios was based on conditions in the year 2050, assuming precipitation based on a balanced energy use and the 50 year storm event. This section provides a description of the specific flood mitigation projects considered, the model iteration process to evaluate the impact of different project combinations, and the resulting improvements.

4.1 Central Street Culvert and Tide Gate

The Town of Manchester-by-the-Sea has recognized that 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. This location has been identified for many years as a source of flooding upstream due to this hydraulic restriction, particularly during large rainfall events. The elevated water behind the tide gate is also putting pressure on the seawall at Central Street, causing seepage though the rock voids in the wall.

Reviewing the flood elevations and profiles from Chart 3-3 in the previous section, the flood elevations change significantly across the Central Street Bridge and tide gate area, indicating that this location is a significant bottleneck along the channel. The structures were observed by Tighe & Bond in July 2015, and improvements were identified to address safety, drainage and fish passage.

Looking upstream (low tide) toward tide gate and Central St culvert

The options for the Central Street crossing and tide gate are presented in Table 4-1, while stream restoration options are presented in Table 4-2.

Table 4-1
Sawmill Brook Central Street Design Concept Alternatives

Option	Design Element
Option 1	Remove tide gate Rehabilitate existing bridge/culvert/seawall structure Restore Sawmill Brook at Central Pond
Option 2	Remove tide gate Replace and widen culvert /restore seawall and guard rail Restore Sawmill Brook at Central Pond

Table 4-2
Sawmill Brook Stream Restoration and Flood Stage Alternatives

Design Element	Purpose
Widen bottleneck	Improve hydraulic flow through system, decrease upstream impounding
Augment instream vegetation	Stabilize sediment, reduce downstream deposition, provide wildlife habitat
Build up island and augment instream vegetation	Stabilize sediment, reduce downstream deposition, provide wildlife habitat
Connect islands and augment instream vegetation	Direct stream flow into main channel, provide wildlife habitat
Dredge central channel	Improve hydraulics, improve fish passage
Dredge sediment from central pond	Remove fines and sources of nutrients, increase flood storage
Maintain shallow channel	Minimize sediment management requirements, accommodate spawning areas
Build up rock outcrop at mouth	Increase aeration, improve fish passage, naturalize transition between harbor and stream
Create rock riffles	Improve fisheries/spawning habitat
Stabilize banks	Minimize sedimentation of stream channel and harbor, protect adjacent land uses
Flood bank storage	Improve flood storage capacity, reduce downstream flooding severity

Water seepage (flow) coming from the stone culvert side wall

The HEC-RAS model was used to evaluate Option 2, removal of the tide gate, and widening the current dimensions of the Central Street culvert to maximize the cross sectional area available for flow. Stream restoration options will be considered in the conceptual design phase of the project.

Tables 4-3 and 4-4 summarize modeling runs for widening the culvert and removing the tide gate. The tables compare combinations of flooding and emissions scenarios for the years 2015-2100 to evaluate the range of conditions under which flooding would be mitigated. The results indicate that the improvements will substantially improve capacity for most storm events, even with sea level rise, however with the addition of storm surge, the roadway would be overtopped after the year 2050. Although water elevations are lowered significantly, improvements are only achieved near term under 25-year and 50-year storm events. In addition, the modeling runs with only Central Street improvements lowered water elevations in the stream reach immediately upgradient from Central Street, but did not alleviate flooding problems further upstream. Culverts continued to overtop for School Street, Norwood Street, Lincoln and other locations upstream.

Removal of the tide gate has two additional benefits beyond flood mitigation. The gate is 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. Removal of the tide gate will significantly improve the ability of fish to migrate upstream, particularly Rainbow Smelt, who cannot jump up the existing weirs.

In addition, removal of the tide gate will alleviate the hydraulic pressure on the Central Street Seawall. With the tide gate in place, the seawall is technically define by the state as dam because the water impounded behind the wall exceeds five feet in height at a 100-year design storm. With removal of the tide gate, the technical definition will no longer apply, along with any jurisdictional responsibilities.

Table 4-3
Overtopping at Central Street with Tide Gate Removed and Culvert widened, Balanced Energy Use with Sea Level Rise

Year	25 yr		50 yr		100 yr	
	Exist.	**Prop.**	**Exist.**	**Prop.**	**Exist.**	**Prop.**
2015	Overtops	Capacity	Overtops	Capacity	Overtops	Overtops
2025	Overtops	Capacity	Overtops	Capacity	Overtops	Overtops
2050	Overtops	Capacity	Overtops	Capacity	Overtops	Overtops
2100	Overtops	Capacity	Overtops	Capacity	Overtops	Overtops

Table 4-4
Overtopping at Central Street with Tide Gate Removed and Culvert widened, Balanced Energy Use with Storm Surge

Year	25 yr		50 yr		100 yr	
	Exist.	**Prop.**	**Exist.**	**Prop.**	**Exist.**	**Prop.**
2015	Overtops	Capacity	Overtops	Capacity	Overtops	Overtops
2025	Overtops	Capacity	Overtops	Overtops	Overtops	Overtops
2050	Overtops	Overtops	Overtops	Overtops	Overtops	Overtops
2100	Overtops	Overtops	Overtops	Overtops	Overtops	Overtops

Enlarging the culvert and eliminating the tide gate would result in significant reductions in water surface elevation. Although the water surface elevation would drop in comparison with existing conditions if the proposed improvements were undertaken, the roadway would still eventually overtop because the surge elevation exceeds the roadway centerline elevation for 2050 and beyond. When only sea level rise is taken into account, the improvements have a larger impact on reducing water surface elevations.

Given the existing constraints in the area of the existing roadway elevation and development on both banks of the river, options to improve the situation at Central Street will need to included additional upstream culvert improvements and flood storage. Reducing storm surge might be achieved with some sort of hurricane barrier. A hurricane barrier might be situated at the mouth of Manchester Harbor.

4.2 Increasing Flood Storage

Four locations were evaluated for potential flood storage:

- Old School Street north of 128;
- Municipal land near Knights Circle;
- Land abutting the Coach Field Playground, and
- The Essex County Golf Course.

Modeling involved adjustment of model parameters at the project site to simulate potential flood attenuation. The model was run to determine the change in stream discharge for a 50-year storm, in the year 2050 using a balance energy emission scenario.

The land next to Coach Field Playground consists of municipally owned area abutting Sawmill Brook upstream of Norwood Avenue. This area is lightly vegetated (with some large diameter trees) with opportunity to create flood storage on the bank of the stream. A project would include re-grading the area and installing natural plantings while leaving the large diameter trees. Approximately 13,000 square feet of area could potentially be utilized.

Municipal land upstream of the School Street culvert, across from Knight's Circle, includes a potential opportunity to create a flood storage area to the left side of the Sawmill Brook looking upstream from School Street culvert. The project would include re-grading the bank area to allow for storage of flood waters by increasing the floodplain. It was assumed that the area on the north bank would be excavated beginning at 12 inches above the bottom of the stream in order to maintain a low-flow channel.

Tighe & Bond modeled these potential flood storage opportunities by modifying the corresponding cross sections in the HEC-RAS model. Because these two areas manage such small areas of floodwater compared to the overall Sawmill Brook watershed, they did not produce any discernable benefit. Two sites for flood storage, Old School Street and the Essex County Golf Course, produced discernable benefits and are described in more detail below.

4.2.1 Upstream of Old School Street

There is a significant area of storage upstream of Old School Street north of Route 128. If the road centerline of Old School Street were raised, additional stormwater could be impounded behind it. 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 conceptual design included replacing the three existing culverts with two reinforced concrete box culverts with natural bottoms and one reinforced concrete pipe culvert. The road elevation of Old School Street would be raised by approximately 4 feet to elevation 46 feet NAVD88.

In order to model the raising of Old School Street, the stage-storage-discharge table at Old School Street was updated to account for the additional flow attenuation. The revised tabular data was then entered the into the HEC-HMS model to measure the flood attenuation that would result along the watercourse with the proposed modification.

Inlet of one of Old School Street Culverts

To assess the benefit of increasing storage behind Old School Street, flow rates on the main stem of Sawmill Brook downstream of Old School Street were modeled for a 50-year storm event in the year 2050, utilizing a balanced energy emission scenario. Flows were entered into the HEC-RAS model to determine the resultant water surface elevations downstream and to demonstrate the impact of the proposed additional flood attenuation capacity at select locations on the river..

Increasing the storage behind Old School Street reduces the flow rates downstream and reduces the frequency and amount of instances where culverts overtop downstream. The flood reduction benefit is limited to a stream reach of approximately one mile. The flood storage project has the potential to reduce flows by 16% to 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.

4.2.2 Golf Course

The golf course was selected based on opportunities to manage flooding on both municipally owned or privately owned portions of the Essex County Club. Projects would include increasing flood storage areas abutting the stream channel by generally increasing the cross sectional area of the waterbody. In addition, restoring the channel to a more natural orientation would improve aesthetics. Improvements to this location would require coordination with the golf course and considerations for public safety.

Essex County Club flood plain area

Tighe & Bond looked at increasing flood storage on the course by re-grading an area abutting the stream channel to create approximately 6.6 acre-feet of storage. This would alter approximately 13.8 acres on the golf course property.

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.

4.3 Culvert Rightsizing

Flooding can be managed by changing the dimensions of (i.e. "rightsizing") culverts throughout the watershed. Using the HEC-RAS model, Tighe & Bond evaluated culverts throughout Manchester-by-the-Sea to identify the preliminary impact on downstream and upstream flooding. Based on our evaluation, increasing the cross-sectional area of the following culverts has the most benefit to reducing overall watershed flooding:

- Culvert 23, School Street
- Culvert 22, Norwood Avenue
- Culvert 17, Lincoln Street

Inlet of School Street Culvert

4.3.1 Culvert Improvements at School Street

Several design concepts were evaluated for culvert improvements at School Street to maximize flood mitigation. Additional HEC-RAS modeling runs were performed using a 50-year future design storm for the year 2050 under a balanced energy precipitation scenario, incorporating parameters for several sizes of culverts, and channel widening. After carefully evaluating the physical environment, site constraints and HEC-RAS modeling results, the following project elements were proposed to re-size the culvert at School Street to accommodate existing and future flood conditions.

- Remove the existing School Street culvert and replace with 6.6 foot tall by 16 foot wide box culvert
- 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.

Outlet of School Street Culvert

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, widening and lowering of limited segments of Sawmill Brook, in addition to 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%. It should be noted that some channel improvements are necessary for culvert widening.

4.3.2 Culvert Improvements at Norwood Avenue

Several design concepts were evaluated for culvert improvements at Norwood Avenue to maximize flood mitigation. Additional HEC-RAS modeling runs were performed using a 50-year future design storm for the year 2050 under a balanced energy precipitation scenario, incorporating parameters for several sizes of culverts, and channel widening. After carefully evaluating the physical environment, site constraints and HEC-RAS modeling, the following project elements were proposed to re-size the culvert at Norwood Avenue to accommodate existing and future flood conditions.

- 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

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, 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 before School Street and approximately 13% downstream of School Street. As noted for the School Street culvert, some channel improvements are necessary for culvert widening.

Outlet of Norwood Avenue Culvert

4.3.3 Culvert Improvements at Lincoln Street

Several design concepts were evaluated for culvert improvements at Lincoln Street to maximize flood mitigation. Additional HEC-RAS modeling runs were performed using a 50-year future design storm for the year 2050 under a balanced energy precipitation scenario, incorporating parameters for several sizes of culverts. After carefully evaluating the physical environment, site constraints and HEC-RAS modeling, the following project elements were proposed to re-size the culvert at Lincoln Street to accommodate the 50-year storm for existing and future flood conditions.

- 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.

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.

Stone Arch Construction of the Lincoln Street Culvert

4.4 Green Infrastructure

Tighe & Bond conducted an assessment of the potential benefit of installation of green infrastructure practices also known as Low Impact Development Best Management Practices (LID BMP's). For a complete description of the Green Infrastructure BMP Analysis, please refer to the Tighe & Bond Report, "Opportunities for Flood Mitigation within Sawmill Brook", July 30, 2015. As described in this report, opportunities to install green infrastructure throughout the watershed included the following locations:

- Parking lot abutting the Town Fire Station at 12 School Street;
- Parking lot for the Coach Field Playground;
- High School; and
- Elementary School.

Green infrastructure practices manage small areas of runoff compared to the overall Sawmill Brook watershed. Tighe & Bond evaluated these locations as part of the HEC RAS modeling. For example, for the Elementary School, we assumed that all of the existing pavement would be converted to permeable pavement, approximately 39,000 square feet. The curve number calculation for this location was adjusted for the land use coverage assuming that the area would be converted to permeable pavement. The runoff curve number dropped from 74 to 73, which is not significant. Additional model runs were performed to account for the reduced runoff curve number. We found that, under all modeling conditions, there was only a slight reduction (generally 2 cfs) in the flow rate downstream of the elementary school and that culvert overtopping was not reduced (i.e. the project would not have a significant impact on the water surface elevations).

Of the areas identified as potentially feasible for green infrastructure installation, the Coach Field Parking Area was selected by the Town to further explore the flood benefits from installation of porous pavement or LID BMPs.

4.4.1 Recommended Project - Porous Asphalt for Coach Field Parking

HEC-RAS modeling was evaluated for the potential benefit of installing porous asphalt in the Coach Field 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 water quality and reduce thermal loading to Sawmill Brook. This project would consist of the following elements:

View of parking area from Norwood Avenue

- 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.

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.

4.5 Storm Surge Barrier

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.

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.

View of Manchester Harbor

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.

4.6 Evaluation of Combined Projects

To achieve optimal flood reduction benefits, a combination of culvert resizing projects and flood storage is desirable. HEC-RAS modeling runs were completed for a series of combined projects as shown below in **Table 4-5** to evaluate the potential benefits from cumulative flood mitigation. **Appendix E** provides a summary of the HEC-RAS modeling iterations with the project combinations. This information will be used in combination with other considerations to refine and prioritize projects for the final Task 6 memo.

Table 4-5
Summary Table of Combined Flood Mitigation Projects

Project Elements	**Modeling Iterations**												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Culvert Improvements*													
Central Street	X		X			X	X	X	X	X	X	X	X
School Street	X		X			X	X	X	X	X	X	X	X
Norwood	X		X			X	X	X	X	X	X	X	X
Lincoln						X	X	X	X				
Channel Improvements													
School –Norwood Widen	X		X			X					X	X	X
School-Norwood Widen and Deepen												X	X
Flood Storage													
Essex County Golf Course				X	X								
Old School Street		X	X		X	X		X					

The following presents notes on the various model iterations:

- Iteration 1: Includes increasing dimension of culverts at Central Street to 19' wide 8' tall, School Street to 20' wide by 7.5' tall, and Norwood Avenue to 20' wide 7' tall (all three are proposed box culverts) and widening the Sawmill Brook channel between School Street and Norwood Avenue by eight feet on each side of the stream channel.

- Iteration 2: Includes only flood storage by raising Old School Street by approximately 4 feet to elevation 48.1.

- Iteration 3: Includes increasing dimension of culverts at Central Street to 19’ wide 8’ tall, School Street to 20’ wide by 7.5’ tall, and Norwood Avenue to 20’ wide 7’ tall (all three are proposed box culverts) and widening the Sawmill Brook channel between School Street and Norwood Avenue by eight feet on each side of the stream channel, and raising Old School street by approximately 4 feet to elevation 48.1 to create flood storage (Iteration 2).

- Iteration 4: Includes only flood storage at the Essex County Club by expanding area by 38 acre-feet at elevation 18.

- Iteration 5: Combines flood storage using Old School Street and the Essex County Club (Iterations 2 and 4).

- Iteration 6: Includes increasing dimension of culverts at Central Street to 20’ wide 8’ tall, School Street to 20’ wide by 7.5’ tall, Norwood Avenue to 20’ wide 7’ tall, and Lincoln Street to 20’ wide by 6’ tall (all four are proposed box culverts) and widening the Sawmill Brook channel between School Street and Norwood Avenue by ten feet on each side of the stream channel.

- Iteration 7: Includes increasing dimension of culverts at Central Street to 20’ wide 8’ tall, School Street to 20’ wide by 7.5’ tall, Norwood Avenue to 20’ wide 7’ tall, and Lincoln Street to 20’ wide by 6’ tall (all four are proposed box culverts) along with using flood storage at the Essex County Club (Iteration 4).

- Iteration 8: Includes increasing dimension of culverts at Central Street to 20’ wide 8’ tall, School Street to 20’ wide by 7.5’ tall, Norwood Avenue to 20’ wide 7’ tall, and Lincoln Street to 20’ wide by 6’ tall (all four are proposed box culverts) along with raising Old School Street to create flood storage (Iteration 2).

- Iteration 9: Includes increasing dimension of culverts at Central Street to 20’ wide 8’ tall, School Street to 20’ wide by 7.5’ tall, and Norwood Avenue to 20’ wide 7’ tall (all three as box culverts) and reducing the Lincoln Street to 10’ wide by 5.9’ tall (as an arch culvert) for creation of upstream flooding in Essex County Club.

- Iteration 10: Includes increasing dimension of culverts at Central Street to 20’ wide 8’ tall, School Street to 20’ wide by 7.5’ tall, and Norwood Avenue to 20’ wide 7’ tall (all three are proposed box culverts), with no other channel improvements.

- Iteration 11: Includes increasing dimension of culverts at Central Street to 20’ wide 8’ tall, School Street to 14’ wide by 5.64’ tall, and Norwood Avenue to 20’ wide 4.65’ tall (all three are proposed Con/Span® culverts), with widening Sawmill Brook by approximately four feet on each side in the vicinity of School Street, ten feet on each side in the vicinity of Norwood Avenue, and seven feet on each side in the area between School Street and Norwood Avenue.

- Iteration 12: Includes increasing dimension of culverts at Central Street to 20’ wide 8’ tall, School Street to 16’ wide by 8’ tall, and Norwood Avenue to 20’ wide 7’ tall (all three are proposed Con/Span® culverts), with widening Sawmill Brook by approximately four feet on each side in the vicinity of School Street, ten feet on each side in the vicinity of Norwood Avenue, and seven feet on each side in the area between School Street and Norwood Avenue. This also includes deepening Sawmill Brook by approximately 1.9 feet at School Street, 2.3 feet at Norwood Avenue, and up to 2 feet in the channel between the two culverts.

- Iteration 13: Includes increasing dimension of culverts at Central Street to 20' wide 8' tall, School Street to 16' wide by 8' tall, and Norwood Avenue to 16' wide 7' tall (all three are proposed Con/Span® culverts), with widening Sawmill Brook by approximately four feet on each side in the vicinity of School Street, ten feet on each side in the vicinity of Norwood Avenue, and seven feet on each side in the area between School Street and Norwood Avenue. This also includes deepening Sawmill Brook by approximately 1.9 feet at School Street, 2.3 feet at Norwood Avenue, and up to 2 feet in the channel between the two culverts.

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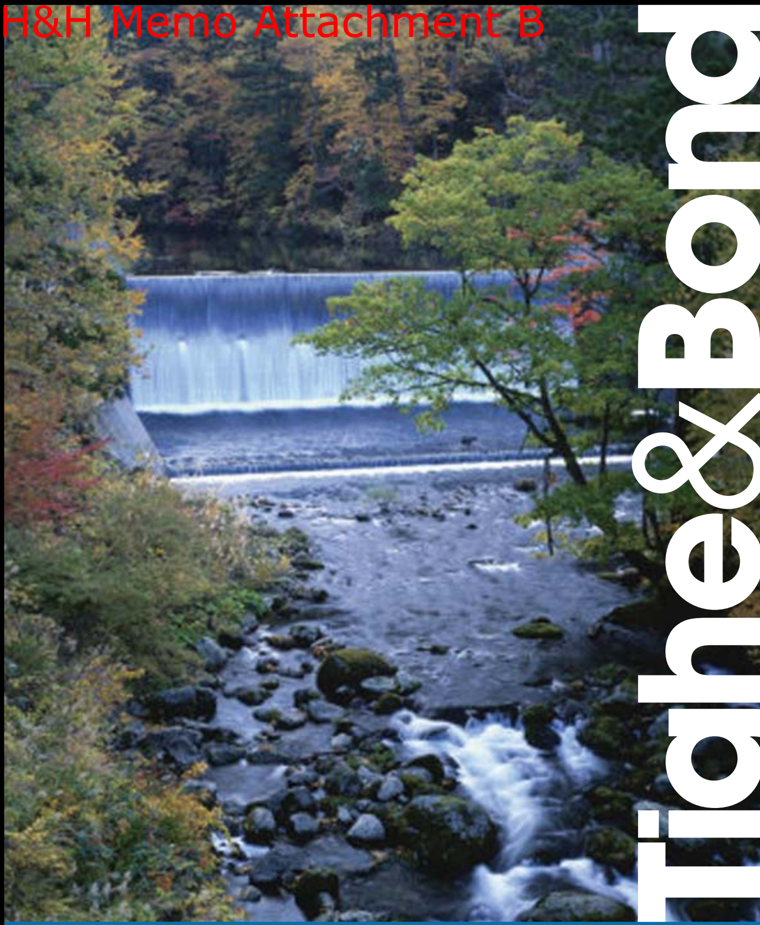


Tighe&Bond

SECTION 5

Section 5
Project Summary & Recommendations

5.1 Summary

Tighe & Bond evaluated the existing and future hydrology and hydraulics within the Sawmill Brook watershed under varying climatic events. Evaluation including modeling existing watershed conditions using information about soils, topography, ground cover (impervious cover and land uses), existing wetlands and waterbodies, water travel times, existing structures that control discharges (e.g. Central Street tide gate, culverts, etc.), rainfall depths developed by the Cornell University Northeast Regional Climate Center, and tidal influences using data from Flood Insurance Study for Essex County (July 2014). The existing conditions model was calibrated against the May 2006 storm (Mother's Day storm) that represent 25-year single day and 100-year consecutive day storm conditions.

Future watershed conditions were modeled to build off the existing conditions model and consider anticipated impacts from climate change and sea level rise in 2025, 2050, and 2100. For the future conditions model, precipitation estimates from the existing conditions scenario were replaced with estimates of future rainfall depths for 2025, 2050, and 2100 from the Oyster River Culvert Analysis project completed in Durham, New Hampshire (UNH, 2010). In addition, sea level rise and storm surge were considered using data from the Inundation Risk Model (IRM) outputs developed by Keil Schmid (Geoscience, 2015).

Using the future conditions model, we evaluated potential impacts on existing infrastructure (e.g. Central Street tide gate, culverts, crossings) from storm surge, sea level rise, and future precipitation conditions in 2025, 2050, and 2100. The future condition model for the year 2050 using a 50-year storm and a balance energy emission scenario was also used to evaluate right sizing culverts sizes and needed upgrades, and the mitigation value of proposed stormwater best management practices including green stormwater infrastructure, conveyance projects, and flood storage.

In general, the floodplain will continue to expand over time for the proposed climate change scenarios, and as a result of the increased flow and higher tailwater elevations exerted by tidal forces, by 2100, under a fossil intensive projection, 60% of the culverts in the watershed will overtop during a 25-year storm, and 70% will overtop during a 100-year storm under both storm surge conditions and sea level rise conditions.

Tighe & Bond expanded the modeling to look at potential improvements to flooding by relieving channel restrictions at Central Street, providing additional flood storage north of Route 128, rightsizing culverts, and utilizing green infrastructure best management practices at a variety of pre-screened locations. Based on the modeling results looking at individual projects, the scenario with resizing the culvert at Central Street has by far the largest improvement in the watercourse's flood carrying capacity.

To achieve optimal flood reduction benefits, a combination of culvert resizing projects and flood storage is desirable. HEC-RAS modeling runs were completed for a series of combined projects. This information will be utilized to make recommendations for prioritizing projects as part of Task 6.

5.2 Recommendations

Tighe & Bond met with Town staff on October 26, 2015, to review the modeling effort and preliminary results and to identify projects for further evaluation under Task 5, conceptual designs and preliminary permitting evaluation. Based on discussions at this meeting, conceptual designs will be prepared for the following nine projects:

1. Removing channel restrictions at Central Street (Option 1) consists of removing the tide gate and keeping the configuration of the culvert, potentially with a rock riffle to keep Central Pond full of water
2. Removing channel restrictions at Central Street (Option 2) consist of removing the tide gate, opening the culvert, removing the dam, and changing the entire crossing to be a bridge, and restoring the historic stream channel
3. Increasing the dimensions of the School Street culvert (23) with modifications to the channel of Sawmill Brook to account for increased culvert sizing
4. Increasing the dimensions of the Norwood Avenue culvert (22) with modifications to the Sawmill Brook channel to account for the increased culvert dimensions
5. Increasing the dimensions of the Lincoln Avenue culvert (17)
6. Flood storage in the Essex County Club Golf Course.
7. Flood storage upstream of Old School Street culvert (2)
8. Development of a hurricane barrier located in Manchester Harbor to manage overtopping from storm surge and hurricanes
9. Installation of a green infrastructure practice, porous pavement, at the Coach Field parking lot

Removing Channel Restrictions at Central Street & Installation of a Hurricane Barrier

- When only sea level rise is taken into account, the Central Street improvements have the largest impact on reducing water surface elevations upstream. Due to the locations of business on the east bank of the river, and the roadway on the west bank, any widening of the river approach would be difficult, but eliminating the tide gate would result in reductions in water surface elevation. Culvert enlargements would also result in significant reductions in water surface elevation upstream, and would restore the stream crossing to historic conditions. Both improvement alternatives will improve smelt passage and spawning potential.

- Under worst case future storm conditions, even with modifications to the Central Street Bridge, the roadway would still overtop because the surge elevation exceeds the roadway centerline elevation for 2050 and beyond. This may be addressed with use of a hurricane barrier or raising the elevation of Central Street. A hurricane barrier might be located at the mouth of Manchester Harbor.

Removing Channel Restrictions at Culverts

- Improving conveyance of Sawmill Brook in the “downtown” area of Manchester (i.e. culverts at School Street, Norwood Avenue, and Lincoln Street) will reduce the overall watershed flooding.

Increasing Flood Storage at the Golf Course

- The golf course is located at approximately the halfway point in the watershed, includes Town-owned land, and has a large area for flood management before Sawmill Brook flows into Manchester's downtown area. These reasons make the golf course an excellent candidate for managing floodwaters with limited impacts to abutters.

Improving Flood Storage behind Old School Street

- Increasing the storage behind Old School Street (north of Route 128) reduces the flow rate for the stretch of stream channel between School Street and the confluence of Causeway Brook at Lincoln Street for large storm events. Most improvement would be between School Street and Mill Street. Further downstream, flows from other areas in the watershed combine, increasing flow in the watershed, so the contribution of the storage decreases until it disappears by the time the brook meets Causeway Brook.

Installation of Green Infrastructure at the Coach Field Playground Parking Area

- The Coach Field Playground parking area was identified as a priority over the Elementary School parking area due to proximity to Sawmill Brook and planned improvements at the Elementary School. While installation of porous pavement at the Coach Field Playground parking area does not reduce flood elevations in Sawmill Brook, it does have an excellent opportunity to improve water quality and result in localized reductions in discharge from the parking lot. This is also an excellent location for public education.

References

University of New Hampshire (2010). The Oyster River Culvert Analysis.

Schmidt, Keil. Integrated Risk Model Website: http://www.geosciconsultants.com/projects/2015/5/27/coastal-risk-mapping-in-salem-sound

Tighe & Bond (6/2015). Memo to Mary Reilly, "Manchester-by-the-Sea, Grants Coordinator, Sawmill Brook Central St Seawall, Tide Gate & Culvert Observations".

Tighe & Bond (7/2015). Report, "Opportunities for Flood Mitigation within Sawmill Brook

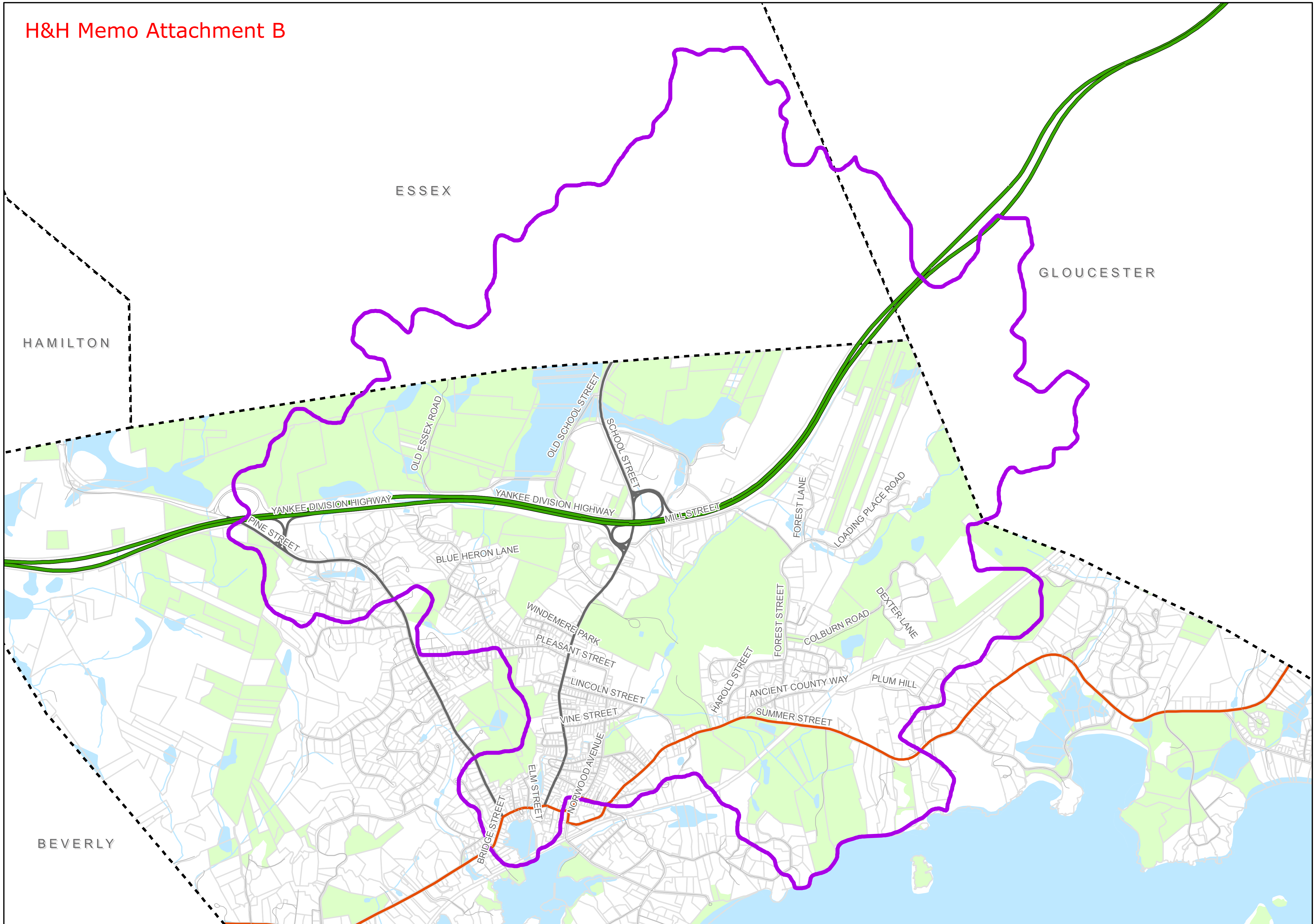
Tighe & Bond (7/2015). "Manchester-by-the-Sea, Massachusetts, Stream Crossing Evaluation, Sawmill Brook Watershed".

Tighe & Bond (9/ 2015). Technical Memorandum "Potential Climate Change Impacts to Manchester-by-the-Sea".

H&H Memo Attachment B

FIGURES

H&H Memo Attachment B



SAWMILL BROOK WATERSHED

LEGEND

Sawmill Brook Watershed

LOCUS MAP

N

0 875 1,750

Feet

1:21,000

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 1

Sawmill Brook Culvert & Green Infrastructure Analysis
Manchester-by-the-Sea, Massachusetts

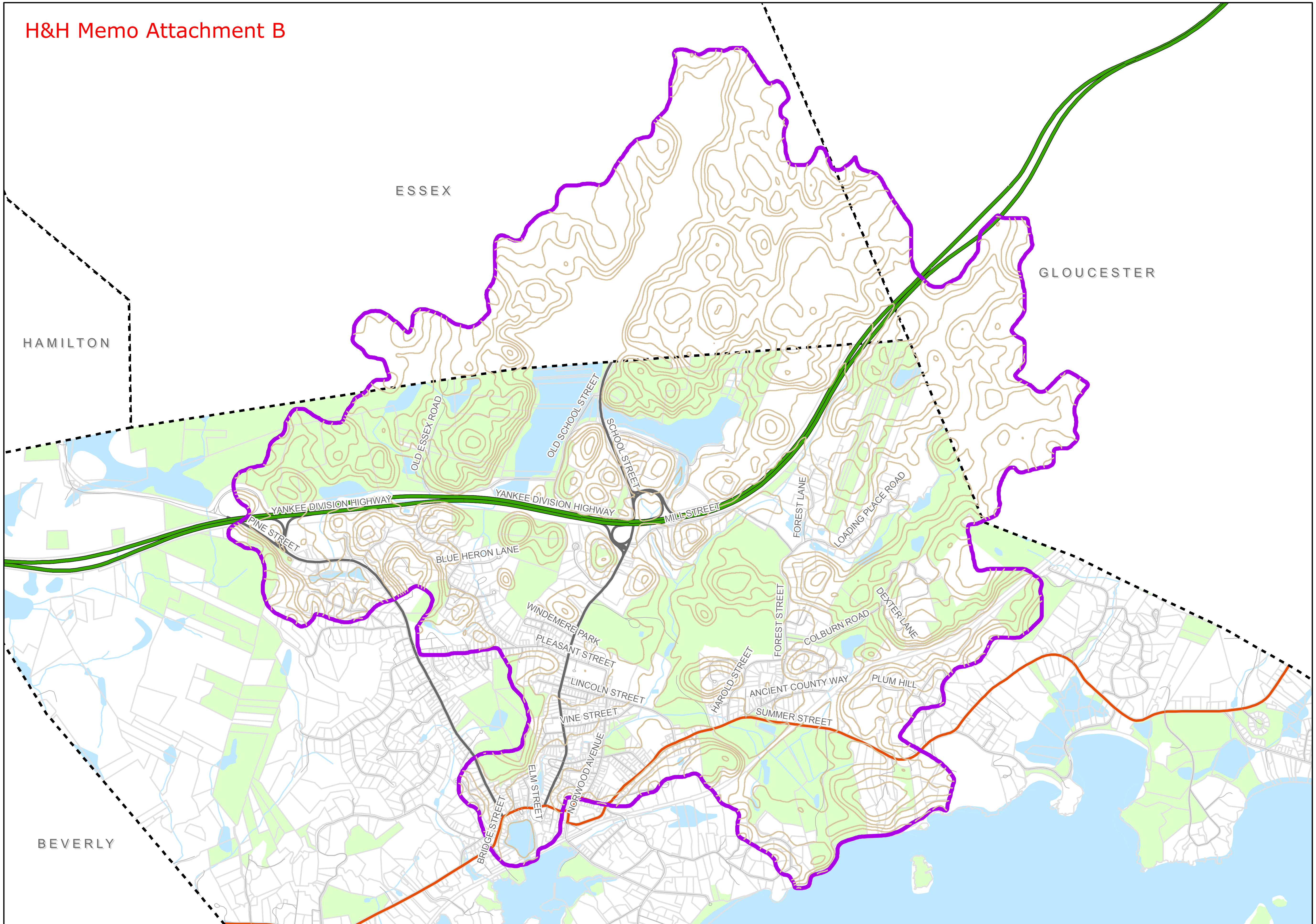
September 2015

Tighe&Bond
Consulting Engineers
Environmental Specialists

Path: G:\GIS\MA\ManchesterMA\avproj\WatershedBoundary.mxd

M-1476

H&H Memo Attachment B



SAWMILL BROOK TOPOGRAPHY

LEGEND

20' Contours

Sawmill Brook Watershed

LOCUS MAP

N

0 875 1,750

Feet

1:21,000

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 2

Sawmill Brook Culvert & Green Infrastructure Analysis Manchester-by-the-Sea, Massachusetts

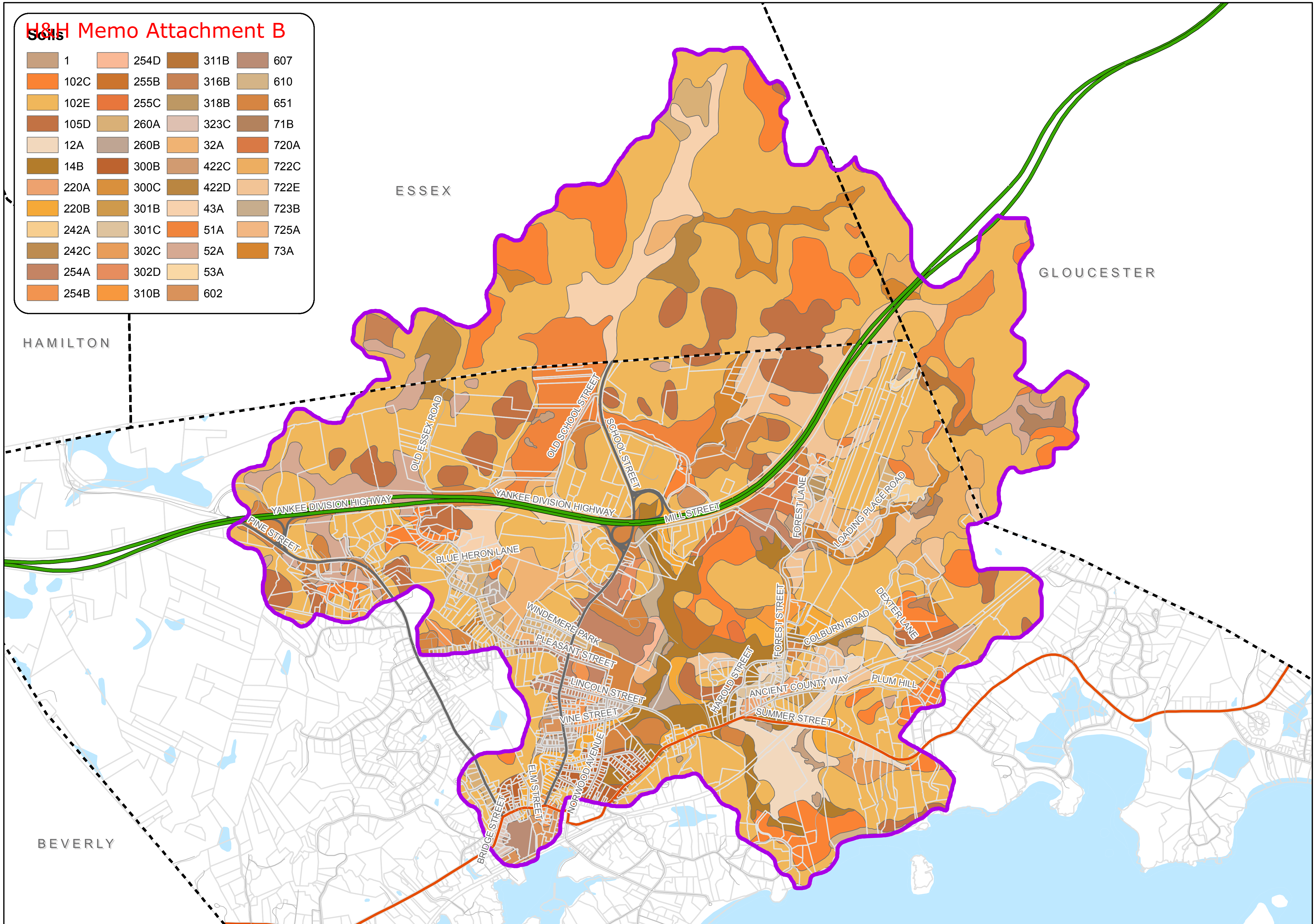
September 2015

Tighe&Bond
Consulting Engineers
Environmental Specialists

Path: G:\GIS\MA\ManchesterMA\avproj\WatershedTopography.mxd

M-1476

H&H Memo Attachment B



SAWMILL BROOK SOILS

LEGEND

Sawmill Brook Watershed

LOCUS MAP

0 875 1,750

Feet

1:21,000

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 3

Sawmill Brook Culvert & Green Infrastructure Analysis Manchester-by-the-Sea, Massachusetts

September 2015

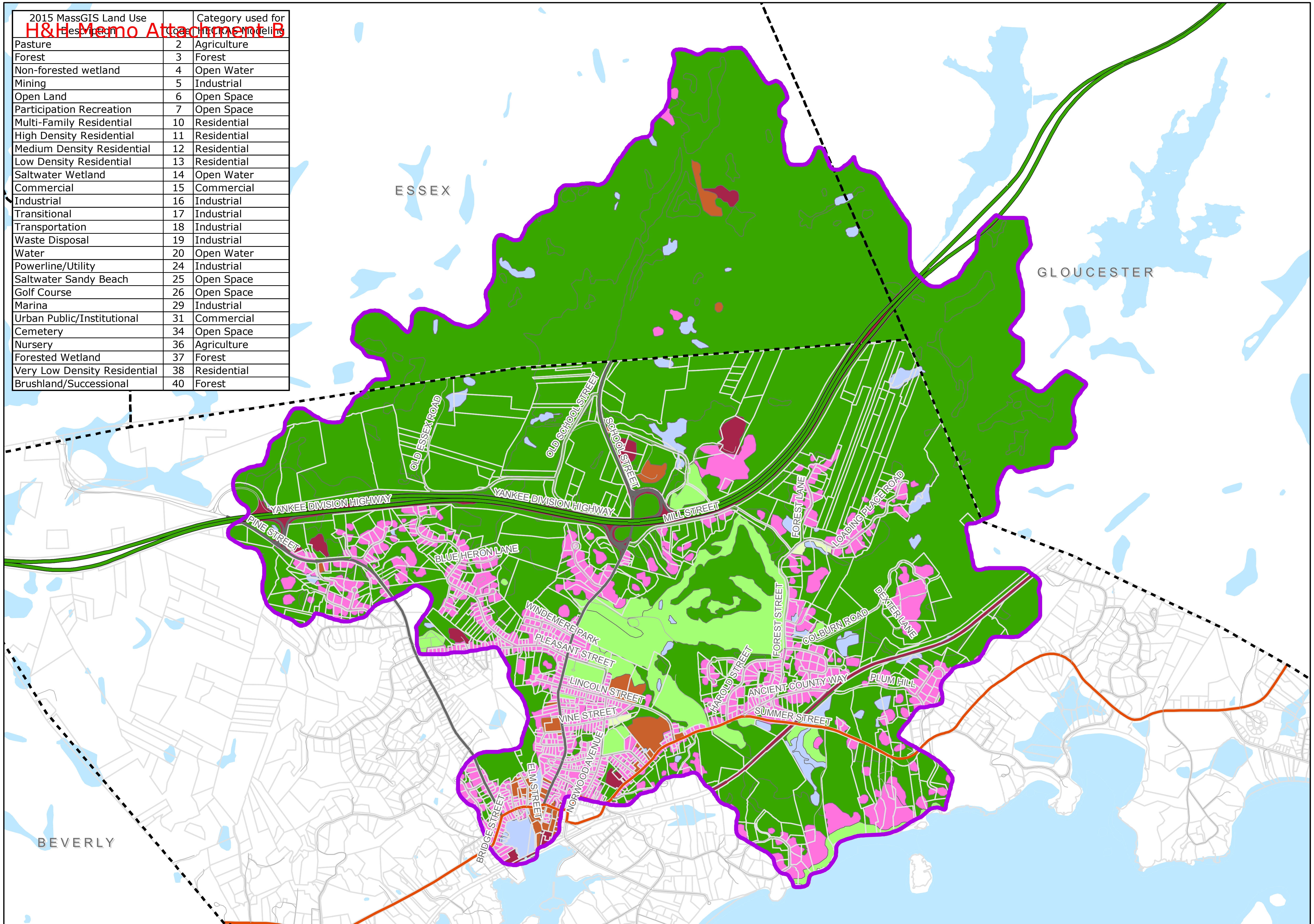
Tighe&Bond
Consulting Engineers
Environmental Specialists

Path: G:\GIS\MA\ManchesterMA\avproj\WatershedSoils.mxd

M-1476

H&H Memo Attachment B

2015 MassGIS Land Use Description	Code	Category used for HECRAS Modeling
Pasture	2	Agriculture
Forest	3	Forest
Non-forested wetland	4	Open Water
Mining	5	Industrial
Open Land	6	Open Space
Participation Recreation	7	Open Space
Multi-Family Residential	10	Residential
High Density Residential	11	Residential
Medium Density Residential	12	Residential
Low Density Residential	13	Residential
Saltwater Wetland	14	Open Water
Commercial	15	Commercial
Industrial	16	Industrial
Transitional	17	Industrial
Transportation	18	Industrial
Waste Disposal	19	Industrial
Water	20	Open Water
Powerline/Utility	24	Industrial
Saltwater Sandy Beach	25	Open Space
Golf Course	26	Open Space
Marina	29	Industrial
Urban Public/Institutional	31	Commercial
Cemetery	34	Open Space
Nursery	36	Agriculture
Forested Wetland	37	Forest
Very Low Density Residential	38	Residential
Brushland/Successional	40	Forest



SAWMILL BROOK LAND USE

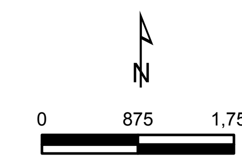
LEGEND

- Sawmill Brook Watershed

Aggregated Land Use

- Agriculture
- Commercial
- Forest
- Industrial
- Open Space
- Open Water
- Residential

LOCUS MAP



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NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 4

Sawmill Brook Culvert & Green Infrastructure Analysis Manchester-by-the-Sea, Massachusetts

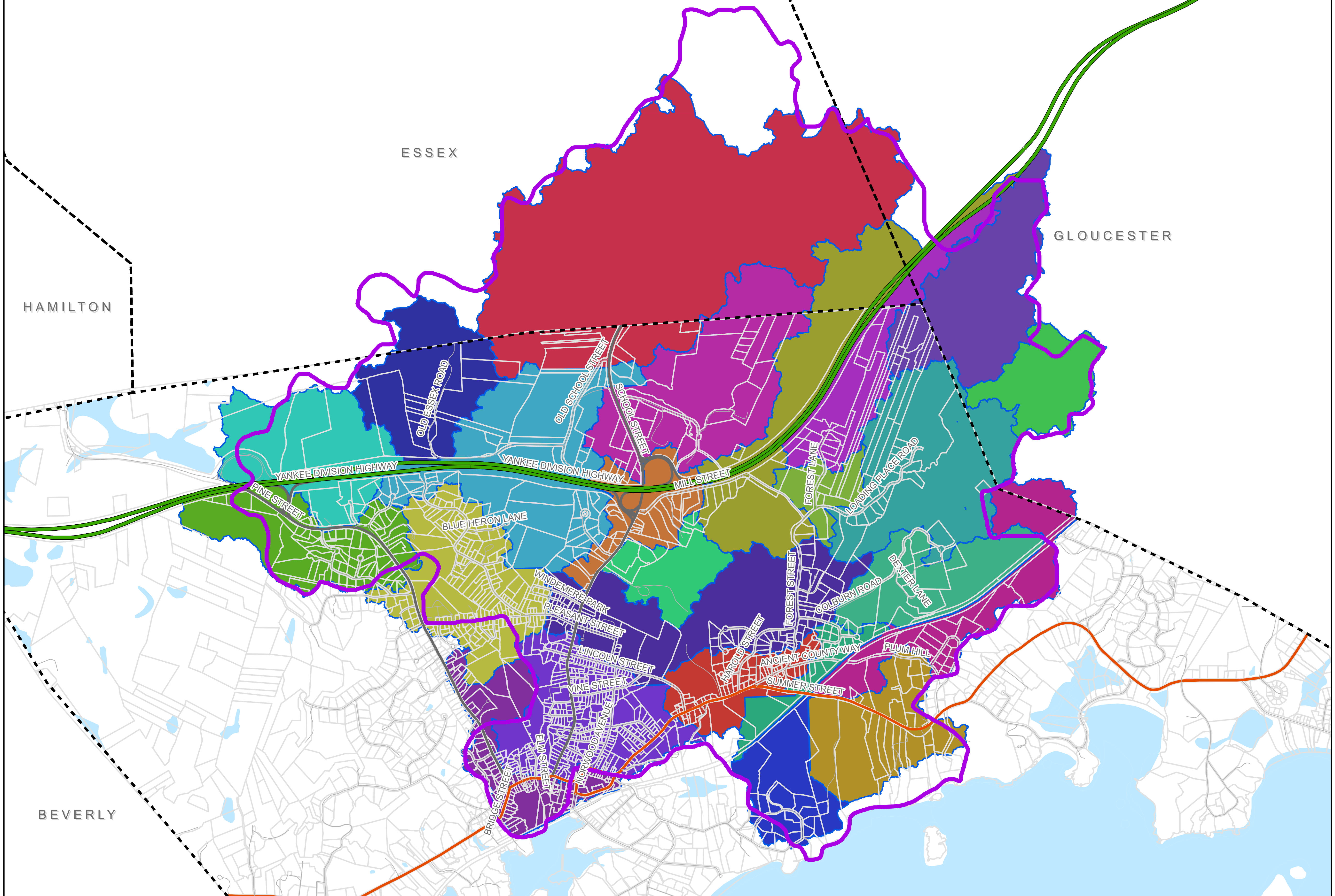
November 2015

Tighe&Bond
Consulting Engineers
Environmental Specialists

Path: G:\GIS\MA\ManchesterMA\avproj\WatershedLandUse.mxd

M-1476

H&H Memo Attachment B



SAWMILL BROOK SUBAREAS

LEGEND

Sawmill Brook Watershed

Watershed Subareas

LOCUS MAP

N

0 875 1,750

Feet

1:21,000

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 5

Sawmill Brook Culvert & Green Infrastructure Analysis
Manchester-by-the-Sea, Massachusetts

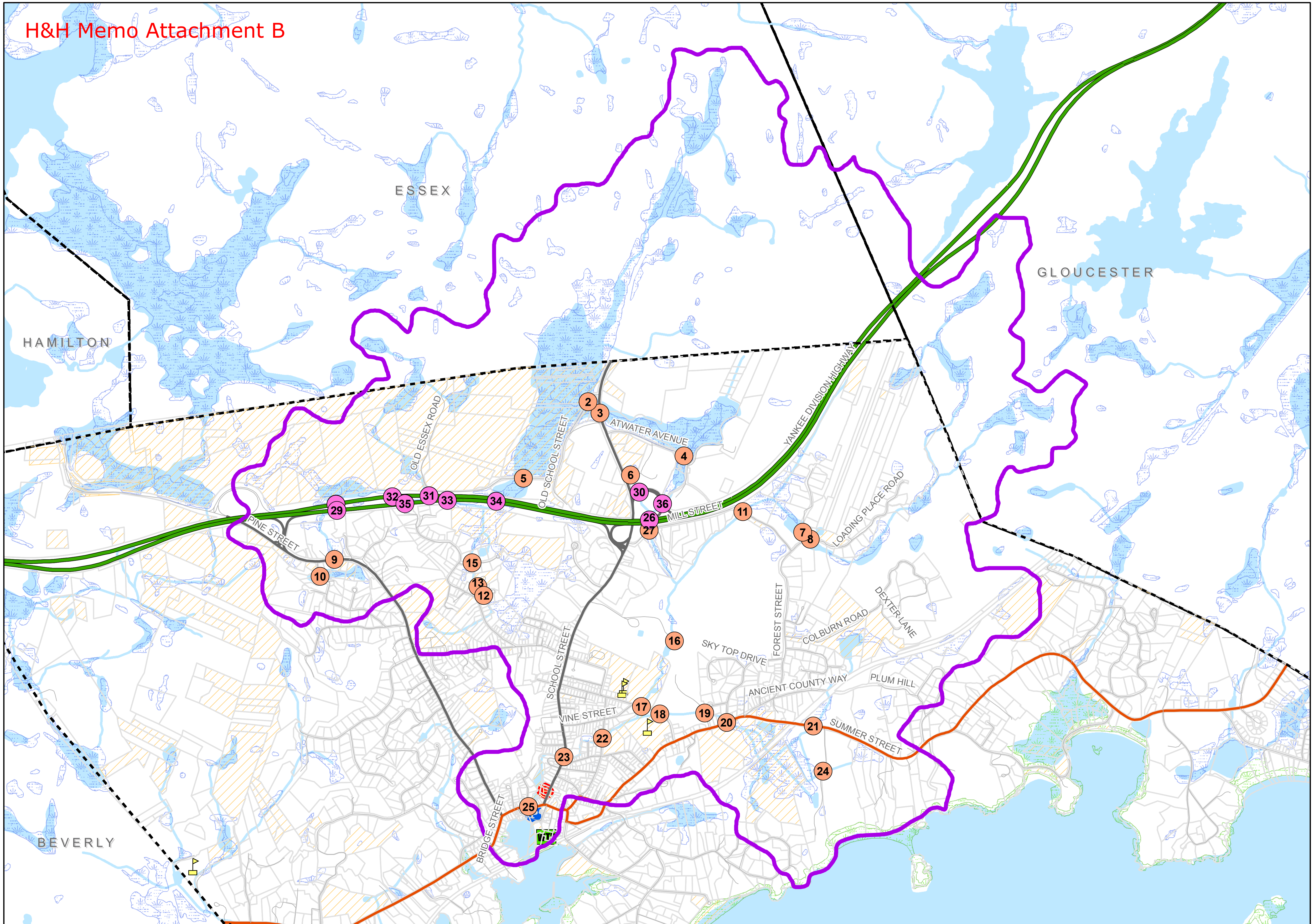
September 2015

Tighe&Bond
Consulting Engineers
Environmental Specialists

Path: G:\GIS\MA\ManchesterMA\avproj\WatershedSubAreas.mxd

M-1476

H&H Memo Attachment B

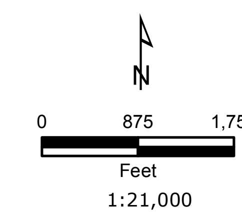


SAWMILL BROOK CULVERT LOCATIONS

LEGEND

- Sawmill Brook Watershed
- Town Boundary
- MassDOT Culvert
- Culvert
- Fire Station
- Police Station
- Wastewater Treatment Plant
- Schools (PK - High School)
- Town Owned Property
- Inland Wetlands
- Coastal Wetlands
- Waterbodes

LOCUS MAP



NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 6

Sawmill Brook Culvert & Green Infrastructure Analysis Manchester-by-the-Sea, Massachusetts

November 2015

Tighe&Bond
Consulting Engineers
Environmental Specialists

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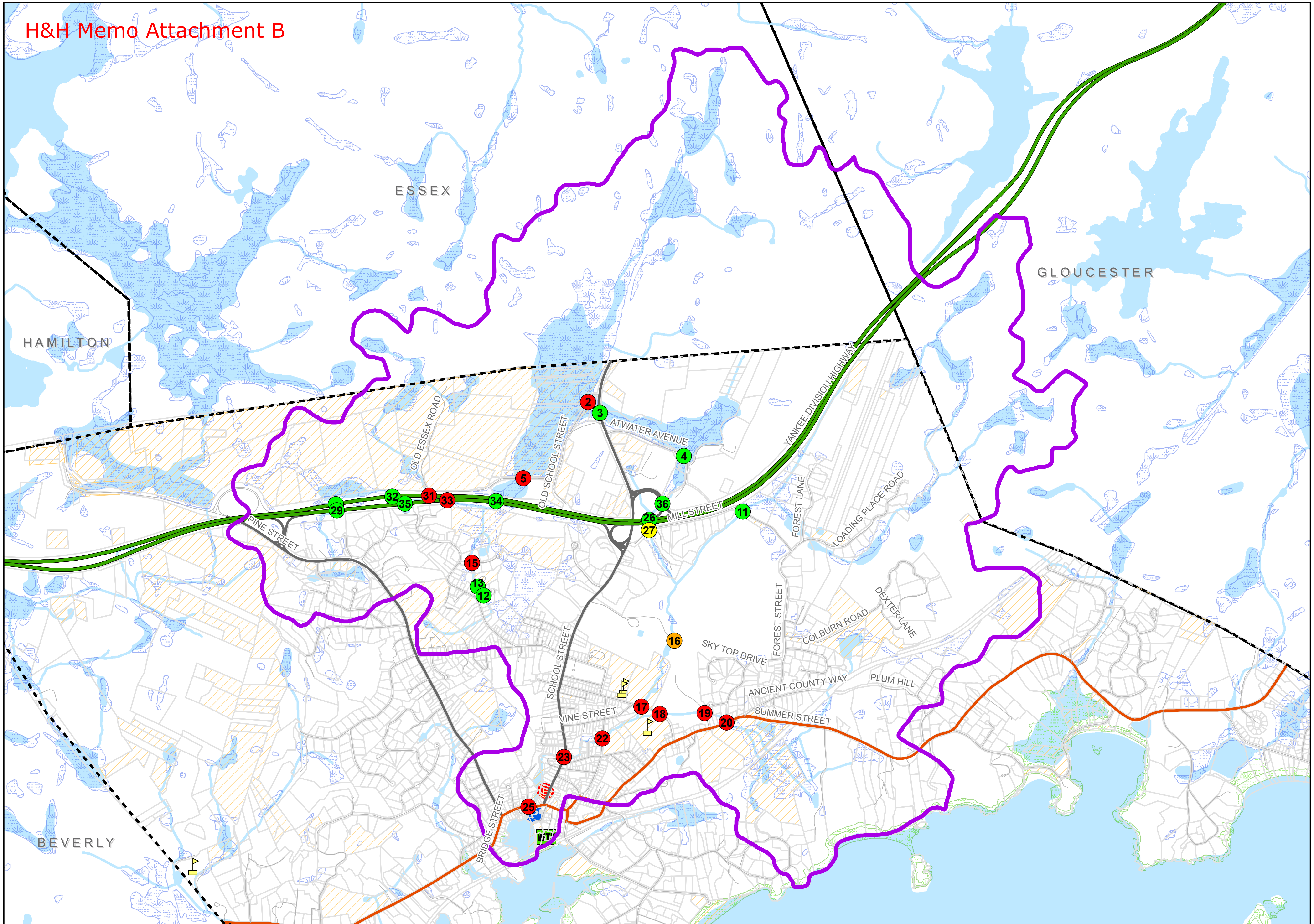
H&H Memo Attachment B



2015 STORM FREQUENCY CAUSING OVERTOPPING Existing Conditions Model

LEGEND

Culvert Overtopped

- >100 Year
- 25 Year Storm
- 50 Year Storm
- 100 Year Storm
- Sawmill Brook Watershed
- Town Boundary
- Town Owned Property
- Inland Wetlands
- Coastal Wetlands
- Waterbodies

LOCUS MAP

0 875 1,750
Feet
1:21,000

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 7

Sawmill Brook Culvert & Green Infrastructure Analysis Manchester-by-the-Sea, Massachusetts

November 2015

Tighe&Bond
Consulting Engineers
Environmental Specialists

Path: G:\GIS\MA\ManchesterMA\avproj\CulvertOvertopping_2015.mxd

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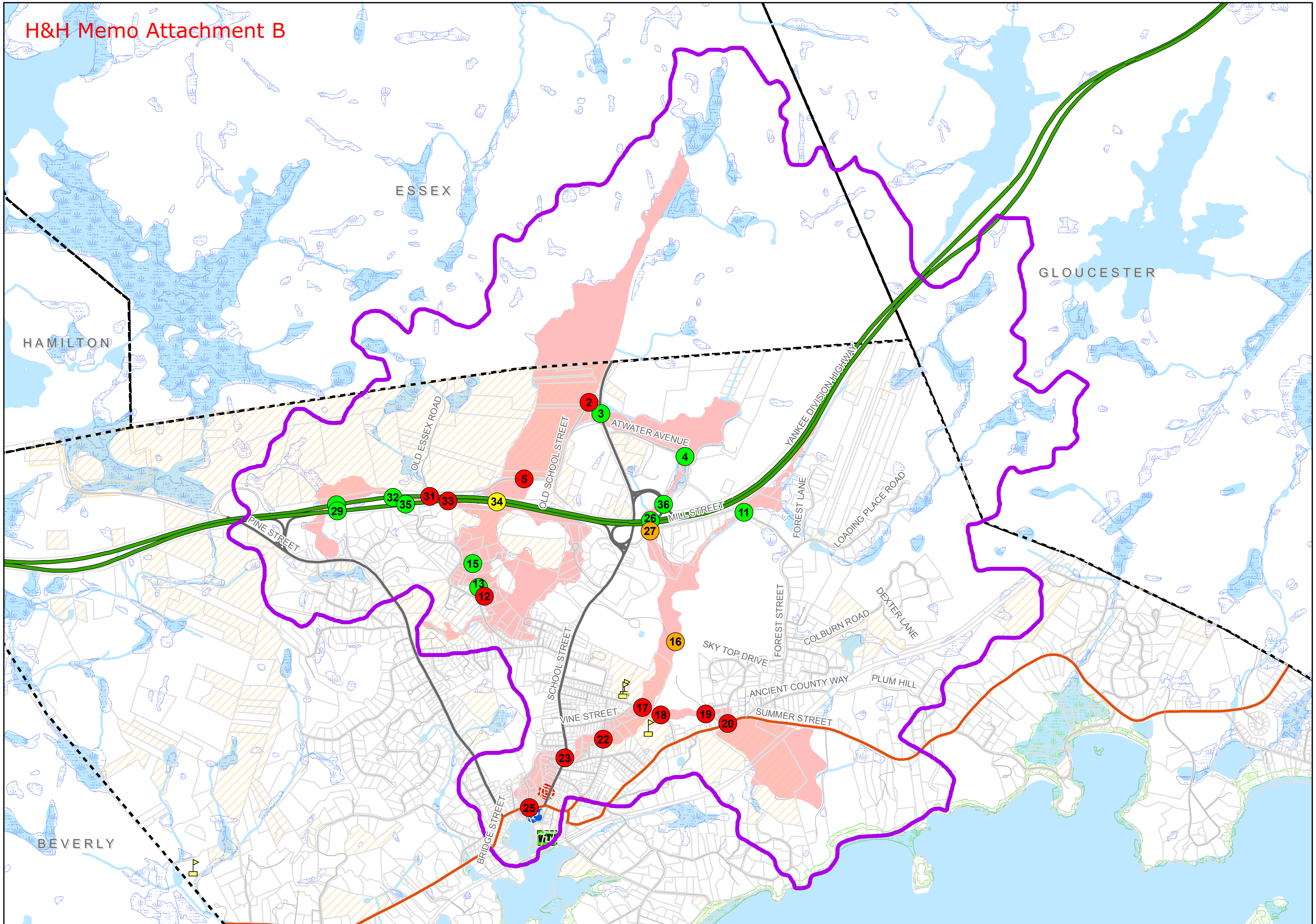
H&H Memo Attachment B



2025 STORM FREQUENCY CAUSING OVERTOPPING

Balanced Energy Use,
Storm Surge or Sea Level Rise

LEGEND

Storm Frequency Causing Overtopping

- 25 Year Storm
- 50 Year Storm
- 100 Year Storm
- >100 Year Storm
- Sawmill Brook Watershed
- Town Owned Property
- Sea Level Rise Balanced
- Inland Wetlands
- Coastal Wetlands
- Waterbodies

LOCUS MAP

0 875 1,750
Feet
1:21,000

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 8A

Sawmill Brook Culvert & Green Infrastructure Analysis
Manchester-by-the-Sea, Massachusetts
November 2015

Tighe&Bond
Consulting Engineers
Environmental Specialists

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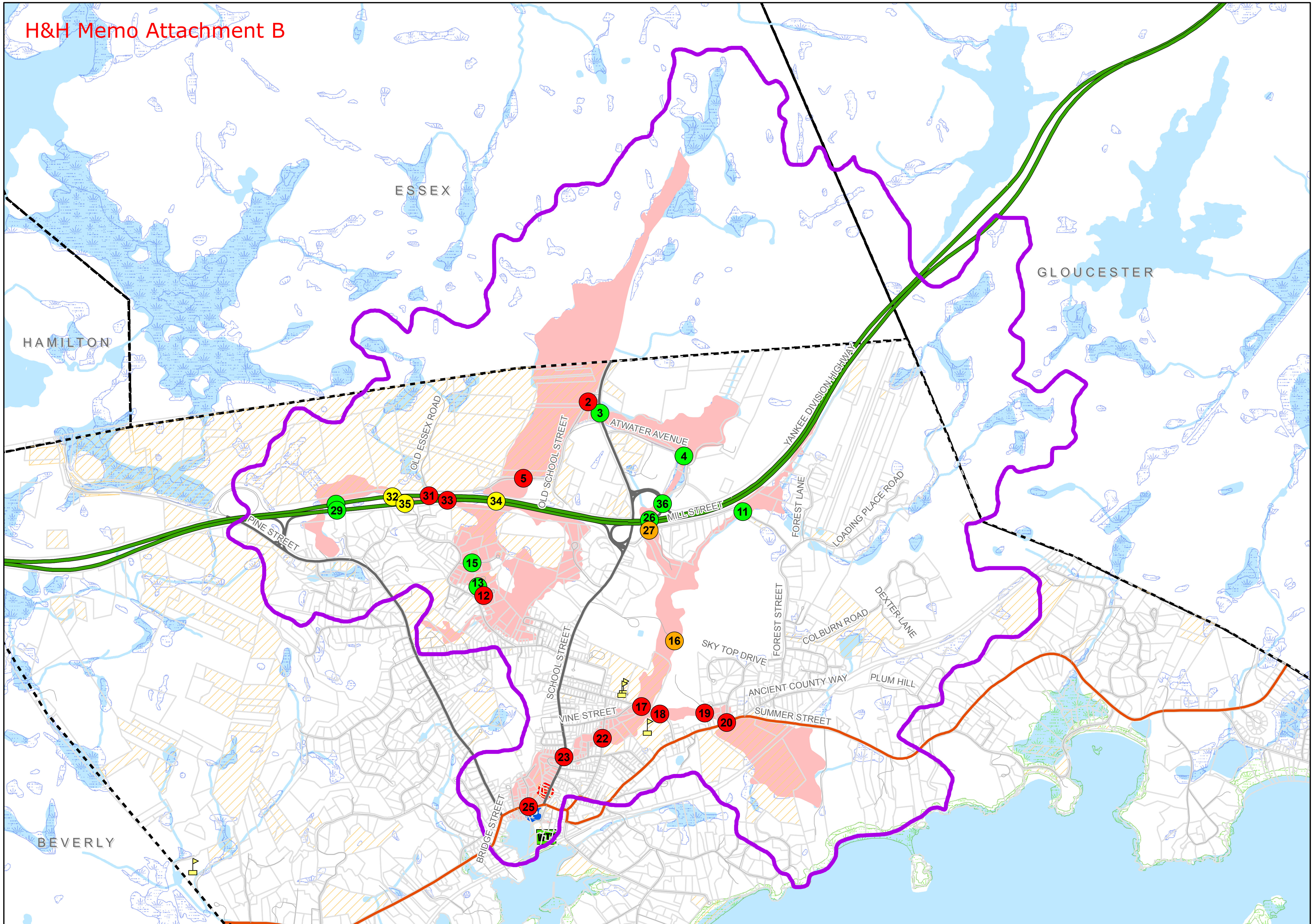

2050 STORM FREQUENCY CAUSING OVERTOPPING
Balanced Energy Use,
Storm Surge or Sea Level Rise

LEGEND

Storm Frequency Causing Overtopping

- 25 Year Storm
- 50 Year Storm
- 100 Year Storm
- >100 Year Storm
- Sawmill Brook Watershed
- Town Owned Property
- Sea Level Rise Balanced
- Inland Wetlands
- Coastal Wetlands
- Waterbodies

LOCUS MAP

N

0 875 1,750
Feet
1:21,000

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 8B

Sawmill Brook Culvert & Green Infrastructure Analysis
Manchester-by-the-Sea, Massachusetts
November 2015

Tighe&Bond
Consulting Engineers
Environmental Specialists

Path: G:\GIS\MA\ManchesterMA\avproj\SeaLevelRise_BalancedEnergy2050.mxd

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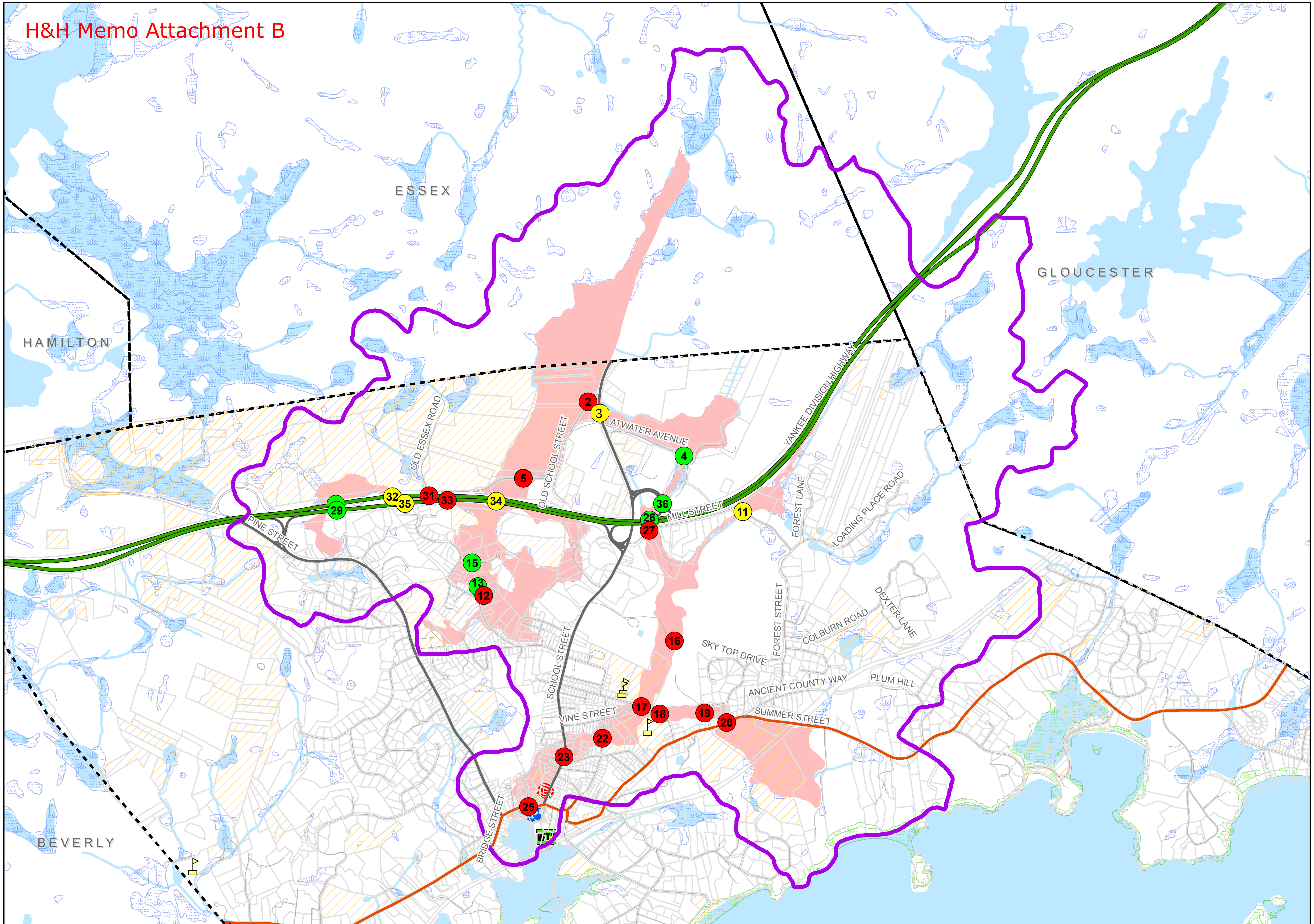
H&H Memo Attachment B



2100 STORM FREQUENCY CAUSING OVERTOPPING
Balanced Energy Use,
Storm Surge and Sea Level Rise

LEGEND

Storm Frequency Causes Overtopping

- 25 Year Storm
- 50 Year Storm
- 100 Year Storm
- >100 Year Storm
- Sawmill Brook Watershed
- Town Owned Property
- Sea Level Rise Balanced
- Inland Wetlands
- Coastal Wetlands
- Waterbodies

LOCUS MAP

0 875 1,750
Feet
1:21,000

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 8C

Sawmill Brook Culvert & Green Infrastructure Analysis
Manchester-by-the-Sea, Massachusetts
November 2015

Tighe&Bond
Consulting Engineers
Environmental Specialists

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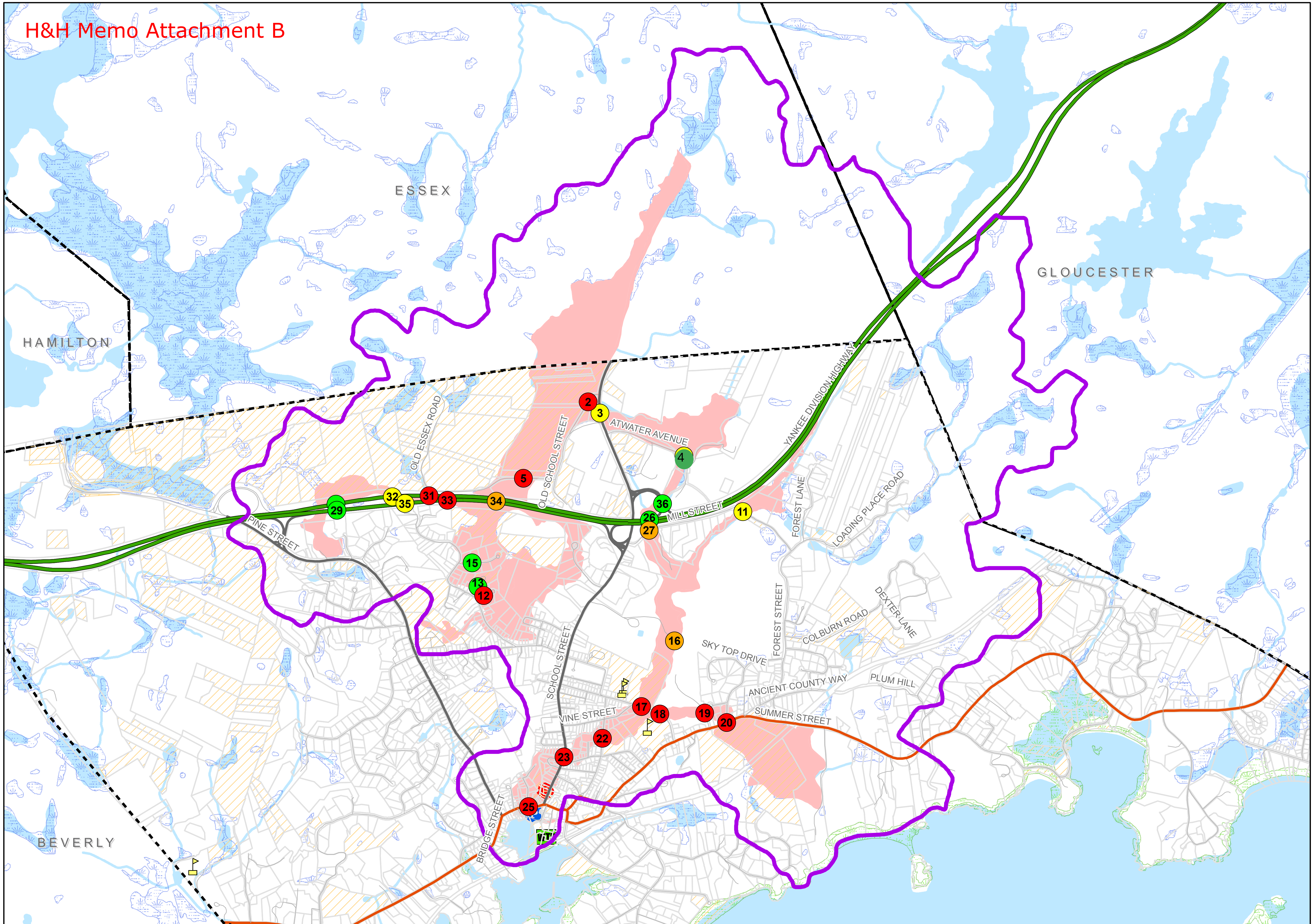

2025 STORM FREQUENCY CAUSING OVERTOPPING
Fossil Intensive Energy Use
Storm Surge or Sea Level Rise

LEGEND

Storm Frequency Causing Overtopping

- 25 Year storm
- 50 Year Storm
- 100 Year Storm
- >100 Year Storm
- Sawmill Brook Watershed
- Town Owned Property
- Model Output
- Inland Wetlands
- Coastal Wetlands
- Waterbodies

LOCUS MAP

N

0 875 1,750
Feet
1:21,000

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 9A

Sawmill Brook Culvert & Green Infrastructure Analysis Manchester-by-the-Sea, Massachusetts

November 2015

Tighe&Bond
Consulting Engineers
Environmental Specialists

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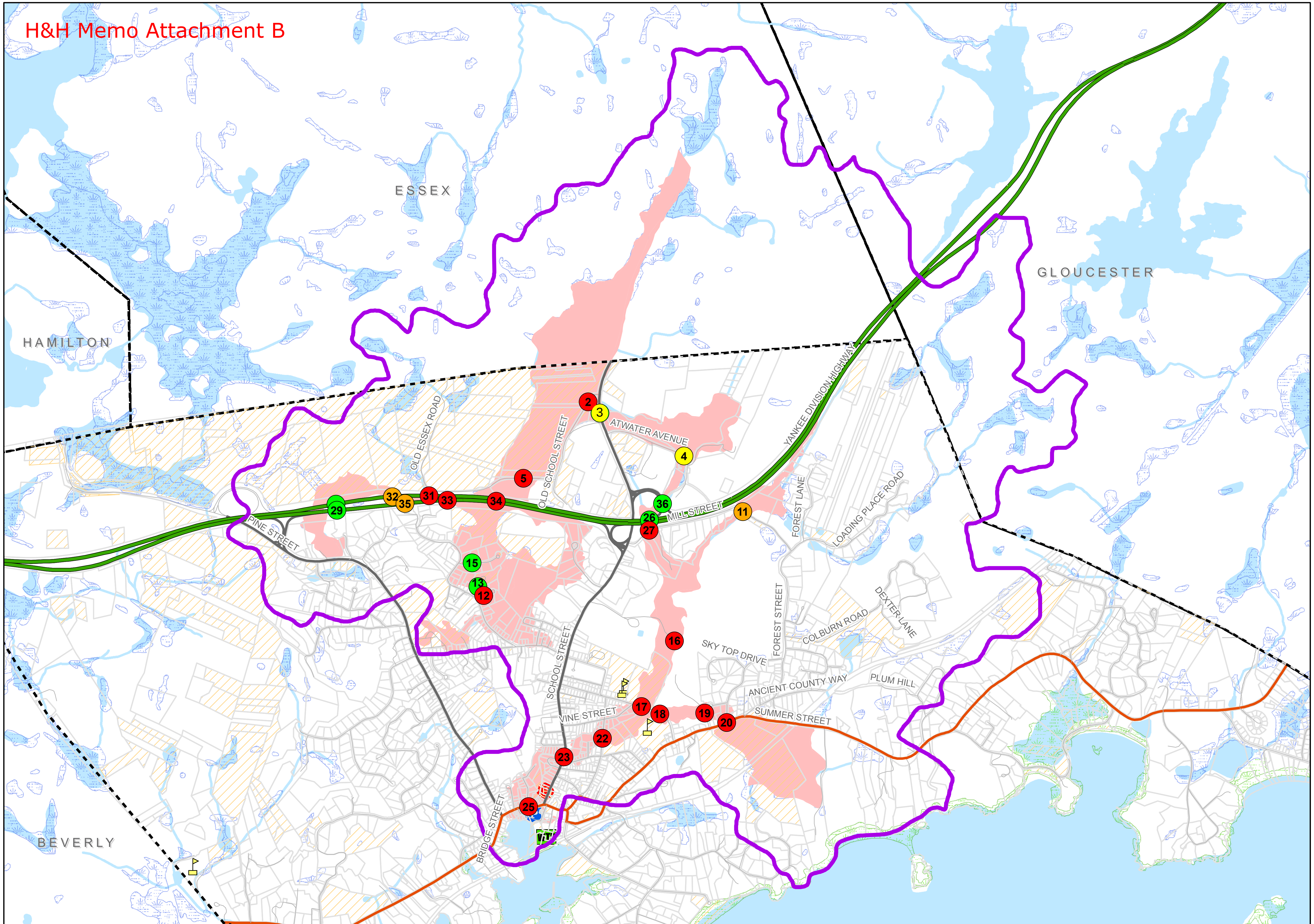
H&H Memo Attachment B



2050 STORM FREQUENCY CAUSING OVERTOPPING
Fossil Intensive Energy Use
Storm Surge or Sea Level Rise

LEGEND

Storm Frequency Causing Overtopping
- 25 Year Storm
- 50 Year Storm
- 100 Year Storm
- >100 Year Storm
- Sawmill Brook Watershed
- Town Owned Property
- Model Output
- Inland Wetlands
- Coastal Wetlands
- Waterbodies

LOCUS MAP

0 875 1,750
Feet
1:21,000

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 9B

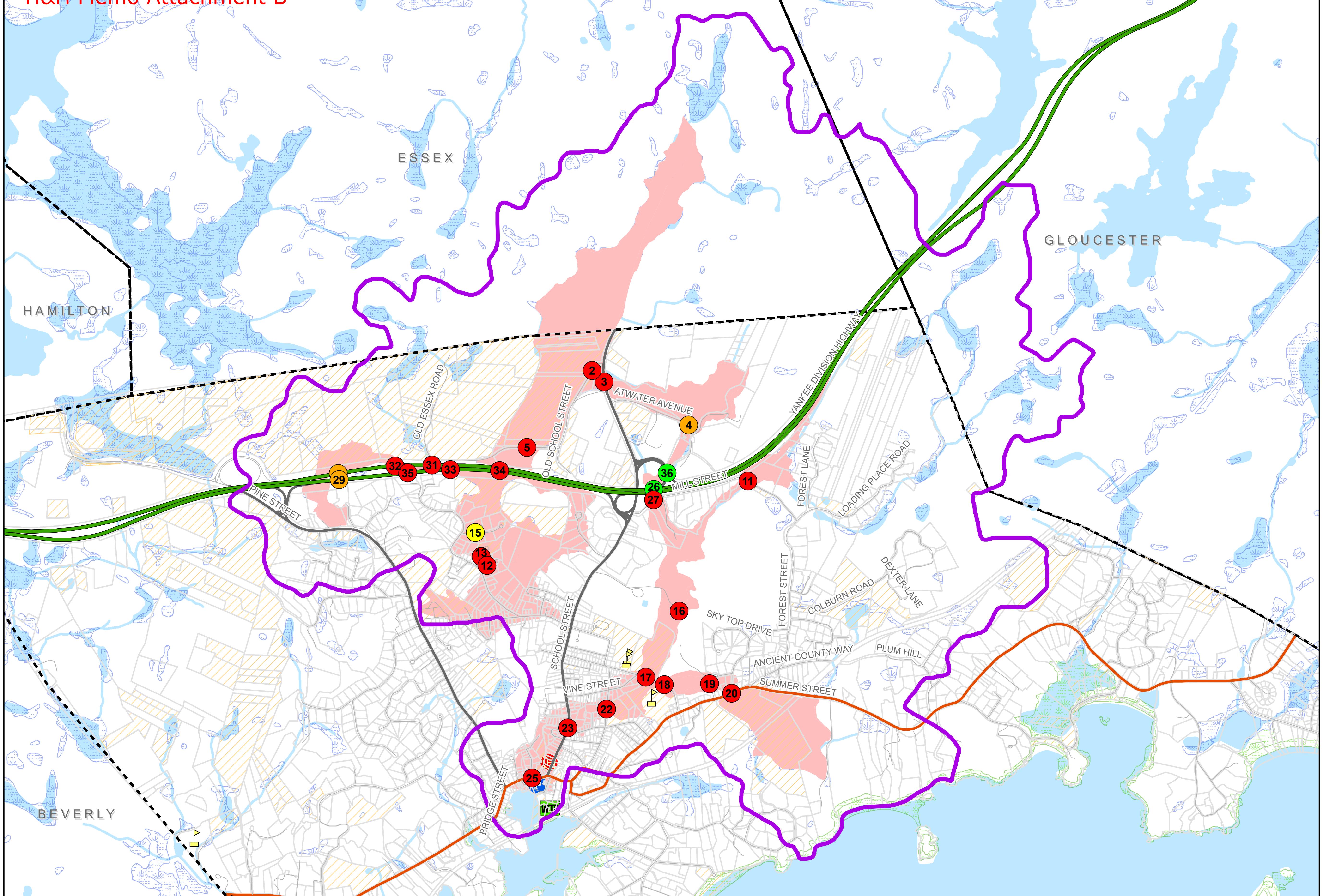
Sawmill Brook Culvert & Green Infrastructure Analysis
Manchester-by-the-Sea, Massachusetts
November 2015

Tighe&Bond
Consulting Engineers
Environmental Specialists

Path: G:\GIS\MA\ManchesterMA\avproj\StormSurge_FossilIntensive_2050.mxd

M-1476

H&H Memo Attachment B



2100 STORM FREQUENCY CAUSING OVERTOPPING
Fossil Intensive Energy Use
Storm Surge or Sea Level Rise

LEGEND

Storm Frequency Causing Overtopping

- 25 Year Storm
- 50 Year Storm
- 100 Year Storm
- >100 Year Storm
- Sawmill Brook Watershed
- Town Owned Property
- Sea Level Rise Fossil Intensive
- Inland Wetlands
- Coastal Wetlands
- Waterbodies

LOCUS MAP

N

0 875 1,750
Feet
1:21,000

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Figure 9C

Sawmill Brook Culvert & Green Infrastructure Analysis
Manchester-by-the-Sea, Massachusetts
November 2015

Tighe&Bond
Consulting Engineers
Environmental Specialists

Path: G:\GIS\MA\ManchesterMA\avproj\SeaLevelRise_FossilIntensive2100.mxd

M-1476

H&H Memo Attachment B

H&H Memo Attachment B

APPENDIX A

H&H Memo Attachment B

USDA United States Department of Agriculture

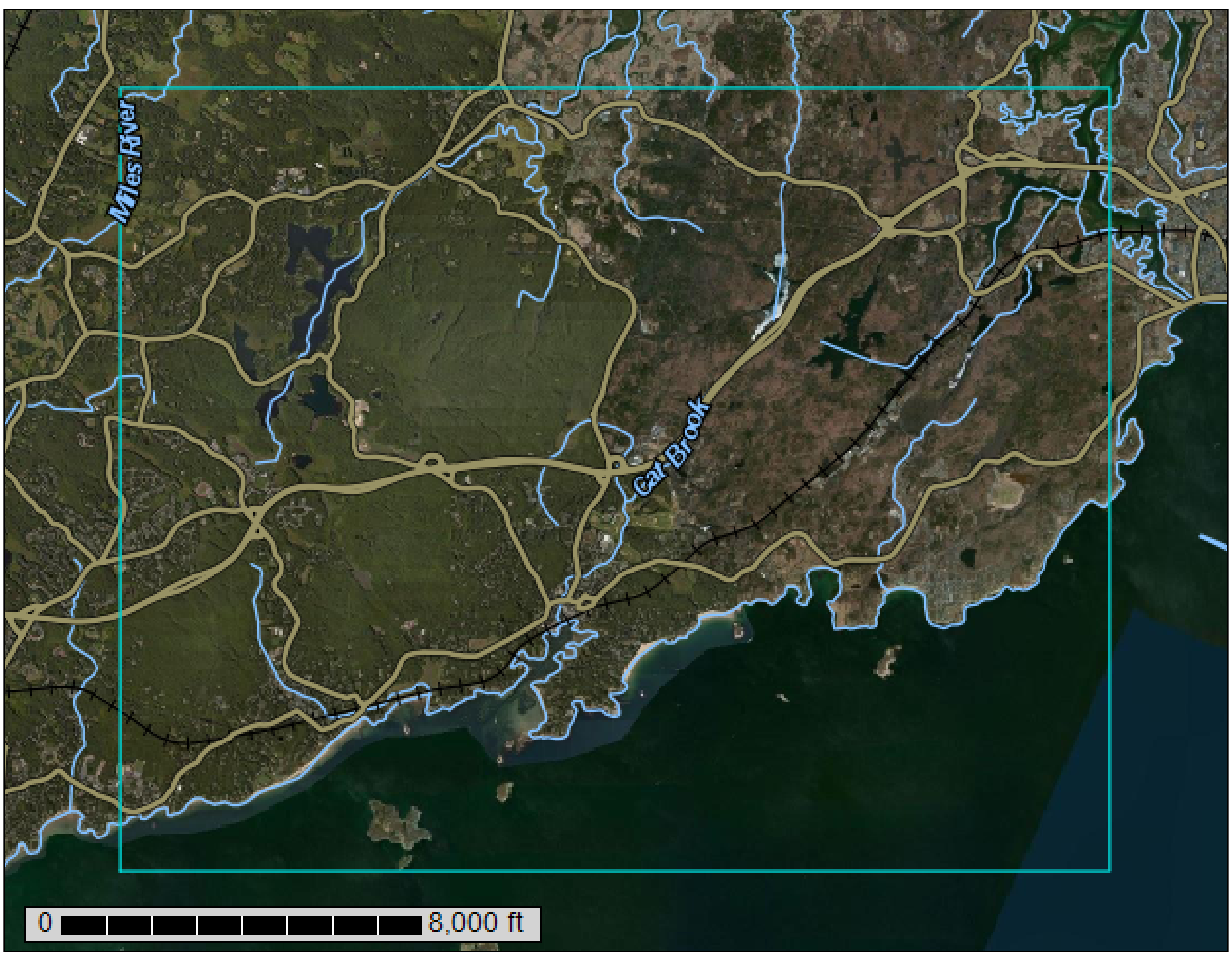
NRCS Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for

Essex County, Massachusetts, Southern Part

NOTE: The original report included additional data on the soil types. The full report can be provided upon request.



October 10, 2015

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (http://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

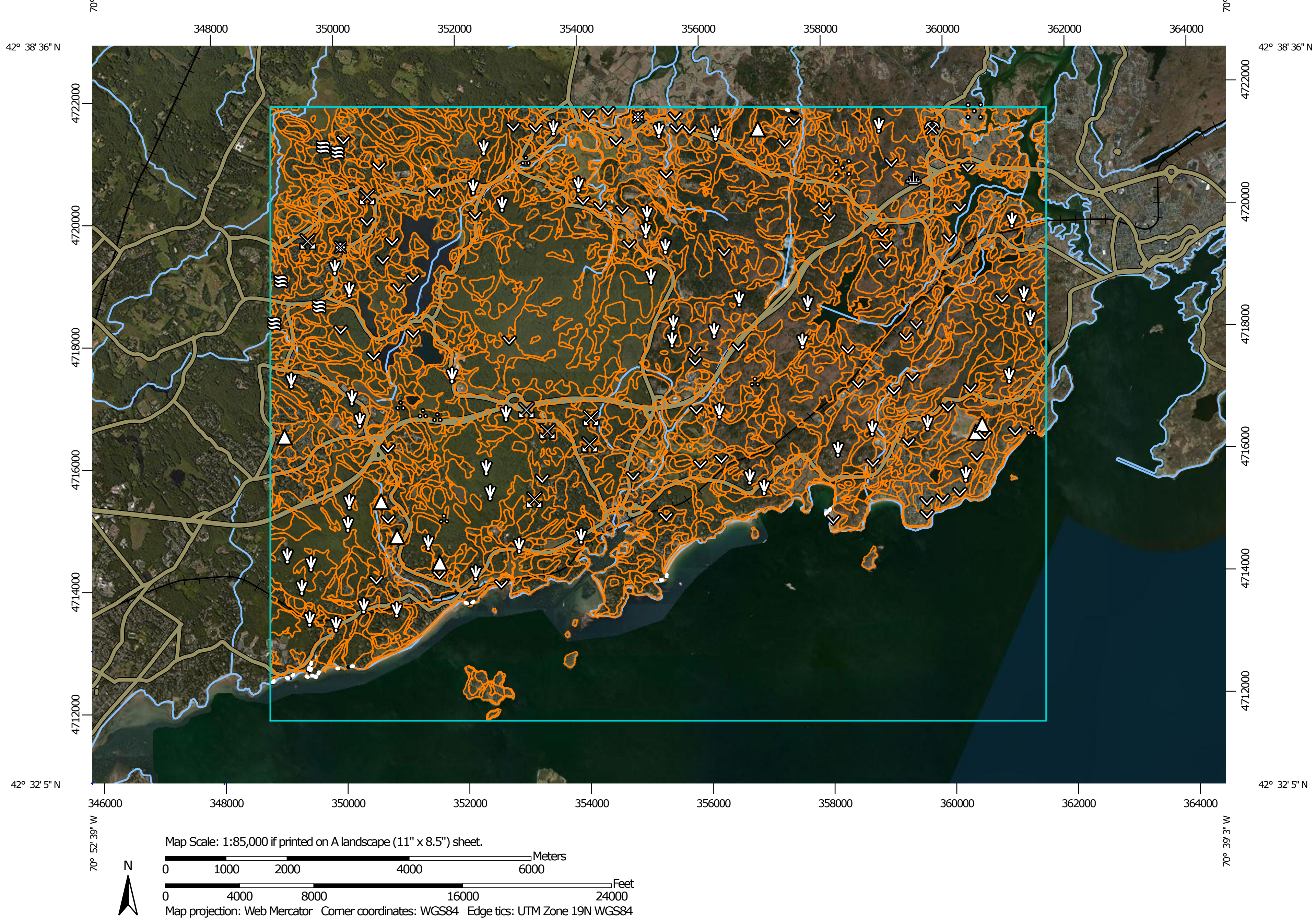
The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or a part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, D.C. 20250-9410 or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

H&H Memo Attachment B

Soil Map



H&H Memo Attachment B

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features

- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:15,800.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Essex County, Massachusetts, Southern Part
Survey Area Data: Version 11, Sep 19, 2014

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Jan 1, 1999—Sep 19, 2014

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Essex County, Massachusetts, Southern Part (MA606)			
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
1	Water	715.7	2.3%
12A	Maybid silt loam, 0 to 3 percent slopes	259.0	0.8%
14B	Scitico silt loam, 0 to 5 percent slopes	432.7	1.4%
31A	Walpole sandy loam, 0 to 3 percent slopes	166.0	0.5%
31B	Walpole fine sandy loam, 3 to 8 percent slopes	10.9	0.0%
32A	Wareham loamy sand, 0 to 3 percent slopes	101.1	0.3%
38A	Pipestone loamy fine sand, 0 to 3 percent slopes	6.3	0.0%
43A	Scarboro mucky fine sandy loam, 0 to 3 percent slopes	352.8	1.1%
51A	Swansea muck, 0 to 1 percent slopes	256.8	0.8%
52A	Freetown muck, 0 to 1 percent slopes	1,344.9	4.2%
53A	Freetown muck, ponded, 0 to 1 percent slopes MLRA 144A	107.2	0.3%
70B	Ridgebury fine sandy loam, 0 to 6 percent slopes	16.6	0.1%
71A	Ridgebury fine sandy loam, 0 to 3 percent slopes, extremely stony	27.5	0.1%
71B	Ridgebury fine sandy loam, 3 to 8 percent slopes, extremely stony	300.2	0.9%
73A	Whitman loam, 0 to 3 percent slopes, extremely stony	530.9	1.7%
102C	Chatfield-Hollis-Rock outcrop complex, 3 to 15 percent slopes	2,499.8	7.9%
102E	Chatfield-Hollis-Rock outcrop complex, 15 to 35 percent slopes	7,900.6	24.9%
105D	Rock outcrop-Hollis complex, 3 to 25 percent slopes	616.9	1.9%
220A	Boxford silt loam, 0 to 3 percent slopes	65.8	0.2%
220B	Boxford silt loam, 3 to 8 percent slopes	264.6	0.8%
220C	Boxford silt loam, 8 to 15 percent slopes	16.1	0.1%

Essex County, Massachusetts, Southern Part (MA606)			
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
225B	Belgrade very fine sandy loam, 0 to 8 percent slopes	33.8	0.1%
242A	Hinckley gravelly fine sandy loam, 0 to 3 percent slopes	222.9	0.7%
242B	Hinckley gravelly fine sandy loam, 3 to 8 percent slopes	297.2	0.9%
242C	Hinckley gravelly fine sandy loam, 8 to 15 percent slopes	124.0	0.4%
242D	Hinckley gravelly fine sandy loam, 15 to 25 percent slopes	89.7	0.3%
242E	Hinckley gravelly fine sandy loam, 25 to 45 percent slopes	49.8	0.2%
250B	Pollux fine sandy loam, 0 to 8 percent slopes	31.3	0.1%
254A	Merrimac fine sandy loam, 0 to 3 percent slopes	181.7	0.6%
254B	Merrimac fine sandy loam, 3 to 8 percent slopes	349.3	1.1%
254C	Merrimac fine sandy loam, 8 to 15 percent slopes	111.3	0.4%
254D	Merrimac fine sandy loam, 15 to 25 percent slopes	44.6	0.1%
255A	Windsor loamy sand, 0 to 3 percent slopes	15.8	0.0%
255B	Windsor loamy sand, 3 to 8 percent slopes	36.7	0.1%
255C	Windsor loamy sand, 8 to 15 percent slopes	2.4	0.0%
256A	Deerfield loamy fine sand, 0 to 3 percent slopes	121.7	0.4%
260A	Sudbury fine sandy loam, 0 to 3 percent slopes	547.6	1.7%
260B	Sudbury fine sandy loam, 3 to 8 percent slopes	237.5	0.7%
276B	Ninigret fine sandy loam, 3 to 8 percent slopes	8.3	0.0%
300B	Montauk fine sandy loam, 3 to 8 percent slopes	44.6	0.1%
300C	Montauk fine sandy loam, 8 to 15 percent slopes	2.8	0.0%
301B	Montauk fine sandy loam, 3 to 8 percent slopes, very stony	70.8	0.2%
301C	Montauk fine sandy loam, 8 to 15 percent slopes, very stony	43.5	0.1%
301D	Montauk fine sandy loam, 15 to 25 percent slopes, very stony	22.5	0.1%
302C	Montauk fine sandy loam, 8 to 15 percent slopes, extremely stony	8.9	0.0%

Essex County, Massachusetts, Southern Part (MA606)			
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
302D	Montauk fine sandy loam, 15 to 25 percent slopes, extremely stony	10.0	0.0%
305B	Paxton fine sandy loam, 3 to 8 percent slopes	37.4	0.1%
305C	Paxton fine sandy loam, 8 to 15 percent slopes	30.7	0.1%
305D	Paxton fine sandy loam, 15 to 25 percent slopes	4.6	0.0%
306B	Paxton fine sandy loam, 3 to 8 percent slopes, very stony	58.6	0.2%
306C	Paxton fine sandy loam, 8 to 15 percent slopes, very stony	28.6	0.1%
306D	Paxton fine sandy loam, 15 to 25 percent slopes, very stony	81.9	0.3%
310B	Woodbridge fine sandy loam, 3 to 8 percent slopes	44.1	0.1%
310C	Woodbridge fine sandy loam, 8 to 15 percent slopes	16.7	0.1%
311B	Woodbridge fine sandy loam, 0 to 8 percent slopes, very stony	138.7	0.4%
311C	Woodbridge fine sandy loam, 8 to 15 percent slopes, very stony	69.9	0.2%
311D	Woodbridge fine sandy loam, 15 to 25 percent slopes, very stony	14.1	0.0%
315B	Scituate fine sandy loam, 3 to 8 percent slopes	11.1	0.0%
316B	Scituate fine sandy loam, 3 to 8 percent slopes, very stony	190.4	0.6%
316C	Scituate fine sandy loam, 8 to 15 percent slopes, very stony	22.1	0.1%
317B	Scituate fine sandy loam, 3 to 8 percent slopes, extremely stony	4.3	0.0%
318B	Scituate fine sandy loam, 3 to 8 percent slopes, extremely bouldery	176.5	0.6%
318C	Scituate fine sandy loam, 8 to 15 percent slopes, extremely bouldery	53.3	0.2%
323B	Poquonock loamy sand, 3 to 8 percent slopes, very stony	14.4	0.0%
323C	Poquonock loamy sand, 8 to 15 percent slopes, very stony	30.6	0.1%
323D	Poquonock loamy sand, 15 to 25 percent slopes, very stony	10.0	0.0%

Essex County, Massachusetts, Southern Part (MA606)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
392E	Paxton and Montauk fine sandy loams, 25 to 45 percent slopes, extremely stony	4.4	0.0%
420B	Canton fine sandy loam, 3 to 8 percent slopes	25.6	0.1%
420C	Canton fine sandy loam, 8 to 20 percent slopes	3.2	0.0%
421B	Canton fine sandy loam, 3 to 8 percent slopes, very stony	139.3	0.4%
421C	Canton fine sandy loam, 8 to 15 percent slopes, very stony	168.4	0.5%
421D	Canton fine sandy loam, 15 to 25 percent slopes, very stony	76.2	0.2%
422B	Canton fine sandy loam, 3 to 8 percent slopes, extremely stony	72.6	0.2%
422C	Canton fine sandy loam, 8 to 15 percent slopes, extremely stony	162.3	0.5%
422D	Canton fine sandy loam, 15 to 25 percent slopes, extremely stony	120.7	0.4%
422E	Canton fine sandy loam, 25 to 35 percent slopes, extremely stony	45.3	0.1%
600	Pits, gravel	84.8	0.3%
602	Urban land	185.2	0.6%
607	Water, saline	421.3	1.3%
610	Beaches	65.0	0.2%
616A	Fluvaquents, frequently flooded, 0 to 3 percent slopes	11.3	0.0%
626B	Merrimac-Urban land complex, gently sloping	69.1	0.2%
651	Udorthents, smoothed	389.2	1.2%
652	Udorthents, refuse substratum	69.5	0.2%
702C	Udipsamments, rolling	7.0	0.0%
712A	Ipswich and Westbrook mucky peats, 0 to 2 percent slopes, very frequently flooded	565.2	1.8%
714B	Melrose fine sandy loam, 3 to 8 percent slopes	21.4	0.1%
720A	Whately Variant mucky fine sandy loam, 0 to 1 percent slopes	26.1	0.1%
722B	Annisquam fine sandy loam, 3 to 8 percent slopes, extremely bouldery	184.3	0.6%

Essex County, Massachusetts, Southern Part (MA606)			
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
722C	Annisquam fine sandy loam, 8 to 15 percent slopes, extremely bouldery	349.6	1.1%
722E	Annisquam fine sandy loam, 15 to 35 percent slopes, extremely bouldery	711.1	2.2%
723A	Elmridge fine sandy loam, 0 to 3 percent slopes	1.7	0.0%
723B	Elmridge fine sandy loam, 3 to 8 percent slopes	35.8	0.1%
725A	Shaker fine sandy loam, 0 to 3 percent slopes	45.0	0.1%
Subtotals for Soil Survey Area		**23,799.5**	**75.0%**
Totals for Area of Interest		**31,724.8**	**100.0%**

Map Unit Descriptions

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used. Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however, onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha-Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

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H&H Memo Attachment B

Tighe&Bond
Consulting Engineers
Environmental Specialists

Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 1**
Location:

Cover Type	Area, ac	CN	A x CN
Commercial - Soil Type A	0.0000000	89	0.0000
Commercial - Soil Type B	0.4813295	92	44.2823
Commercial - Soil Type C	0.2013695	94	18.9287
Commercial - Soil Type D	0.7687470	95	73.0310
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	59.7666670	55	3287.1667
Forest - Soil Type C	4.5745470	70	320.2183
Forest - Soil Type D	22.3574500	77	1721.5237
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	3.3827060	88	297.6781
Industrial - Soil Type C	1.5265560	91	138.9166
Industrial - Soil Type D	0.1003350	93	9.3312
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	0.1823675	61	11.1244
Open Space - Soil Type C	0.1823675	74	13.4952
Open Space - Soil Type D	0.0000000	80	0.0000
Open Water	0.7380440	98	72.3283
Residential - Soil Type A	0.0000000	51	0.0000
Residential - Soil Type B	21.2265220	68	1443.4035
Residential - Soil Type C	3.0271120	79	239.1418
Residential - Soil Type D	5.8960520	84	495.2684
	124.4121720		8185.8382

Weighted CN: 66

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.16	22.2

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.11	5.35	610	1.9
Segment C - D	unpaved	0.02	2.28	230	1.7
Segment D - E	unpaved	0.15	6.25	210	0.6
Segment E - F	unpaved	0.01	1.61	620	6.4

Total Tc = 32.7 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

Tighe&Bond
Consulting Engineers
Environmental Specialists

Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 2**
Location:

Cover Type	Area, ac	CN	A x CN
Commercial - Soil Type A	0.0000000	89	0.0000
Commercial - Soil Type B	0.0295055	92	2.7145
Commercial - Soil Type C	0.0295055	94	2.7735
Commercial - Soil Type D	0.0000000	95	0.0000
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	78.5247715	55	4318.8624
Forest - Soil Type C	1.0337415	70	72.3619
Forest - Soil Type D	39.3928500	77	3033.2495
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	6.6709650	88	587.0449
Industrial - Soil Type C	5.1479850	91	468.4666
Industrial - Soil Type D	3.2584850	93	303.0391
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	0.3073545	61	18.7486
Open Space - Soil Type C	0.0123755	74	0.9158
Open Space - Soil Type D	0.0000000	80	0.0000
Residential - Soil Type A	0.0000000	51	0.0000
Residential - Soil Type B	2.1432190	68	145.7389
Residential - Soil Type C	0.2189090	79	17.2938
Residential - Soil Type D	0.3870230	84	32.5099
	137.1566900		9003.7195

Weighted CN: 66

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.06	32.8

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.055	3.78	290	1.3
Segment C - D	unpaved	0.01	1.61	3990	41.2

Total Tc = 75.3 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

Tighe&Bond
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Environmental Specialists

Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 3**
Location:

Cover Type	Area, ac	CN	A x CN
Commercial - Soil Type A	0.0000000	89	0.0000
Commercial - Soil Type B	0.0000000	92	0.0000
Commercial - Soil Type C	0.0000000	94	0.0000
Commercial - Soil Type D	0.0000000	95	0.0000
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	91.2347725	55	5017.9125
Forest - Soil Type C	0.4559385	70	31.9157
Forest - Soil Type D	25.7968300	77	1986.3559
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	0.0000000	88	0.0000
Industrial - Soil Type C	0.0000000	91	0.0000
Industrial - Soil Type D	0.4411070	93	41.0230
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	0.7374990	61	44.9874
Open Space - Soil Type C	0.0000000	74	0.0000
Open Space - Soil Type D	2.3157050	80	185.2564
Residential - Soil Type A	0.0000000	51	0.0000
Residential - Soil Type B	0.0000000	68	0.0000
Residential - Soil Type C	0.0000000	79	0.0000
Residential - Soil Type D	0.0000000	84	0.0000
	120.9818520		7307.4509

Weighted CN: 60

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.12	24.9

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.18	6.85	365	0.9
Segment C - D	unpaved	0.02	2.28	2150	15.7
Segment D - E	unpaved	0.01	1.61	1660	17.1

Total Tc = 58.6 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

Tighe&Bond
Consulting Engineers
Environmental Specialists

Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 4**
Location:

Cover Type	Area, ac	CN	A x CN
Cultivated Land - Soil Type A	0.0000000	72	0.0000
Cultivated Land - Soil Type B	0.2832580	81	22.9439
Cultivated Land - Soil Type C	0.0000000	88	0.0000
Cultivated Land - Soil Type D	0.0000000	91	0.0000
Commercial - Soil Type A	0.0000000	89	0.0000
Commercial - Soil Type B	0.2121410	92	19.5170
Commercial - Soil Type C	0.0000000	94	0.0000
Commercial - Soil Type D	0.3709880	95	35.2439
Forest - Soil Type A	1.9701730	25	49.2543
Forest - Soil Type B	66.3823440	55	3651.0289
Forest - Soil Type C	7.9728160	70	558.0971
Forest - Soil Type D	6.7207360	77	517.4967
Industrial - Soil Type A	0.1547980	81	12.5386
Industrial - Soil Type B	0.8209655	88	72.2450
Industrial - Soil Type C	0.7870605	91	71.6225
Industrial - Soil Type D	0.0000000	93	0.0000
Open Space - Soil Type A	1.0156190	39	39.6091
Open Space - Soil Type B	2.1298345	61	129.9199
Open Space - Soil Type C	1.8269695	74	135.1957
Open Space - Soil Type D	0.0000000	80	0.0000
Open Water	0.0160190	98	1.5699
Residential - Soil Type A	2.1383920	51	109.0580
Residential - Soil Type B	53.2291420	68	3619.5817
Residential - Soil Type C	2.8236280	79	223.0666
Residential - Soil Type D	3.7732600	84	316.9538
	152.6281440		9584.9426

Weighted CN: 63

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.07	30.9

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.12	5.59	365	1.1
Segment C - D	unpaved	0.01	1.61	3390	35.0

Total Tc = 67.0 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 5**
Location:

Cover Type	Area, ac	CN	A x CN
Commercial - Soil Type A	0.0000000	89	0.0000
Commercial - Soil Type B	4.5807180	92	421.4261
Commercial - Soil Type C	0.0000000	94	0.0000
Commercial - Soil Type D	0.4414000	95	41.9330
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	400.1507000	55	22008.2885
Forest - Soil Type C	7.0185110	70	491.2958
Forest - Soil Type D	158.6166000	77	12213.4782
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	2.7357220	88	240.7435
Industrial - Soil Type C	0.0000000	91	0.0000
Industrial - Soil Type D	0.0000000	93	0.0000
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	5.1837990	61	316.2117
Open Space - Soil Type C	0.0546360	74	4.0431
Open Space - Soil Type D	5.0924340	80	407.3947
Residential - Soil Type A	0.0000000	51	0.0000
Residential - Soil Type B	0.8820270	68	59.9778
Residential - Soil Type C	0.0000000	79	0.0000
Residential - Soil Type D	0.7779140	84	65.3448
	585.5344610		36270.1372

Weighted CN: 62

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.1	26.8

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.11	5.35	340	1.1
Segment C - D	unpaved	0.023	2.45	2840	19.3
Segment D - E	unpaved	0.005	1.14	4300	62.8

Total Tc = 110.0 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 6**
Location:

Cover Type	Area, ac	CN	A x CN
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	77.1055250	55	4240.8039
Forest - Soil Type C	31.6154950	70	2213.0847
Forest - Soil Type D	79.9118000	77	6153.2086
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	4.7944175	88	421.9087
Industrial - Soil Type C	2.9058525	91	264.4326
Industrial - Soil Type D	5.7669230	93	536.3238
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	0.7483435	61	45.6490
Open Space - Soil Type C	0.2092595	74	15.4852
Open Space - Soil Type D	0.0771170	80	6.1694
Open Water	1.5568290	98	152.5692
Residential - Soil Type A	0.0000000	51	0.0000
Residential - Soil Type B	11.6022500	68	788.9530
Residential - Soil Type C	1.1815200	79	93.3401
Residential - Soil Type D	4.9056750	84	412.0767
	222.3810070		15344.0048

Weighted CN: 69

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.15	22.7

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.1	5.10	620	2.0
Segment C - D	unpaved	0.004	1.02	4890	79.9

Total Tc = 104.6 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 7**
Location:

Cover Type	Area, ac	CN	A x CN
Commercial - Soil Type A	0.0000000	89	0.0000
Commercial - Soil Type B	7.6448645	92	703.3275
Commercial - Soil Type C	1.5274255	94	143.5780
Commercial - Soil Type D	0.1847730	95	17.5534
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	82.2797180	55	4525.3845
Forest - Soil Type C	22.0388780	70	1542.7215
Forest - Soil Type D	54.5009900	77	4196.5762
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	7.4969680	88	659.7332
Industrial - Soil Type C	3.2601710	91	296.6756
Industrial - Soil Type D	0.4708370	93	43.7878
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	0.7639410	61	46.6004
Open Space - Soil Type C	0.0000000	74	0.0000
Open Space - Soil Type D	5.8189200	80	465.5136
Residential - Soil Type A	0.0000000	51	0.0000
Residential - Soil Type B	8.3506505	68	567.8442
Residential - Soil Type C	3.9453645	79	311.6838
Residential - Soil Type D	0.7794350	84	65.4725
	199.0629360		13586.4523

Weighted CN: 68

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.3	17.2

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.06	3.95	1290	5.4
Segment C - D	unpaved	0.005	1.14	1211	17.7
Segment D - E	unpaved	0.01	1.61	841	8.7

Total Tc = 49.1 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 8**
Location:

Cover Type	Area, ac	CN	A x CN
Commercial - Soil Type A	0.0030000	89	0.2670
Commercial - Soil Type B	0.8806055	92	81.0157
Commercial - Soil Type C	0.1805565	94	16.9723
Commercial - Soil Type D	0.0000000	95	0.0000
Forest - Soil Type A	1.3140500	25	32.8513
Forest - Soil Type B	24.5143300	55	1348.2882
Forest - Soil Type C	16.4080900	70	1148.5663
Forest - Soil Type D	0.0396170	77	3.0505
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	7.8476305	88	690.5915
Industrial - Soil Type C	6.2926515	91	572.6313
Industrial - Soil Type D	0.1354370	93	12.5956
Open Space - Soil Type A	1.1303490	39	44.0836
Open Space - Soil Type B	0.0010770	61	0.0657
Open Space - Soil Type C	0.0000000	74	0.0000
Open Space - Soil Type D	0.0000000	80	0.0000
Residential - Soil Type A	2.6127490	51	133.2502
Residential - Soil Type B	5.6295575	68	382.8099
Residential - Soil Type C	3.6306515	79	286.8215
Residential - Soil Type D	0.0000000	84	0.0000
	70.6203520		4753.8605

Weighted CN: 67

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.15	22.7

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.008	1.44	1420	16.4

Total Tc = 39.1 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 9**
Location:

Cover Type	Area, ac	CN	A x CN
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	114.3190950	55	6287.5502
Forest - Soil Type C	11.3404050	70	793.8284
Forest - Soil Type D	23.0580800	77	1775.4722
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	0.8992280	88	79.1321
Industrial - Soil Type C	0.0000000	91	0.0000
Industrial - Soil Type D	0.0000000	93	0.0000
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	0.5846950	61	35.6664
Open Space - Soil Type C	0.8978510	74	66.4410
Open Space - Soil Type D	2.0889870	80	167.1190
	153.1883410		9205.2091

Weighted CN: 60

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.15	22.7

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.1	5.10	530	1.7
Segment C - D	unpaved	0.008	1.44	3540	40.9

Total Tc = 65.4 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 10**
Location:

Cover Type	Area, ac	CN	A x CN
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	49.0138700	55	2695.7629
Forest - Soil Type C	9.5524960	70	668.6747
Forest - Soil Type D	12.5813700	77	968.7655
	71.1477360		4333.2031

Weighted CN: 61

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.12	24.9

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.02	2.28	2254	16.5

Total Tc = 41.3 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 11**
Location:

Cover Type	Area, ac	CN	A x CN
Cultivated Land - Soil Type A	0.0000000	72	0.0000
Cultivated Land - Soil Type B	0.0685500	81	5.5526
Cultivated Land - Soil Type C	0.0685500	88	6.0324
Cultivated Land - Soil Type D	0.8803650	91	80.1132
Forest - Soil Type A	2.6996860	25	67.4922
Forest - Soil Type B	91.1689330	55	5014.2913
Forest - Soil Type C	63.1804330	70	4422.6303
Forest - Soil Type D	16.5103600	77	1271.2977
Open Space - Soil Type A	0.6526330	39	25.4527
Open Space - Soil Type B	0.9131650	61	55.7031
Open Space - Soil Type C	1.6288510	74	120.5350
Open Space - Soil Type D	0.5415190	80	43.3215
Open Water	0.2306420	98	22.6029
Residential - Soil Type A	2.4906710	51	127.0242
Residential - Soil Type B	4.3719895	68	297.2953
Residential - Soil Type C	8.4222135	79	665.3549
Residential - Soil Type D	1.5005030	84	126.0423
	195.3290640		12350.7414

Weighted CN: 63

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.05	35.3

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.07	4.27	840	3.3
Segment C - D	unpaved	0.01	1.61	4120	42.6

Total Tc = 81.1 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 12**
Location:

Cover Type	Area, ac	CN	A x CN
Cultivated Land - Soil Type A	0.6340950	72	45.6548
Cultivated Land - Soil Type B	0.0069025	81	0.5591
Cultivated Land - Soil Type C	0.2796655	88	24.6106
Cultivated Land - Soil Type D	0.1347230	91	12.2598
Forest - Soil Type A	2.6848930	25	67.1223
Forest - Soil Type B	6.1097505	55	336.0363
Forest - Soil Type C	10.8562465	70	759.9373
Forest - Soil Type D	4.3346270	77	333.7663
Open Water	2.5482710	98	249.7306
Residential - Soil Type A	1.5636160	51	79.7444
Residential - Soil Type B	1.0276765	68	69.8820
Residential - Soil Type C	4.7672715	79	376.6144
Residential - Soil Type D	0.1794950	84	15.0776
	35.1272330		2370.9954

Weighted CN: 67

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.086	28.4

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.056	3.82	920	4.0
Segment C - D	unpaved	0.012	1.77	1290	12.2

Total Tc = 44.6 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 13**
Location:

Cover Type	Area, ac	CN	A x CN
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	15.0106400	55	825.5852
Forest - Soil Type C	16.3488900	70	1144.4223
Forest - Soil Type D	0.6096530	77	46.9433
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	1.6537130	88	145.5267
Industrial - Soil Type C	2.7249300	91	247.9686
Industrial - Soil Type D	0.2542820	93	23.6482
	36.6021080		2434.0944

Weighted CN: 67

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.053	34.5

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.11	5.35	700	2.2
Segment C - D	unpaved	0.01	1.61	2595	26.8

Total Tc = 63.5 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 14**
Location:

Cover Type	Area, ac	CN	A x CN
Cultivated Land - Soil Type A	0.0610400	72	4.3949
Cultivated Land - Soil Type B	0.0000000	81	0.0000
Cultivated Land - Soil Type C	0.1430460	88	12.5880
Cultivated Land - Soil Type D	0.0000000	91	0.0000
Commercial - Soil Type A	0.0000000	89	0.0000
Commercial - Soil Type B	0.7424845	92	68.3086
Commercial - Soil Type C	0.6956585	94	65.3919
Commercial - Soil Type D	0.0000000	95	0.0000
Forest - Soil Type A	4.3478540	25	108.6964
Forest - Soil Type B	64.2755335	55	3535.1543
Forest - Soil Type C	35.1635835	70	2461.4508
Forest - Soil Type D	43.7558400	77	3369.1997
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	7.6404400	88	672.3587
Industrial - Soil Type C	13.8440500	91	1259.8086
Industrial - Soil Type D	0.8397800	93	78.0995
Open Space - Soil Type A	2.5349470	39	98.8629
Open Space - Soil Type B	5.6881740	61	346.9786
Open Space - Soil Type C	3.3474700	74	247.7128
Open Space - Soil Type D	0.5405180	80	43.2414
Residential - Soil Type A	0.4185010	51	21.3436
Residential - Soil Type B	2.8704970	68	195.1938
Residential - Soil Type C	1.4716380	79	116.2594
Residential - Soil Type D	0.8012590	84	67.3058
	189.1823140		12772.3497

Weighted CN: 68

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.086	28.4

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.11	5.35	825	2.6
Segment C - D	unpaved	0.01	1.61	3590	37.1
Segment E - F	unpaved	0.015	1.98	1900	16.0

Total Tc = 84.1 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 15**
Location:

Cover Type	Area, ac	CN	A x CN
Commercial - Soil Type A	1.1053290	89	98.3743
Commercial - Soil Type B	2.7624160	92	254.1423
Commercial - Soil Type C	3.6066940	94	339.0292
Commercial - Soil Type D	0.0000000	95	0.0000
Forest - Soil Type A	1.4780120	25	36.9503
Forest - Soil Type B	7.0487515	55	387.6813
Forest - Soil Type C	11.6029625	70	812.2074
Forest - Soil Type D	0.0000000	77	0.0000
Open Space - Soil Type A	6.2413210	39	243.4115
Open Space - Soil Type B	4.3844480	61	267.4513
Open Space - Soil Type C	12.2569380	74	907.0134
Open Space - Soil Type D	0.0000000	80	0.0000
Open Water	0.7575120	98	74.2362
Residential - Soil Type A	2.8504210	51	145.3715
Residential - Soil Type B	1.2505335	68	85.0363
Residential - Soil Type C	1.6199555	79	127.9765
Residential - Soil Type D	0.0039260	84	0.3298
	56.9692200		3779.2112

Weighted CN: 66

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.12	24.9

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.11	5.35	225	0.7
Segment C - D	unpaved	0.013	1.84	2420	21.9

Total Tc = 47.5 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 16**
Location:

Cover Type	Area, ac	CN	A x CN
Cultivated Land - Soil Type A	0.0000000	72	0.0000
Cultivated Land - Soil Type B	0.0000000	81	0.0000
Cultivated Land - Soil Type C	0.0738820	88	6.5016
Cultivated Land - Soil Type D	0.0000000	91	0.0000
Commercial - Soil Type A	0.5998970	89	53.3908
Commercial - Soil Type B	6.2823150	92	577.9730
Commercial - Soil Type C	6.9572250	94	653.9792
Commercial - Soil Type D	0.0000000	95	0.0000
Forest - Soil Type A	1.0710070	25	26.7752
Forest - Soil Type B	25.8914065	55	1424.0274
Forest - Soil Type C	27.1233665	70	1898.6357
Forest - Soil Type D	3.3719570	77	259.6407
Open Space - Soil Type A	28.2593400	39	1102.1143
Open Space - Soil Type B	16.9178495	61	1031.9888
Open Space - Soil Type C	29.2607295	74	2165.2940
Open Space - Soil Type D	0.0000000	80	0.0000
Residential - Soil Type A	7.6001010	51	387.6052
Residential - Soil Type B	16.7912330	68	1141.8038
Residential - Soil Type C	17.5399530	79	1385.6563
Residential - Soil Type D	1.6941540	84	142.3089
	189.4344160		12257.6947

Weighted CN: 65

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.19	20.7

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.04	3.23	1395	7.2
Segment C - D	unpaved	0.005	1.14	3055	44.6

Total Tc = 72.5 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 17**
Location:

Cover Type	Area, ac	CN	A x CN
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	58.8637300	55	3237.5052
Forest - Soil Type C	7.2655540	70	508.5888
Forest - Soil Type D	16.8892200	77	1300.4699
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	0.8738010	88	76.8945
Industrial - Soil Type C	0.0000000	91	0.0000
Industrial - Soil Type D	0.3864040	93	35.9356
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	0.0983860	61	6.0015
Open Space - Soil Type C	0.5108140	74	37.8002
Open Space - Soil Type D	0.2498860	80	19.9909
Open Water	2.3070120	98	226.0872
Residential - Soil Type A	0.0000000	51	0.0000
Residential - Soil Type B	8.9858820	68	611.0400
Residential - Soil Type C	2.2805250	79	180.1615
Residential - Soil Type D	0.5916320	84	49.6971
	99.3028460		6290.1723

Weighted CN: 63

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.06	32.8

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.09	4.84	1150	4.0
Segment C - D	unpaved	0.01	1.61	3280	33.9

Total Tc = 70.7 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 18**
Location:

Cover Type	Area, ac	CN	A x CN
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	67.5319475	55	3714.2571
Forest - Soil Type C	8.9334105	70	625.3387
Forest - Soil Type D	10.7447800	77	827.3481
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	2.3922210	88	210.5154
Industrial - Soil Type C	0.6760360	91	61.5193
Industrial - Soil Type D	1.8701820	93	173.9269
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	1.0169250	61	62.0324
Open Space - Soil Type C	0.3940770	74	29.1617
Open Space - Soil Type D	3.7764440	80	302.1155
Residential - Soil Type A	0.0000000	51	0.0000
Residential - Soil Type B	12.0038800	68	816.2638
Residential - Soil Type C	0.0974100	79	7.6954
Residential - Soil Type D	0.2069950	84	17.3876
	109.6443080		6847.5620

Weighted CN: 62

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.09	27.9

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.12	5.59	505	1.5
Segment C - D	unpaved	0.011	1.69	4615	45.5

Total Tc = 74.9 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 19**
Location:

Cover Type	Area, ac	CN	A x CN
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	56.7524920	55	3121.3871
Forest - Soil Type C	10.5942720	70	741.5990
Forest - Soil Type D	10.8942400	77	838.8565
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	0.9408105	61	57.3894
Open Space - Soil Type C	0.9948375	74	73.6180
Open Space - Soil Type D	6.1952120	80	495.6170
Open Water	3.8543420	98	377.7255
Residential - Soil Type A	0.0000000	51	0.0000
Residential - Soil Type B	17.0980300	68	1162.6660
Residential - Soil Type C	2.7846000	79	219.9834
Residential - Soil Type D	0.3797200	84	31.8965
	110.4885560		7120.7384

Weighted CN: 64

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.1	26.8

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.064	4.08	1190	4.9
Segment C - D	unpaved	0.013	1.84	1430	13.0

Total Tc = 44.6 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 20**
Location:

Cover Type	Area, ac	CN	A x CN
Commercial - Soil Type A	0.0000000	89	0.0000
Commercial - Soil Type B	0.5878800	92	54.0850
Commercial - Soil Type C	0.8112100	94	76.2537
Commercial - Soil Type D	0.0089780	95	0.8529
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	6.0729415	55	334.0118
Forest - Soil Type C	4.2213490	70	295.4944
Forest - Soil Type D	7.7075540	77	593.4817
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	0.4432680	88	39.0076
Industrial - Soil Type C	0.3894590	91	35.4408
Industrial - Soil Type D	1.6570170	93	154.1026
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	0.0000000	61	0.0000
Open Space - Soil Type C	0.0000000	74	0.0000
Open Space - Soil Type D	0.0003650	80	0.0292
Open Water	0.3600720	98	35.2871
Residential - Soil Type A	0.0000000	51	0.0000
Residential - Soil Type B	1.8431930	68	125.3371
Residential - Soil Type C	8.6666330	79	684.6640
Residential - Soil Type D	3.5837980	84	301.0390
	36.3537175		2729.0868

Weighted CN: 75

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.13	24.1

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.07	4.27	470	1.8
Segment C - D	unpaved	0.005	1.14	2085	30.5

Total Tc = 56.4 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 21**
Location:

Cover Type	Area, ac	CN	A x CN
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	30.9244700	55	1700.8459
Forest - Soil Type C	7.7738120	70	544.1668
Forest - Soil Type D	17.5871800	77	1354.2129
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	0.2626280	61	16.0203
Open Space - Soil Type C	0.1036110	74	7.6672
Open Space - Soil Type D	1.6182250	80	129.4580
Open Water	0.5985200	98	58.6550
Residential - Soil Type A	0.0000000	51	0.0000
Residential - Soil Type B	14.9731800	68	1018.1762
Residential - Soil Type C	0.1875550	79	14.8168
Residential - Soil Type D	0.4614880	84	38.7650
	74.4906690		4882.7841

Weighted CN: 66

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.19	20.7

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.015	1.98	2355	19.9

Total Tc = 40.6 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 22**
Location:

Cover Type	Area, ac	CN	A x CN
Commercial - Soil Type A	0.0000000	89	0.0000
Commercial - Soil Type B	1.6856195	92	155.0770
Commercial - Soil Type C	4.4715885	94	420.3293
Commercial - Soil Type D	1.0450260	95	99.2775
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	11.5052245	55	632.7873
Forest - Soil Type C	8.3242075	70	582.6945
Forest - Soil Type D	5.8662210	77	451.6990
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	1.6990270	61	103.6406
Open Space - Soil Type C	8.0298160	74	594.2064
Open Space - Soil Type D	0.0000000	80	0.0000
Open Water	0.2445050	98	23.9615
Residential - Soil Type A	0.0000000	51	0.0000
Residential - Soil Type B	5.1140770	68	347.7572
Residential - Soil Type C	20.2266740	79	1597.9072
Residential - Soil Type D	1.3563090	84	113.9300
	69.5682950		5123.2676

Weighted CN: 74

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.2	20.3

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.01	1.61	2640	27.3

Total Tc = 47.5 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 23**
Location:

Cover Type	Area, ac	CN	A x CN
Cultivated Land - Soil Type A	0.0000000	72	0.0000
Cultivated Land - Soil Type B	0.1615515	81	13.0857
Cultivated Land - Soil Type C	1.1720855	88	103.1435
Cultivated Land - Soil Type D	0.0000000	91	0.0000
Commercial - Soil Type A	1.0393830	89	92.5051
Commercial - Soil Type B	6.1427160	92	565.1299
Commercial - Soil Type C	14.1682360	94	1331.8142
Commercial - Soil Type D	0.0000000	95	0.0000
Forest - Soil Type A	1.1550670	25	28.8767
Forest - Soil Type B	31.1801290	55	1714.9071
Forest - Soil Type C	8.2102310	70	574.7162
Forest - Soil Type D	0.0000000	77	0.0000
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	0.0000000	88	0.0000
Industrial - Soil Type C	2.2760550	91	207.1210
Industrial - Soil Type D	0.0000000	93	0.0000
Open Space - Soil Type A	1.2117320	39	47.2575
Open Space - Soil Type B	0.0000000	61	0.0000
Open Space - Soil Type C	0.1933880	74	14.3107
Open Space - Soil Type D	0.0000000	80	0.0000
Open Water	1.9125480	98	187.4297
Residential - Soil Type A	17.9797300	51	916.9662
Residential - Soil Type B	21.4814870	68	1460.7411
Residential - Soil Type C	38.9467670	79	3076.7946
Residential - Soil Type D	0.0000000	84	0.0000
	147.2311060		10218.5700

Weighted CN: 69

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.013	60.5

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.017	2.10	2970	23.5

Total Tc = 84.0 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

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Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Existing Conditions CN & Tc Calculations**
Prepared By: **CRD** Date: **September 8, 2015**

Designation: **Area 24**
Location:

Cover Type	Area, ac	CN	A x CN
Commercial - Soil Type A	1.9172210	89	170.6327
Commercial - Soil Type B	4.5329700	92	417.0332
Commercial - Soil Type C	5.4558450	94	512.8494
Commercial - Soil Type D	0.0000000	95	0.0000
Forest - Soil Type A	0.0000000	25	0.0000
Forest - Soil Type B	26.7715400	55	1472.4347
Forest - Soil Type C	0.1550690	70	10.8548
Forest - Soil Type D	3.0804360	77	237.1936
Industrial - Soil Type A	0.0000000	81	0.0000
Industrial - Soil Type B	2.2327755	88	196.4842
Industrial - Soil Type C	2.2327755	91	203.1826
Industrial - Soil Type D	0.0000000	93	0.0000
Open Space - Soil Type A	0.0000000	39	0.0000
Open Space - Soil Type B	0.0024505	61	0.1495
Open Space - Soil Type C	0.3150935	74	23.3169
Open Space - Soil Type D	0.0000000	80	0.0000
Open Water	8.1189770	98	795.6597
Residential - Soil Type A	0.5921410	51	30.1992
Residential - Soil Type B	20.2509870	68	1377.0671
Residential - Soil Type C	11.8766070	79	938.2520
Residential - Soil Type D	0.0000000	84	0.0000
	87.5348880		6385.3097

Weighted CN: 73

Time of Concentration

(computed in accordance with ConnDOT Drainage Manual, Sec. 6C)

Overland				
Segment	**Surface "n"**	**Flow Length (ft.)**	**Slope (ft/ft)**	**Time (min.)**
Segment A - B	0.4	300	0.06	32.8

Shallow Concentrated Flow					
Segment		**Slope (ft/ft)**	**V (ft/s)**	**Length (ft)**	**Time (min.)**
Segment B - C	unpaved	0.165	6.55	230	0.6
Segment C - D	unpaved	0.017	2.10	3465	27.5

Total Tc = 60.9 Min.

Note: Overland time of concentration computed using "Kinematic Wave" equation
Gutter and pipe time of concentration computed using Manning's equation

H&H Memo Attachment B

Appendix A-3
Saw Mill Brook Culvert Summary

Culvert #	Stream	Street	Inlet Dimensions (ft)		Inlet Elevation	Doucet Inlet Elevation	Doucet Road Centerline	Top of Road	Outlet Dimensions (ft)		Outlet Elevation	Doucet Outlet Elevation	Top of Road	Length (ft)	# of Crossings	Culvert Type	Culvert	
			Width	Height					Width	Height							Material	Condition
2	Cedar Swamp	School Street	2.67	2.67	40.20	***39.20***	***44.90***	45.80	3.33	2.83	39.10	***39.30***	45.80	45.00	3	box culvert	Dry Stone	old
2a	Cedar Swamp	School Street	1.50	1.50	41.40	***40.00***	***44.70***	45.40	1.50	1.50	41.10	***40..7***	45.40			round culvert	clay pipie	
2b	Cedar Swamp	School Street	3.00	2.58	40.80	***39.50***	***39.10***	44.90	3.00	3.33	40.40	***39.10***	45.00			dry stone culvert box		
3	Sawmill Brook	School Street	15.35	6.58	40.10	***38.40***	***48.10***	50.10	15.35	6.58	40.20	***38.40***	48.90	58.00	1	open bottom arch	Metal	new
4	Sawmill Brook	Atwater Avenue	14.70	8.30		***37.70***	***48.10***		14.70	8.30		***37.70***		42.00	1	open bottom arch	Metal	old
5	Sawmill Brook	Conservation Winchester Drive	9.00	5.58	40.10			47.10	9.00	5.67	39.80		47.10	38.00	1	open bottom arch	Metal	rusted
6	Sawmill Brook	School Street	1.10	1.10	N/A			N/A	1.10	1.10	N/A		N/A	28.00	1	round culvert	Concrete	new
7	Cat Brook	Forrest Road	11.60	2.90	43.60			48.20	11.60	2.90	43.90		48.50	20.20	1	open bottom arch	Stone	old- collapsing
8	Cat Brook	Load Place	2.00	2.00	44.30			47.90	2.00	2.00	44.30		47.30	30.70	3	round culvert	Plastic	new
9	Sawmill Brook	Pine Street	2.92	2.92	N/A			N/A	2.92	2.92	N/A		N/A	42.00	2	round culvert	Metal	old
10	Sawmill Brook	Rockwood Heights	1.83	1.58	N/A				1.83	1.25	N/A		N/A	25.00	2	embedded round culvert	concrete/stone	old
11	Cat Brook	Mill Street	12.50	3.70	33.50			40.40	12.00	5.58	31.70		40.50	20.10	1	open bottom arch	concrete	
12	Sawmill Brook	Millet Lane	5.00	5.00	46.50			49.30	2.50	2.50	46.30		52.20	35.00	1	round culvert	Concrete/metal	rusty outlet
13	Sawmill Brook	The Plains	5.00	2.00	45.80			51.20	5.00	2.75	45.00		51.80	40.00	1	open bottom arch (actually round)	Concrete	new
15	Sawmill Brook	Blue Heron Lane	2.50	2.50	N/A			N/A	2.50	2.50	N/A		N/A	28.00	1	open bottom arch	concrete	new
16	Sawmill Brook	Golf Course	12.00	9.42	11.50			21.60	11.50	9.58	11.40		21.60	20.00	*1*	*open bottom box culvert*	*stone*	
17	Sawmill Brook	Lincoln Street	12.00	6.00		***8.70***	***17.30***		12.00	6.00		***8.60***		50.00	1	open bottom arch	stone	good

H&H Memo Attachment B

Table 2-1
Saw Mill Brook Culvert Summary

Culvert #	Stream	Street	Inlet Dimensions (ft)		Inlet Elevation	Doucet Inlet Elevation	Doucet Road Centerline	Top of Road	Outlet Dimensions (ft)		Outlet Elevation	Doucet Outlet Elevation	Top of Road	Length (ft)	# of Crossings	Culvert Type	Culvert	
			Width	Height					Width	Height							Material	Condition
18	Causeway Brook	Lincoln Street	14.50	3.67		8.20	16.30		13.00	3.67		8.20		60.00	1	open bottom arch	stone	old but good
19	Causeway Brook	School Street- Golf	8.33	4.50		9.00	15.60		7.75	4.08		8.90		41.25	1	open bottom arch	metal	old but good
20	Causeway Brook	Summer Street	8.17	4.25		10.70	17.90		10.25	4.92		10.70		15.00	1	open bottom arch	metal	old
21	Causeway Brook	Summer Street	5.42	3.10	N/A			N/A	5.42	3.10	N/A		N/A	59.25	1	box culvert	concrete	old
22	Sawmill Brook	Norwood Avenue	14.25	5.50		7.50	16.00		13.00	5.42		7.50		42.00	1	bridge with abutments	metal/stone	old
23	Sawmill Brook	School Street	8.76	4.67		3.60	13.10		8.92	4.83		3.10		36.00	2	open bottom arch	concrete/stone	old
24	Causeway Brook	Summer Street	3.58	2.10	N/A			N/A	1.58	1.58	N/A		N/A	60.15	1	upstream bridge with abutments, dowstream round culvert	concrete/plastic	old- rusted
25	Sawmill Brook	Central Street	16.00	6.67		-0.04	10.60		14.00	8.25		-4.00		42.00	1	open bottom arch	stone	old collapsing
26	Sawmill Brook	MassDOT Mill Street	14.70	8.10		17.80			14.70	8.10		17.50			1	bridge with abutments	concrete	old
27	Sawmill Brook	Mill Street	7.10	7.10		16.20	24.40		6.80	6.80		15.60		47.00	1	round culvert	metal	old
30	Sawmill Brook	MassDOT Rte 128	14.00	6.50	26.1			44.6	14	6.5	18.3		45,5	60	1	box culvert	concrete	
36	Sawmill Brook	Mass DOT Rte 128 ramp	14.00	8.00	31.4			53.8	14	8	31.4		51.6	60	1	box culvert	concrete	

Notes:
July 2015 Survey completed by Doucet Survey Associates. Horizontal datum reference NAD83/2011 Massachusetts State Plane, Verticle Datum NAVD88.
August 24, 20017 Survey completed by Corcoran Associates, Inc. Horizantal Reference NAD 83 (FT), Vertical Datum NGVD 29 (FT)
Reminder of information results of May 30, 2015, volunteer data collection in Manchester-by-the-Sea

Pond Report

Hydraflow Hydrographs Extension for AutoCAD® Civil 3D® 2015 by Autodesk, Inc. v10.4

Friday, 10 / 2 / 2015

Pond No. 1 - Pond 1

Pond Data

Contours -User-defined contour areas. Conic method used for volume calculation. Begining Elevation = 56.00 ft

Stage / Storage Table

Stage (ft)	Elevation (ft)	Contour area (sqft)	Incr. Storage (cuft)	Total storage (cuft)
0.00	56.00	23,500	0	0
2.00	58.00	148,330	153,898	153,898
4.00	60.00	247,610	391,685	545,583

Culvert / Orifice Structures

	[A]	[B]	[C]	[PrfRsr]
Rise (in)	= 35.16	0.00	0.00	0.00
Span (in)	= 35.16	0.00	0.00	0.00
No. Barrels	= 2	0	0	0
Invert El. (ft)	= 56.00	0.00	0.00	0.00
Length (ft)	= 40.00	0.00	0.00	0.00
Slope (%)	= 2.00	0.00	0.00	n/a
N-Value	= .013	.013	.013	n/a
Orifice Coeff.	= 0.60	0.60	0.60	0.60
Multi-Stage	= n/a	No	No	No

Weir Structures

	[A]	[B]	[C]	[D]
Crest Len (ft)	= 0.00	0.00	0.00	0.00
Crest El. (ft)	= 0.00	0.00	0.00	0.00
Weir Coeff.	= 3.33	3.33	3.33	3.33
Weir Type	= ---	---	---	---
Multi-Stage	= No	No	No	No

Exfil.(in/hr) = 0.000 (by Contour)
TW Elev. (ft) = 0.00

Note: Culvert/Orifice outflows are analyzed under inlet (ic) and outlet (oc) control. Weir risers checked for orifice conditions (ic) and submergence (s).

Stage / Storage / Discharge Table

Stage ft	Storage cuft	Elevation ft	Clv A cfs	Clv B cfs	Clv C cfs	PrfRsr cfs	Wr A cfs	Wr B cfs	Wr C cfs	Wr D cfs	Exfil cfs	User cfs	Total cfs
0.00	0	56.00	0.00	---	---	---	---	---	---	---	---	---	0.000
0.20	15,390	56.20	0.61 ic	---	---	---	---	---	---	---	---	---	0.611
0.40	30,780	56.40	2.38 ic	---	---	---	---	---	---	---	---	---	2.384
0.60	46,169	56.60	5.24 ic	---	---	---	---	---	---	---	---	---	5.240
0.80	61,559	56.80	9.12 ic	---	---	---	---	---	---	---	---	---	9.118
1.00	76,949	57.00	13.86 ic	---	---	---	---	---	---	---	---	---	13.86
1.20	92,339	57.20	19.43 ic	---	---	---	---	---	---	---	---	---	19.43
1.40	107,729	57.40	25.64 ic	---	---	---	---	---	---	---	---	---	25.64
1.60	123,119	57.60	32.45 ic	---	---	---	---	---	---	---	---	---	32.45
1.80	138,508	57.80	39.70 ic	---	---	---	---	---	---	---	---	---	39.70
2.00	153,898	58.00	47.22 ic	---	---	---	---	---	---	---	---	---	47.22
2.20	193,067	58.20	54.87 ic	---	---	---	---	---	---	---	---	---	54.87
2.40	232,235	58.40	62.37 ic	---	---	---	---	---	---	---	---	---	62.37
2.60	271,404	58.60	68.99 oc	---	---	---	---	---	---	---	---	---	68.99
2.80	310,572	58.80	72.03 oc	---	---	---	---	---	---	---	---	---	72.03
3.00	349,740	59.00	75.30 oc	---	---	---	---	---	---	---	---	---	75.30
3.20	388,909	59.20	83.50 oc	---	---	---	---	---	---	---	---	---	83.50
3.40	428,077	59.40	90.31 ic	---	---	---	---	---	---	---	---	---	90.31
3.60	467,246	59.60	94.86 ic	---	---	---	---	---	---	---	---	---	94.86
3.80	506,414	59.80	99.21 ic	---	---	---	---	---	---	---	---	---	99.21
4.00	545,583	60.00	103.37 ic	---	---	---	---	---	---	---	---	---	103.37

Pond Report

H&H Memo Attachment B

Pond No. 2 - Pond 2

Pond Data

Contours -User-defined contour areas. Conic method used for volume calculation. Begining Elevation = 38.40 ft

Stage / Storage Table

Stage (ft)	Elevation (ft)	Contour area (sqft)	Incr. Storage (cuft)	Total storage (cuft)
0.00	38.40	00	0	0
3.60	42.00	890,820	1,068,877	1,068,877
5.60	44.00	3,846,995	4,392,245	5,461,122
7.60	46.00	4,733,124	8,563,968	14,025,090
9.60	48.00	5,262,020	9,989,478	24,014,568
11.60	50.00	5,717,121	10,974,896	34,989,464
13.60	52.00	6,237,440	11,949,588	46,939,052

Culvert / Orifice Structures

	[A]	[B]	[C]	[PrfRsr]
Rise (in)	= 78.96	0.00	0.00	0.00
Span (in)	= 184.20	0.00	0.00	0.00
No. Barrels	= 1	1	0	0
Invert El. (ft)	= 38.40	0.00	0.00	0.00
Length (ft)	= 58.00	0.00	0.00	0.00
Slope (%)	= 0.10	0.00	0.00	n/a
N-Value	= .013	.013	.013	n/a
Orifice Coeff.	= 0.60	0.60	0.60	0.60
Multi-Stage	= n/a	No	No	No

Weir Structures

	[A]	[B]	[C]	[D]
Crest Len (ft)	= 150.00	0.00	0.00	0.00
Crest El. (ft)	= 50.00	0.00	0.00	0.00
Weir Coeff.	= 2.60	3.33	3.33	3.33
Weir Type	= Broad	---	---	---
Multi-Stage	= No	No	No	No

Exfil.(in/hr) = 0.000 (by Contour)
TW Elev. (ft) = 0.00

Note: Culvert/Orifice outflows are analyzed under inlet (ic) and outlet (oc) control. Weir risers checked for orifice conditions (ic) and submergence (s).

Stage / Storage / Discharge Table

Stage ft	Storage cuft	Elevation ft	Clv A cfs	Clv B cfs	Clv C cfs	PrfRsr cfs	Wr A cfs	Wr B cfs	Wr C cfs	Wr D cfs	Exfil cfs	User cfs	Total cfs
0.00	0	38.40	0.00	---	---	---	0.00	---	---	---	---	---	0.000
0.36	106,888	38.76	6.53 oc	---	---	---	0.00	---	---	---	---	---	6.529
0.72	213,775	39.12	15.12 oc	---	---	---	0.00	---	---	---	---	---	15.12
1.08	320,663	39.48	23.84 oc	---	---	---	0.00	---	---	---	---	---	23.84
1.44	427,551	39.84	32.57 oc	---	---	---	0.00	---	---	---	---	---	32.57
1.80	534,439	40.20	41.29 oc	---	---	---	0.00	---	---	---	---	---	41.29
2.16	641,326	40.56	50.01 oc	---	---	---	0.00	---	---	---	---	---	50.01
2.52	748,214	40.92	58.71 oc	---	---	---	0.00	---	---	---	---	---	58.71
2.88	855,102	41.28	67.41 oc	---	---	---	0.00	---	---	---	---	---	67.41
3.24	961,989	41.64	76.11 oc	---	---	---	0.00	---	---	---	---	---	76.11
3.60	1,068,877	42.00	84.80 oc	---	---	---	0.00	---	---	---	---	---	84.80
3.80	1,508,102	42.20	89.62 oc	---	---	---	0.00	---	---	---	---	---	89.62
4.00	1,947,326	42.40	94.45 oc	---	---	---	0.00	---	---	---	---	---	94.45
4.20	2,386,551	42.60	99.27 oc	---	---	---	0.00	---	---	---	---	---	99.27
4.40	2,825,775	42.80	104.10 oc	---	---	---	0.00	---	---	---	---	---	104.10
4.60	3,265,000	43.00	108.92 oc	---	---	---	0.00	---	---	---	---	---	108.92
4.80	3,704,224	43.20	113.74 oc	---	---	---	0.00	---	---	---	---	---	113.74
5.00	4,143,449	43.40	118.56 oc	---	---	---	0.00	---	---	---	---	---	118.56
5.20	4,582,673	43.60	123.39 oc	---	---	---	0.00	---	---	---	---	---	123.39
5.40	5,021,898	43.80	128.21 oc	---	---	---	0.00	---	---	---	---	---	128.21
5.60	5,461,122	44.00	133.03 oc	---	---	---	0.00	---	---	---	---	---	133.03
5.80	6,317,519	44.20	137.85 oc	---	---	---	0.00	---	---	---	---	---	137.85
6.00	7,173,916	44.40	142.67 oc	---	---	---	0.00	---	---	---	---	---	142.67
6.20	8,030,313	44.60	147.49 oc	---	---	---	0.00	---	---	---	---	---	147.49
6.40	8,886,709	44.80	152.31 oc	---	---	---	0.00	---	---	---	---	---	152.31
6.60	9,743,106	45.00	179.32 oc	---	---	---	0.00	---	---	---	---	---	179.32
6.80	10,599,503	45.20	338.53 oc	---	---	---	0.00	---	---	---	---	---	338.53
7.00	11,455,900	45.40	443.90 oc	---	---	---	0.00	---	---	---	---	---	443.90
7.20	12,312,297	45.60	528.67 oc	---	---	---	0.00	---	---	---	---	---	528.67
7.40	13,168,694	45.80	601.61 oc	---	---	---	0.00	---	---	---	---	---	601.61
7.60	14,025,090	46.00	666.62 oc	---	---	---	0.00	---	---	---	---	---	666.62
7.80	15,024,038	46.20	725.83 oc	---	---	---	0.00	---	---	---	---	---	725.83
8.00	16,022,986	46.40	780.56 oc	---	---	---	0.00	---	---	---	---	---	780.56
8.20	17,021,934	46.60	831.70 oc	---	---	---	0.00	---	---	---	---	---	831.70

Continues on next page...

H&H Memo Attachment B

Pond 2

Stage / Storage / Discharge Table

Stage ft	Storage cuft	Elevation ft	Clv A cfs	Clv B cfs	Clv C cfs	PrfRsr cfs	Wr A cfs	Wr B cfs	Wr C cfs	Wr D cfs	Exfil cfs	User cfs	Total cfs
8.40	18,020,882	46.80	879.87 oc	---	---	---	0.00	---	---	---	---	---	879.87
8.60	19,019,830	47.00	925.53 oc	---	---	---	0.00	---	---	---	---	---	925.53
8.80	20,018,778	47.20	969.05 oc	---	---	---	0.00	---	---	---	---	---	969.05
9.00	21,017,726	47.40	1010.70 oc	---	---	---	0.00	---	---	---	---	---	1010.70
9.20	22,016,674	47.60	1050.69 oc	---	---	---	0.00	---	---	---	---	---	1050.69
9.40	23,015,622	47.80	1089.22 oc	---	---	---	0.00	---	---	---	---	---	1089.22
9.60	24,014,568	48.00	1126.43 oc	---	---	---	0.00	---	---	---	---	---	1126.43
9.80	25,112,058	48.20	1162.45 oc	---	---	---	0.00	---	---	---	---	---	1162.45
10.00	26,209,548	48.40	1197.39 oc	---	---	---	0.00	---	---	---	---	---	1197.39
10.20	27,307,038	48.60	1231.33 oc	---	---	---	0.00	---	---	---	---	---	1231.33
10.40	28,404,528	48.80	1264.37 oc	---	---	---	0.00	---	---	---	---	---	1264.37
10.60	29,502,018	49.00	1296.56 oc	---	---	---	0.00	---	---	---	---	---	1296.56
10.80	30,599,508	49.20	1327.97 oc	---	---	---	0.00	---	---	---	---	---	1327.97
11.00	31,696,998	49.40	1350.38 ic	---	---	---	0.00	---	---	---	---	---	1350.38
11.20	32,794,488	49.60	1367.78 ic	---	---	---	0.00	---	---	---	---	---	1367.78
11.40	33,891,976	49.80	1384.97 ic	---	---	---	0.00	---	---	---	---	---	1384.97
11.60	34,989,464	50.00	1401.94 ic	---	---	---	0.00	---	---	---	---	---	1401.94
11.80	36,184,424	50.20	1418.71 ic	---	---	---	34.88	---	---	---	---	---	1453.59
12.00	37,379,384	50.40	1435.28 ic	---	---	---	98.66	---	---	---	---	---	1533.95
12.20	38,574,344	50.60	1451.67 ic	---	---	---	181.26	---	---	---	---	---	1632.92
12.40	39,769,304	50.80	1467.87 ic	---	---	---	279.06	---	---	---	---	---	1746.93
12.60	40,964,264	51.00	1483.90 ic	---	---	---	390.00	---	---	---	---	---	1873.90
12.80	42,159,224	51.20	1499.75 ic	---	---	---	512.67	---	---	---	---	---	2012.42
13.00	43,354,184	51.40	1515.44 ic	---	---	---	646.04	---	---	---	---	---	2161.48
13.20	44,549,144	51.60	1530.97 ic	---	---	---	789.31	---	---	---	---	---	2320.27
13.40	45,744,104	51.80	1546.34 ic	---	---	---	941.84	---	---	---	---	---	2488.17
13.60	46,939,052	52.00	1561.56 ic	---	---	---	1103.09	---	---	---	---	---	2664.64

...End

Pond Report

H&H Memo Attachment B

Hydraflow Hydrographs Extension for AutoCAD® Civil 3D® 2015 by Autodesk, Inc. v10.4 Friday, 10 / 2 / 2015

Pond No. 3 - Pond 3

Pond Data

Contours -User-defined contour areas. Conic method used for volume calculation. Begining Elevation = 37.70 ft

Stage / Storage Table

Stage (ft)	Elevation (ft)	Contour area (sqft)	Incr. Storage (cuft)	Total storage (cuft)
0.00	37.70	8,961	0	0
4.30	42.00	896,992	1,426,895	1,426,895
6.30	44.00	1,270,225	2,156,208	3,583,103
8.30	46.00	1,403,064	2,671,921	6,255,024
10.30	48.00	1,728,489	3,125,588	9,380,612

Culvert / Orifice Structures

	[A]	[B]	[C]	[PrfRsr]
Rise (in)	= 99.60	0.00	0.00	0.00
Span (in)	= 176.40	0.00	0.00	0.00
No. Barrels	= 1	0	0	0
Invert El. (ft)	= 37.70	0.00	0.00	0.00
Length (ft)	= 42.00	0.00	0.00	0.00
Slope (%)	= 1.00	0.00	0.00	n/a
N-Value	= .013	.013	.013	n/a
Orifice Coeff.	= 0.60	0.60	0.60	0.60
Multi-Stage	= n/a	No	No	No

Weir Structures

	[A]	[B]	[C]	[D]
Crest Len (ft)	= 0.00	0.00	0.00	0.00
Crest El. (ft)	= 0.00	0.00	0.00	0.00
Weir Coeff.	= 3.33	3.33	3.33	3.33
Weir Type	= ---	---	---	---
Multi-Stage	= No	No	No	No

Exfil.(in/hr) = 0.000 (by Contour)
TW Elev. (ft) = 0.00

Note: Culvert/Orifice outflows are analyzed under inlet (ic) and outlet (oc) control. Weir risers checked for orifice conditions (ic) and submergence (s).

Stage / Storage / Discharge Table

Stage ft	Storage cuft	Elevation ft	Clv A cfs	Clv B cfs	Clv C cfs	PrfRsr cfs	Wr A cfs	Wr B cfs	Wr C cfs	Wr D cfs	Exfil cfs	User cfs	Total cfs
0.00	0	37.70	0.00	---	---	---	---	---	---	---	---	---	0.000
0.43	142,690	38.13	14.11 ic	---	---	---	---	---	---	---	---	---	14.11
0.86	285,379	38.56	39.92 ic	---	---	---	---	---	---	---	---	---	39.92
1.29	428,068	38.99	73.33 ic	---	---	---	---	---	---	---	---	---	73.33
1.72	570,758	39.42	102.92 oc	---	---	---	---	---	---	---	---	---	102.92
2.15	713,447	39.85	129.76 oc	---	---	---	---	---	---	---	---	---	129.76
2.58	856,137	40.28	156.57 oc	---	---	---	---	---	---	---	---	---	156.57
3.01	998,826	40.71	183.36 oc	---	---	---	---	---	---	---	---	---	183.36
3.44	1,141,516	41.14	210.14 oc	---	---	---	---	---	---	---	---	---	210.14
3.87	1,284,205	41.57	236.90 oc	---	---	---	---	---	---	---	---	---	236.90
4.30	1,426,895	42.00	263.66 oc	---	---	---	---	---	---	---	---	---	263.66
4.50	1,642,516	42.20	276.10 oc	---	---	---	---	---	---	---	---	---	276.10
4.70	1,858,136	42.40	288.55 oc	---	---	---	---	---	---	---	---	---	288.55
4.90	2,073,757	42.60	300.99 oc	---	---	---	---	---	---	---	---	---	300.99
5.10	2,289,378	42.80	313.43 oc	---	---	---	---	---	---	---	---	---	313.43
5.30	2,504,999	43.00	325.87 oc	---	---	---	---	---	---	---	---	---	325.87
5.50	2,720,620	43.20	338.30 oc	---	---	---	---	---	---	---	---	---	338.30
5.70	2,936,240	43.40	350.74 oc	---	---	---	---	---	---	---	---	---	350.74
5.90	3,151,861	43.60	363.18 oc	---	---	---	---	---	---	---	---	---	363.18
6.10	3,367,482	43.80	375.61 oc	---	---	---	---	---	---	---	---	---	375.61
6.30	3,583,103	44.00	388.05 oc	---	---	---	---	---	---	---	---	---	388.05
6.50	3,850,295	44.20	400.48 oc	---	---	---	---	---	---	---	---	---	400.48
6.70	4,117,487	44.40	412.92 oc	---	---	---	---	---	---	---	---	---	412.92
6.90	4,384,679	44.60	425.35 oc	---	---	---	---	---	---	---	---	---	425.35
7.10	4,651,871	44.80	437.79 oc	---	---	---	---	---	---	---	---	---	437.79
7.30	4,919,063	45.00	450.22 oc	---	---	---	---	---	---	---	---	---	450.22
7.50	5,186,255	45.20	462.65 oc	---	---	---	---	---	---	---	---	---	462.65
7.70	5,453,447	45.40	475.08 oc	---	---	---	---	---	---	---	---	---	475.08
7.90	5,720,639	45.60	487.52 oc	---	---	---	---	---	---	---	---	---	487.52
8.10	5,987,831	45.80	499.95 oc	---	---	---	---	---	---	---	---	---	499.95
8.30	6,255,024	46.00	512.38 oc	---	---	---	---	---	---	---	---	---	512.38
8.50	6,567,583	46.20	618.01 oc	---	---	---	---	---	---	---	---	---	618.01
8.70	6,880,142	46.40	710.73 oc	---	---	---	---	---	---	---	---	---	710.73
8.90	7,192,701	46.60	792.68 oc	---	---	---	---	---	---	---	---	---	792.68
9.10	7,505,260	46.80	866.92 oc	---	---	---	---	---	---	---	---	---	866.92
9.30	7,817,819	47.00	935.28 oc	---	---	---	---	---	---	---	---	---	935.28

Continues on next page...

H&H Memo Attachment B

Pond 3

Stage / Storage / Discharge Table

Stage ft	Storage cuft	Elevation ft	Clv A cfs	Clv B cfs	Clv C cfs	PrfRsr cfs	Wr A cfs	Wr B cfs	Wr C cfs	Wr D cfs	Exfil cfs	User cfs	Total cfs
9.50	8,130,378	47.20	998.98 oc	---	---	---	---	---	---	---	---	---	998.98
9.70	8,442,936	47.40	1058.85 oc	---	---	---	---	---	---	---	---	---	1058.85
9.90	8,755,495	47.60	1115.52 oc	---	---	---	---	---	---	---	---	---	1115.52
10.10	9,068,054	47.80	1169.44 oc	---	---	---	---	---	---	---	---	---	1169.44
10.30	9,380,612	48.00	1220.97 oc	---	---	---	---	---	---	---	---	---	1220.97

...End

H&H Memo Attachment B

Pond Report

Hydraflow Hydrographs Extension for AutoCAD® Civil 3D® 2015 by Autodesk, Inc. v10.4 Friday, 10 / 2 / 2015

Pond No. 4 - Pond 4

Pond Data

Contours -User-defined contour areas. Conic method used for volume calculation. Begining Elevation = 32.80 ft

Stage / Storage Table

Stage (ft)	Elevation (ft)	Contour area (sqft)	Incr. Storage (cuft)	Total storage (cuft)
0.00	32.80	00	0	0
1.20	34.00	5,000	2,000	2,000
3.20	36.00	13,887	18,145	20,145
5.20	38.00	103,621	103,618	123,762
7.20	40.00	262,510	354,005	477,767
9.20	42.00	262,510	524,967	1,002,734

Culvert / Orifice Structures

	[A]	[B]	[C]	[PrfRsr]
Rise (in)	= 44.40	0.00	0.00	0.00
Span (in)	= 150.00	0.00	0.00	0.00
No. Barrels	= 1	0	0	0
Invert El. (ft)	= 32.80	0.00	0.00	0.00
Length (ft)	= 20.00	0.00	0.00	0.00
Slope (%)	= 0.50	0.00	0.00	n/a
N-Value	= .013	.013	.013	n/a
Orifice Coeff.	= 0.60	0.60	0.60	0.60
Multi-Stage	= n/a	No	No	No

Weir Structures

	[A]	[B]	[C]	[D]
Crest Len (ft)	= 0.00	0.00	0.00	0.00
Crest El. (ft)	= 0.00	0.00	0.00	0.00
Weir Coeff.	= 3.33	3.33	3.33	3.33
Weir Type	= ---	---	---	---
Multi-Stage	= No	No	No	No

Exfil.(in/hr) = 0.000 (by Wet area)

TW Elev. (ft) = 0.00

Note: Culvert/Orifice outflows are analyzed under inlet (ic) and outlet (oc) control. Weir risers checked for orifice conditions (ic) and submergence (s).

Stage / Storage / Discharge Table

Stage ft	Storage cuft	Elevation ft	Clv A cfs	Clv B cfs	Clv C cfs	PrfRsr cfs	Wr A cfs	Wr B cfs	Wr C cfs	Wr D cfs	Exfil cfs	User cfs	Total cfs
0.00	0	32.80	0.00	---	---	---	---	---	---	---	---	---	0.000
0.12	200	32.92	1.77 ic	---	---	---	---	---	---	---	---	---	1.769
0.24	400	33.04	5.00 ic	---	---	---	---	---	---	---	---	---	5.004
0.36	600	33.16	8.26 oc	---	---	---	---	---	---	---	---	---	8.261
0.48	800	33.28	11.39 oc	---	---	---	---	---	---	---	---	---	11.39
0.60	1,000	33.40	14.52 oc	---	---	---	---	---	---	---	---	---	14.52
0.72	1,200	33.52	17.64 oc	---	---	---	---	---	---	---	---	---	17.64
0.84	1,400	33.64	20.77 oc	---	---	---	---	---	---	---	---	---	20.77
0.96	1,600	33.76	23.89 oc	---	---	---	---	---	---	---	---	---	23.89
1.08	1,800	33.88	27.00 oc	---	---	---	---	---	---	---	---	---	27.00
1.20	2,000	34.00	30.12 oc	---	---	---	---	---	---	---	---	---	30.12
1.40	3,814	34.20	35.31 oc	---	---	---	---	---	---	---	---	---	35.31
1.60	5,629	34.40	40.49 oc	---	---	---	---	---	---	---	---	---	40.49
1.80	7,443	34.60	45.67 oc	---	---	---	---	---	---	---	---	---	45.67
2.00	9,258	34.80	50.85 oc	---	---	---	---	---	---	---	---	---	50.85
2.20	11,072	35.00	56.03 oc	---	---	---	---	---	---	---	---	---	56.03
2.40	12,887	35.20	61.21 oc	---	---	---	---	---	---	---	---	---	61.21
2.60	14,701	35.40	66.38 oc	---	---	---	---	---	---	---	---	---	66.38
2.80	16,516	35.60	71.55 oc	---	---	---	---	---	---	---	---	---	71.55
3.00	18,330	35.80	76.73 oc	---	---	---	---	---	---	---	---	---	76.73
3.20	20,145	36.00	81.90 oc	---	---	---	---	---	---	---	---	---	81.90
3.40	30,506	36.20	87.07 oc	---	---	---	---	---	---	---	---	---	87.07
3.60	40,868	36.40	92.24 oc	---	---	---	---	---	---	---	---	---	92.24
3.80	51,230	36.60	132.85 oc	---	---	---	---	---	---	---	---	---	132.85
4.00	61,592	36.80	187.88 oc	---	---	---	---	---	---	---	---	---	187.88
4.20	71,953	37.00	230.10 oc	---	---	---	---	---	---	---	---	---	230.10
4.40	82,315	37.20	265.70 oc	---	---	---	---	---	---	---	---	---	265.70
4.60	92,677	37.40	297.06 oc	---	---	---	---	---	---	---	---	---	297.06
4.80	103,039	37.60	325.41 oc	---	---	---	---	---	---	---	---	---	325.41
5.00	113,400	37.80	351.49 oc	---	---	---	---	---	---	---	---	---	351.49
5.20	123,762	38.00	375.76 oc	---	---	---	---	---	---	---	---	---	375.76
5.40	159,163	38.20	398.55 oc	---	---	---	---	---	---	---	---	---	398.55
5.60	194,563	38.40	420.11 oc	---	---	---	---	---	---	---	---	---	420.11
5.80	229,964	38.60	440.61 oc	---	---	---	---	---	---	---	---	---	440.61
6.00	265,364	38.80	453.66 ic	---	---	---	---	---	---	---	---	---	453.66

Continues on next page...

H&H Memo Attachment B

Pond 4

Stage / Storage / Discharge Table

Stage ft	Storage cuft	Elevation ft	Clv A cfs	Clv B cfs	Clv C cfs	PrfRsr cfs	Wr A cfs	Wr B cfs	Wr C cfs	Wr D cfs	Exfil cfs	User cfs	Total cfs
6.20	300,764	39.00	464.46 ic	---	---	---	---	---	---	---	---	---	464.46
6.40	336,165	39.20	475.02 ic	---	---	---	---	---	---	---	---	---	475.02
6.60	371,565	39.40	485.35 ic	---	---	---	---	---	---	---	---	---	485.35
6.80	406,966	39.60	495.46 ic	---	---	---	---	---	---	---	---	---	495.46
7.00	442,366	39.80	505.37 ic	---	---	---	---	---	---	---	---	---	505.37
7.20	477,767	40.00	515.09 ic	---	---	---	---	---	---	---	---	---	515.09
7.40	530,263	40.20	524.63 ic	---	---	---	---	---	---	---	---	---	524.63
7.60	582,760	40.40	534.00 ic	---	---	---	---	---	---	---	---	---	534.00
7.80	635,257	40.60	543.21 ic	---	---	---	---	---	---	---	---	---	543.21
8.00	687,754	40.80	552.26 ic	---	---	---	---	---	---	---	---	---	552.26
8.20	740,250	41.00	561.17 ic	---	---	---	---	---	---	---	---	---	561.17
8.40	792,747	41.20	569.94 ic	---	---	---	---	---	---	---	---	---	569.94
8.60	845,244	41.40	578.57 ic	---	---	---	---	---	---	---	---	---	578.57
8.80	897,741	41.60	587.08 ic	---	---	---	---	---	---	---	---	---	587.08
9.00	950,237	41.80	595.47 ic	---	---	---	---	---	---	---	---	---	595.47
9.20	1,002,734	42.00	603.74 ic	---	---	---	---	---	---	---	---	---	603.74

...End

Pond Report

H&H Memo Attachment B

Hydraflow Hydrographs Extension for AutoCAD® Civil 3D® 2015 by Autodesk, Inc. v10.4 — Friday, 10 / 2 / 2015

Pond No. 5 - Pond 5

Pond Data

Contours -User-defined contour areas. Conic method used for volume calculation. Begining Elevation = 10.70 ft

Stage / Storage Table

Stage (ft)	Elevation (ft)	Contour area (sqft)	Incr. Storage (cuft)	Total storage (cuft)
0.00	10.70	00	0	0
3.30	14.00	13,888	15,275	15,275
5.30	16.00	1,450,420	1,070,717	1,085,992
7.30	18.00	2,260,770	3,680,971	4,766,963

Culvert / Orifice Structures

	[A]	[B]	[C]	[PrfRsr]
Rise (in)	= 51.00	0.00	0.00	0.00
Span (in)	= 98.04	0.00	0.00	0.00
No. Barrels	= 1	0	0	0
Invert El. (ft)	= 10.70	0.00	0.00	0.00
Length (ft)	= 15.00	0.00	0.00	0.00
Slope (%)	= 0.00	0.00	0.00	n/a
N-Value	= .013	.013	.013	n/a
Orifice Coeff.	= 0.60	0.60	0.60	0.60
Multi-Stage	= n/a	No	No	No

Weir Structures

	[A]	[B]	[C]	[D]
Crest Len (ft)	= 0.00	0.00	0.00	0.00
Crest El. (ft)	= 0.00	0.00	0.00	0.00
Weir Coeff.	= 3.33	3.33	3.33	3.33
Weir Type	= ---	---	---	---
Multi-Stage	= No	No	No	No

Exfil.(in/hr) = 0.000 (by Wet area)

TW Elev. (ft) = 0.00

Note: Culvert/Orifice outflows are analyzed under inlet (ic) and outlet (oc) control. Weir risers checked for orifice conditions (ic) and submergence (s).

Stage / Storage / Discharge Table

Stage ft	Storage cuft	Elevation ft	Clv A cfs	Clv B cfs	Clv C cfs	PrfRsr cfs	Wr A cfs	Wr B cfs	Wr C cfs	Wr D cfs	Exfil cfs	User cfs	Total cfs
0.00	0	10.70	0.00	---	---	---	---	---	---	---	---	---	0.000
0.33	1,528	11.03	5.27 ic	---	---	---	---	---	---	---	---	---	5.273
0.66	3,055	11.36	14.91 ic	---	---	---	---	---	---	---	---	---	14.91
0.99	4,583	11.69	27.40 ic	---	---	---	---	---	---	---	---	---	27.40
1.32	6,110	12.02	42.19 ic	---	---	---	---	---	---	---	---	---	42.19
1.65	7,638	12.35	58.96 ic	---	---	---	---	---	---	---	---	---	58.96
1.98	9,165	12.68	77.50 ic	---	---	---	---	---	---	---	---	---	77.50
2.31	10,693	13.01	97.66 ic	---	---	---	---	---	---	---	---	---	97.66
2.64	12,220	13.34	119.32 ic	---	---	---	---	---	---	---	---	---	119.32
2.97	13,748	13.67	142.38 ic	---	---	---	---	---	---	---	---	---	142.38
3.30	15,275	14.00	166.75 ic	---	---	---	---	---	---	---	---	---	166.75
3.50	122,347	14.20	182.14 ic	---	---	---	---	---	---	---	---	---	182.14
3.70	229,419	14.40	197.97 ic	---	---	---	---	---	---	---	---	---	197.97
3.90	336,490	14.60	214.24 ic	---	---	---	---	---	---	---	---	---	214.24
4.10	443,562	14.80	230.93 ic	---	---	---	---	---	---	---	---	---	230.93
4.30	550,634	15.00	50.09 oc	---	---	---	---	---	---	---	---	---	50.09
4.50	657,705	15.20	112.01 oc	---	---	---	---	---	---	---	---	---	112.01
4.70	764,777	15.40	150.28 oc	---	---	---	---	---	---	---	---	---	150.28
4.90	871,849	15.60	180.61 oc	---	---	---	---	---	---	---	---	---	180.61
5.10	978,920	15.80	206.54 oc	---	---	---	---	---	---	---	---	---	206.54
5.30	1,085,992	16.00	229.56 oc	---	---	---	---	---	---	---	---	---	229.56
5.50	1,454,089	16.20	250.47 oc	---	---	---	---	---	---	---	---	---	250.47
5.70	1,822,186	16.40	269.76 oc	---	---	---	---	---	---	---	---	---	269.76
5.90	2,190,283	16.60	287.77 oc	---	---	---	---	---	---	---	---	---	287.77
6.10	2,558,380	16.80	304.71 oc	---	---	---	---	---	---	---	---	---	304.71
6.30	2,926,477	17.00	320.76 oc	---	---	---	---	---	---	---	---	---	320.76
6.50	3,294,574	17.20	336.04 oc	---	---	---	---	---	---	---	---	---	336.04
6.70	3,662,671	17.40	350.65 oc	---	---	---	---	---	---	---	---	---	350.65
6.90	4,030,768	17.60	364.69 oc	---	---	---	---	---	---	---	---	---	364.69
7.10	4,398,866	17.80	372.91 ic	---	---	---	---	---	---	---	---	---	372.91
7.30	4,766,963	18.00	380.33 ic	---	---	---	---	---	---	---	---	---	380.33

H&H Memo Attachment B

APPENDIX B

H&H Memo Attachment B

Extreme Precipitation Tables

Northeast Regional Climate Center

Data represents point estimates calculated from partial duration series. All precipitation amounts are displayed in inches.

Smoothing	Yes
State	Massachusetts
Location	
Longitude	70.772 degrees West
Latitude	42.575 degrees North
Elevation	Unknown/Unavailable
Date/Time	Sat, 19 Sep 2015 14:15:15 -0400

Extreme Precipitation Estimates

	5min	10min	15min	30min	60min	120min
1yr	0.27	0.41	0.51	0.67	0.84	1.06
2yr	0.33	0.51	0.64	0.84	1.06	1.34
5yr	0.39	0.61	0.77	1.03	1.32	1.69
10yr	0.44	0.69	0.88	1.19	1.55	2.00
25yr	0.52	0.83	1.05	1.45	1.92	2.51
50yr	0.58	0.93	1.20	1.68	2.27	3.00
100yr	0.67	1.08	1.39	1.97	2.68	3.56
200yr	0.75	1.23	1.60	2.29	3.17	4.24
500yr	0.91	1.49	1.95	2.82	3.95	5.32

	1hr	2hr	3hr	6hr	12hr	24hr	48hr
1yr	0.72	0.98	1.24	1.60	2.08	2.72	3.00
2yr	0.91	1.24	1.56	1.99	2.53	3.25	3.61
5yr	1.14	1.56	1.97	2.51	3.21	4.09	4.61
10yr	1.34	1.86	2.35	3.01	3.83	4.88	5.56
25yr	1.66	2.34	2.96	3.79	4.85	6.16	7.11
50yr	1.96	2.78	3.55	4.56	5.80	7.34	8.58
100yr	2.31	3.32	4.22	5.43	6.93	8.77	10.35
200yr	2.73	3.95	5.04	6.50	8.29	10.47	12.49
500yr	3.41	4.98	6.35	8.21	10.48	13.24	16.03

	1day	2day	4day	7day	10day	
1yr	2.41	2.88	3.31	4.01	4.70	**1yr**
2yr	2.87	3.47	3.99	4.75	5.39	**2yr**
5yr	3.62	4.43	5.08	6.01	6.77	**5yr**
10yr	4.32	5.34	6.10	7.18	8.05	**10yr**
25yr	5.45	6.84	7.79	9.10	10.14	**25yr**
50yr	6.50	8.25	9.37	10.89	12.07	**50yr**
100yr	7.76	9.96	11.28	13.04	14.38	**100yr**
200yr	9.26	12.01	13.58	15.61	17.14	**200yr**
500yr	11.72	15.41	17.36	19.82	21.62	**500yr**

Lower Confidence Limits

	5min	10min	15min	30min	60min	120min
1yr	0.23	0.35	0.43	0.58	0.71	0.84
2yr	0.32	0.49	0.60	0.82	1.01	1.23
5yr	0.37	0.56	0.70	0.96	1.22	1.46
10yr	0.41	0.62	0.77	1.08	1.40	1.67

	1hr	2hr	3hr	6hr	12hr	24hr	48hr
1yr	0.62	0.82	1.04	1.43	1.83	2.42	2.65
2yr	0.87	1.20	1.41	1.85	2.37	3.13	3.47
5yr	1.06	1.43	1.66	2.15	2.76	3.72	4.20
10yr	1.21	1.64	1.88	2.41	3.09	4.25	4.83

	1day	2day	4day	7day	10day	
1yr	2.14	2.54	2.93	3.56	4.19	1yr
2yr	2.77	3.34	3.85	4.60	5.21	2yr
5yr	3.29	4.04	4.64	5.54	6.23	5yr
10yr	3.76	4.64	5.34	6.34	7.10	10yr

H&H Memo Attachment B

25yr	0.46	0.71	0.88	1.25	1.65	1.98	25yr	1.42	1.94	2.21	2.80	3.57	5.08	5.79	25yr	4.49	5.57	6.42	7.57	8.34	25yr
50yr	0.51	0.77	0.96	1.39	1.87	2.26	50yr	1.61	2.21	2.50	3.12	3.98	5.83	6.63	50yr	5.16	6.37	7.37	8.66	9.70	50yr
100yr	0.57	0.86	1.07	1.55	2.13	2.56	100yr	1.84	2.51	2.82	3.49	4.42	6.69	7.59	100yr	5.92	7.29	8.46	9.92	11.01	100yr
200yr	0.63	0.95	1.20	1.74	2.42	2.92	200yr	2.09	2.86	3.19	3.88	4.89	7.70	8.71	200yr	6.81	8.38	9.73	11.36	12.46	200yr
500yr	0.73	1.08	1.39	2.02	2.88	3.48	500yr	2.48	3.40	3.76	4.47	5.61	9.30	10.47	500yr	8.23	10.07	11.73	13.63	14.69	500yr

Upper Confidence Limits

	5min	10min	15min	30min	60min	120min		1hr	2hr	3hr	6hr	12hr	24hr	48hr		1day	2day	4day	7day	10day	
1yr	0.30	0.46	0.56	0.75	0.93	1.08	1yr	0.80	1.06	1.34	1.72	2.21	2.99	3.35	1yr	2.65	3.22	3.71	4.34	5.18	1yr
2yr	0.35	0.54	0.67	0.90	1.11	1.33	2yr	0.96	1.30	1.53	2.02	2.59	3.40	3.78	2yr	3.01	3.63	4.17	4.98	5.63	2yr
5yr	0.42	0.65	0.81	1.11	1.42	1.74	5yr	1.22	1.70	2.00	2.65	3.39	4.49	5.04	5yr	3.97	4.85	5.52	6.51	7.31	5yr
10yr	0.51	0.78	0.96	1.35	1.74	2.14	10yr	1.50	2.09	2.45	3.27	4.16	5.55	6.31	10yr	4.91	6.07	6.87	8.04	8.97	10yr
25yr	0.64	0.98	1.22	1.74	2.29	2.82	25yr	1.98	2.76	3.22	4.33	5.48	7.34	8.52	25yr	6.49	8.19	9.18	10.60	11.77	25yr
50yr	0.77	1.17	1.46	2.09	2.82	3.49	50yr	2.43	3.41	3.96	5.36	6.77	9.06	10.70	50yr	8.01	10.29	11.43	13.08	14.18	50yr
100yr	0.93	1.40	1.76	2.54	3.48	4.30	100yr	3.00	4.20	4.87	6.64	8.37	11.17	13.45	100yr	9.88	12.93	14.26	16.16	17.40	100yr
200yr	1.11	1.67	2.12	3.07	4.28	5.32	200yr	3.70	5.20	6.00	8.24	10.34	13.75	16.90	200yr	12.17	16.25	17.79	20.00	21.36	200yr
500yr	1.43	2.12	2.73	3.96	5.64	7.02	500yr	4.87	6.86	7.91	10.98	13.73	18.14	22.78	500yr	16.06	21.90	23.75	26.49	28.05	500yr

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Northeast Regional Climate Center

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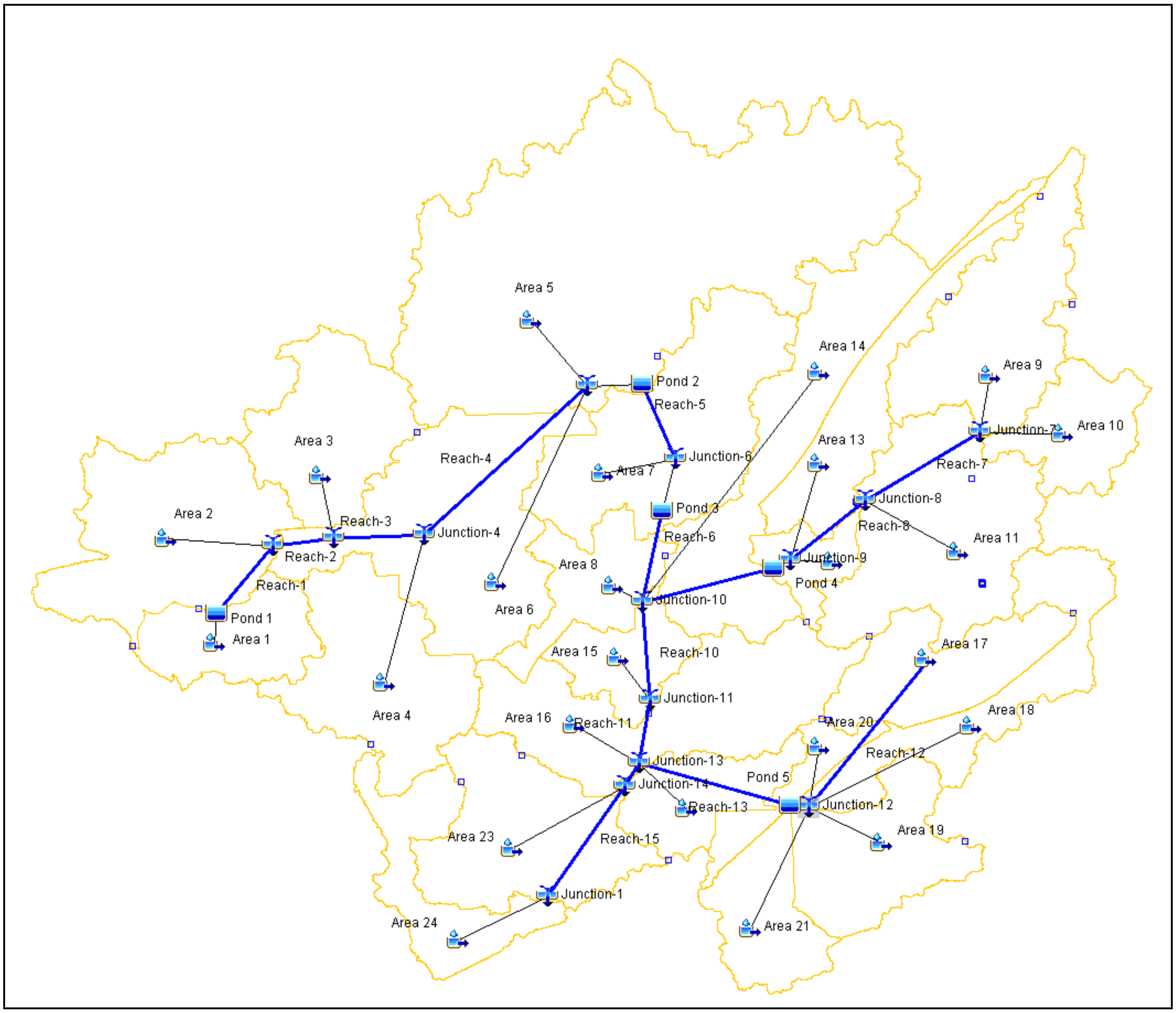
HEC-HMS

Project: MBTS

Basin Model : MBTS Watershed – Normal

Oct 09 13:58:03 EDT 2015



H&H Memo Attachment B

Project: MBTS Simulation Run: 2015 - 025 yr

Start of Run: 19Sep2015, 00:00
End of Run: 20Sep2015, 00:01
Compute Time: 29Sep2015, 16:28:52

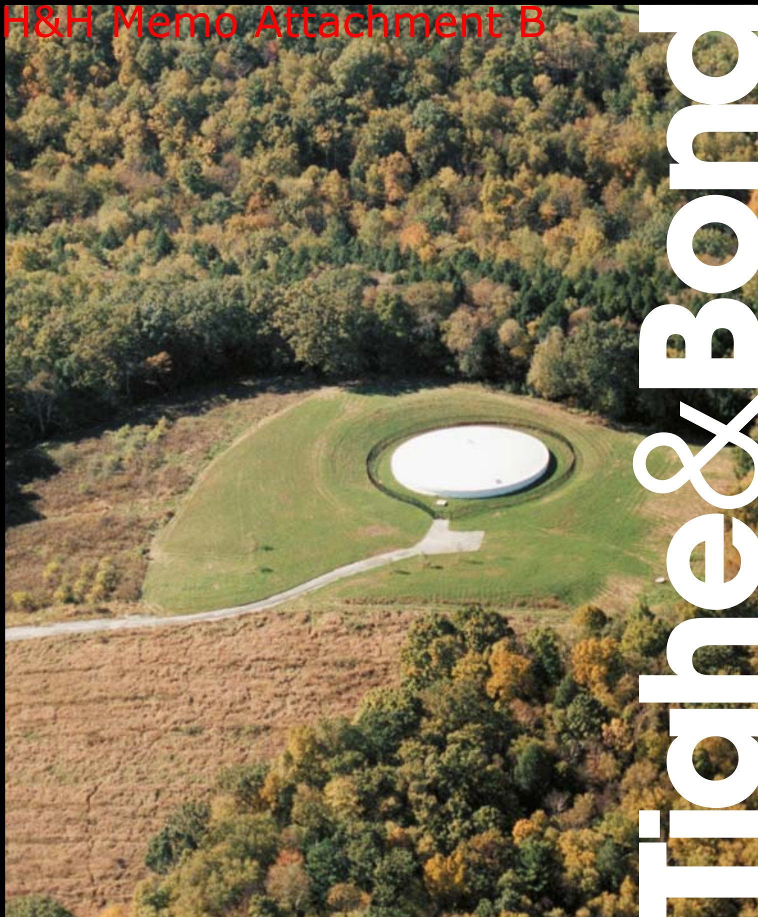
NOTE: The original report included multiple model runs, for simplicity only one example was included for this appendix (using precipitation values from the NRCC). The full report can be provided upon request

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
Area 5	0.9149000	409.0	19Sep2015, 13:17	2.14
Area 2	0.2143070	146.6	19Sep2015, 12:52	2.52
Area 1	0.1202500	130.4	19Sep2015, 12:27	2.72
Pond 1	0.1202500	56.7	19Sep2015, 12:59	2.68
Reach-1	0.1202500	56.7	19Sep2015, 13:12	2.65
Junction-2	0.3345570	199.7	19Sep2015, 12:55	2.57
Reach-2	0.3345570	199.6	19Sep2015, 12:57	2.56
Area 3	0.1890000	114.7	19Sep2015, 12:43	2.00
Junction-3	0.5235570	304.5	19Sep2015, 12:51	2.36
Reach-3	0.5235570	304.4	19Sep2015, 12:53	2.35
Area 4	0.2384815	154.2	19Sep2015, 12:47	2.26
Junction-4	0.7620385	456.6	19Sep2015, 12:51	2.32
Reach-4	0.7620385	456.5	19Sep2015, 13:00	2.30
Area 6	0.3474700	215.2	19Sep2015, 13:11	2.78
Junction-5	2.0244085	1054.8	19Sep2015, 13:07	2.31
Pond 2	2.0244085	198.1	19Sep2015, 16:34	1.37
Reach-5	2.0244085	198.1	19Sep2015, 16:40	1.35
Area 7	0.3110400	294.5	19Sep2015, 12:35	2.72
Junction-6	2.3354485	349.4	19Sep2015, 12:44	1.53
Pond 3	2.3354485	212.7	19Sep2015, 17:34	1.39
Reach-6	2.3354485	212.7	19Sep2015, 17:38	1.38
Area 9	0.2393600	136.1	19Sep2015, 12:47	2.00
Area 10	0.1111700	85.5	19Sep2015, 12:31	2.09
Junction-7	0.3505300	207.7	19Sep2015, 12:40	2.03
Reach-7	0.3505300	207.5	19Sep2015, 12:49	2.00
Area 11	0.3052000	161.7	19Sep2015, 13:04	2.24
Junction-8	0.6557300	359.7	19Sep2015, 12:55	2.11

H&H Memo Attachment B

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
Reach-8	0.6557300	359.6	19Sep2015, 12:59	2.11
Area 13	0.0571908	45.1	19Sep2015, 12:44	2.62
Area 12	0.0548863	52.6	19Sep2015, 12:32	2.63
Junction-9	0.7678071	432.3	19Sep2015, 12:55	2.18
Pond 4	0.7678071	394.0	19Sep2015, 13:10	2.18
Reach-9	0.7678071	394.0	19Sep2015, 13:13	2.17
Area 14	0.2956000	203.8	19Sep2015, 12:57	2.70
Area 8	0.1103443	112.8	19Sep2015, 12:28	2.63
Junction-10	3.5091999	774.7	19Sep2015, 13:04	1.71
Reach-10	3.5091999	774.7	19Sep2015, 13:08	1.69
Area 15	0.0890144	79.4	19Sep2015, 12:34	2.53
Junction-11	3.5982143	815.7	19Sep2015, 13:03	1.71
Reach-11	3.5982143	815.7	19Sep2015, 13:19	1.67
Area 19	0.1726400	146.4	19Sep2015, 12:32	2.36
Area 18	0.1713200	98.8	19Sep2015, 12:53	2.16
Area 17	0.1551600	97.1	19Sep2015, 12:50	2.25
Reach-12	0.1551600	97.0	19Sep2015, 12:56	2.24
Area 21	0.1163900	112.3	19Sep2015, 12:29	2.54
Area 20	0.0568027	62.9	19Sep2015, 12:38	3.38
Junction-12	0.6723127	465.5	19Sep2015, 12:39	2.40
Pond 5	0.6723127	211.4	19Sep2015, 13:31	2.40
Reach-13	0.6723127	211.4	19Sep2015, 13:33	2.39
Area 16	0.2959900	198.9	19Sep2015, 12:51	2.43
Area 22	0.1087000	128.1	19Sep2015, 12:33	3.29
Junction-13	4.6752170	1228.2	19Sep2015, 13:12	1.86
Reach-14	4.6752170	1227.8	19Sep2015, 13:20	1.84
Area 23	0.2300500	164.7	19Sep2015, 12:57	2.79
Junction-14	4.9052670	1363.5	19Sep2015, 13:19	1.88
Reach-15	4.9052670	1362.7	19Sep2015, 13:21	1.87
Area 24	0.1367700	128.0	19Sep2015, 12:46	3.18
Junction-1	5.0420370	1437.7	19Sep2015, 13:21	1.91

H&H Memo Attachment B



APPENDIX C

H&H Memo Attachment B

NOTE: The original report included additional tabular detail. Only the preliminary summary and figure summaries were included for this appendix.

The full report can be provided upon request

Weather History for KBVY - May, 2006

Saturday, May 13, 2006

Daily | Weekly | Monthly | Custom

	Actual	Average (KBOS)	Record (KBOS)
Temperature			
Mean Temperature	**48** °F	**57** °F	
Max Temperature	**51** °F	**65** °F	**87** °F (1947)
Min Temperature	**44** °F	**49** °F	**38** °F (1882)
Degree Days			
Heating Degree Days	18	8	
Month to date heating degree days		133	
Since 1 July heating degree days		5514	
Cooling Degree Days	0	0	
Month to date cooling degree days		0	
Year to date cooling degree days		3	
Moisture			
Dew Point	**46** °F		
Average Humidity	96		
Maximum Humidity	100		
Minimum Humidity	93		
Precipitation			
Precipitation	**4.32** in	**0.10** in	**3.84** in (2006)
Month to date precipitation		1.36	
Year to date precipitation		16.03	

Sea Level Pressure

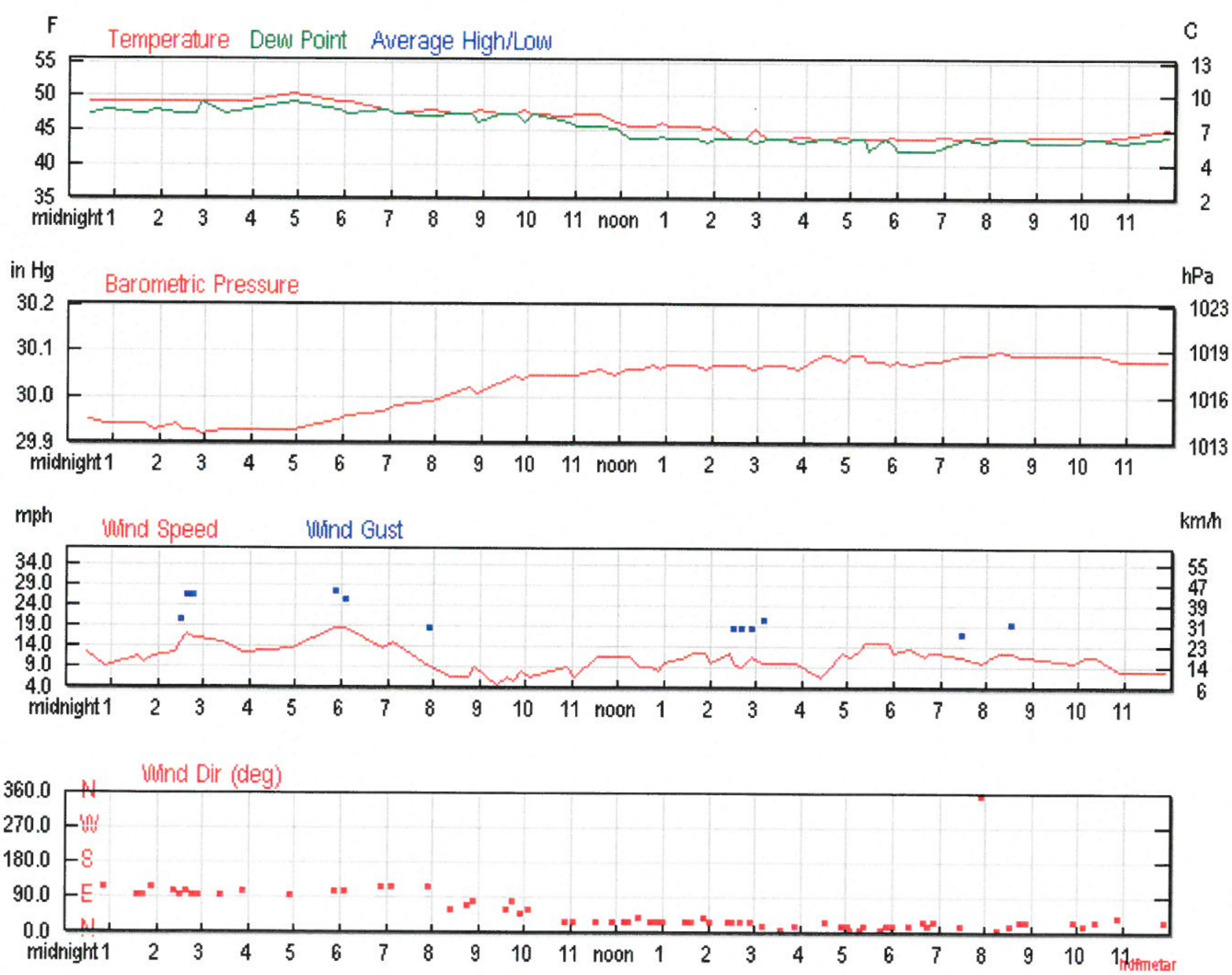
H&H Memo Attachment B

Sea Level Pressure	30.04 in
Wind	
Wind Speed	12 mph (NE)
Max Wind Speed	18 mph
Max Gust Speed	28 mph
Visibility	2 miles
Events	Fog , Rain

T = Trace of Precipitation, MM = Missing Value

Source: NWS Daily Summary

Daily Weather History Graph



Search for Another Location

Airport or City:

KBVY

H&H Memo Attachment B

Weather History for KBVY - May, 2006

Sunday, May 14, 2006

Daily | Weekly | Monthly | Custom

	Actual	Average	Record
Temperature			
Mean Temperature	**46** °F	-	
Max Temperature	**48** °F	**62** °F	**79** °F (1981)
Min Temperature	**44** °F	**42** °F	**33** °F (1999)
Degree Days			
Heating Degree Days	19		
Moisture			
Dew Point	**44** °F		
Average Humidity	94		
Maximum Humidity	100		
Minimum Humidity	93		
Precipitation			
Precipitation	**4.95** in	-	- ()
Sea Level Pressure			
Sea Level Pressure	**30.11** in		
Wind			
Wind Speed	**10** mph (NE)		
Max Wind Speed	**21** mph		
Max Gust Speed	**28** mph		
Visibility	**2** miles		

Events | Rain , Thunderstorm

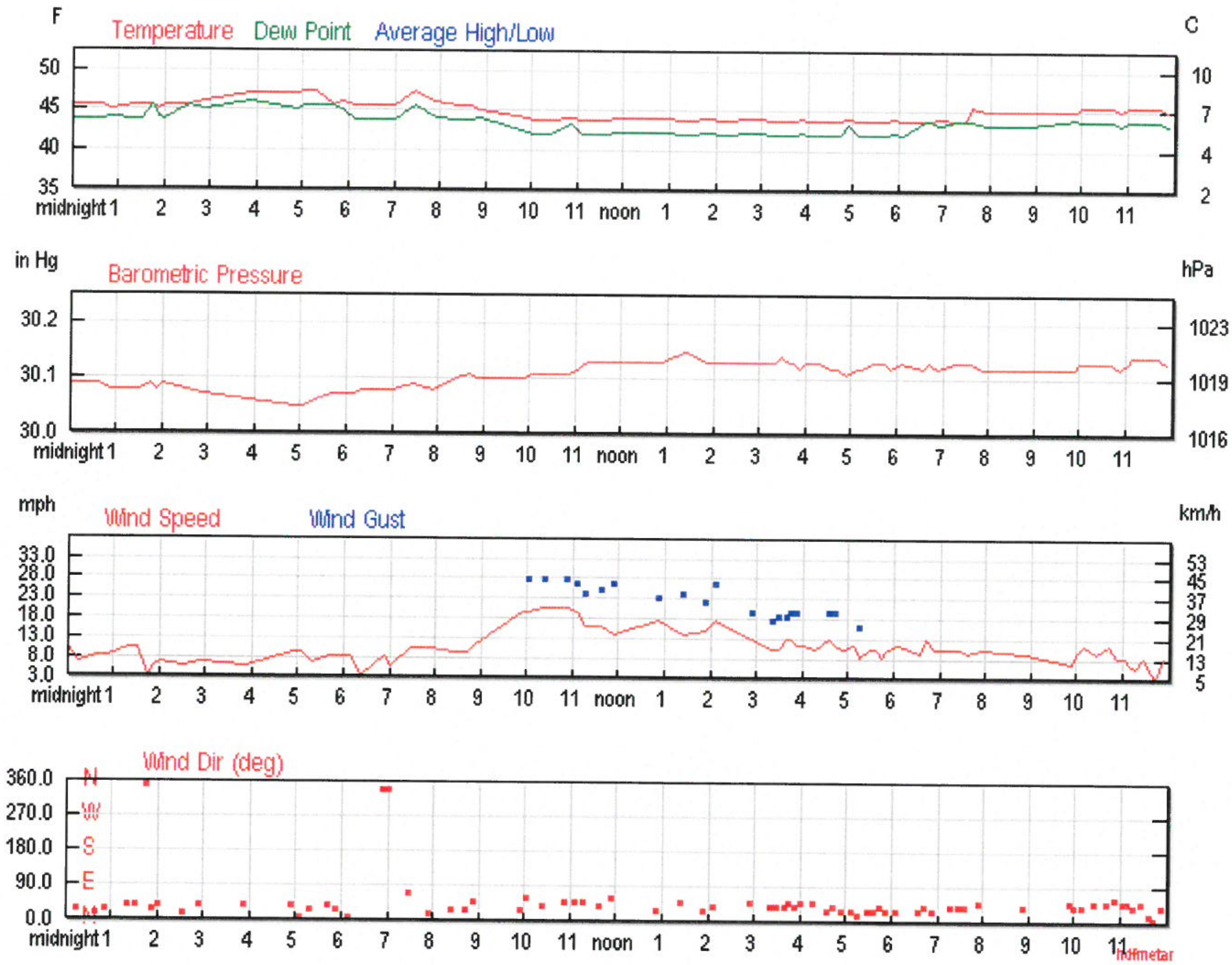
H&H Memo Attachment B

Averages and records for this station are not official NWS values.

T = Trace of Precipitation, MM = Missing Value

Source: NWS Daily Summary

Daily Weather History Graph



Search for Another Location

Airport or City:

KBVY

Submit

Trip Planner

Search our weather history database for the weather conditions in past years. The results will help you decide how hot, cold, wet, or windy it might be!

Date:

H&H Memo Attachment B

Weather History for KBVY - May, 2006

Monday, May 15, 2006

Daily | Weekly | Monthly | Custom

	Actual	Average	Record
Temperature			
Mean Temperature	**48** °F	-	
Max Temperature	**50** °F	**62** °F	**88** °F (2004)
Min Temperature	**46** °F	**42** °F	**37** °F (2013)
Degree Days			
Heating Degree Days	17		
Moisture			
Dew Point	**46** °F		
Average Humidity	96		
Maximum Humidity	100		
Minimum Humidity	93		
Precipitation			
Precipitation	**1.15** in	-	- ()
Sea Level Pressure			
Sea Level Pressure	**30.04** in		
Wind			
Wind Speed	**7** mph (NE)		
Max Wind Speed	**13** mph		
Max Gust Speed	**18** mph		
Visibility	**2** miles		

Events	Fog , Rain , Thunderstorm

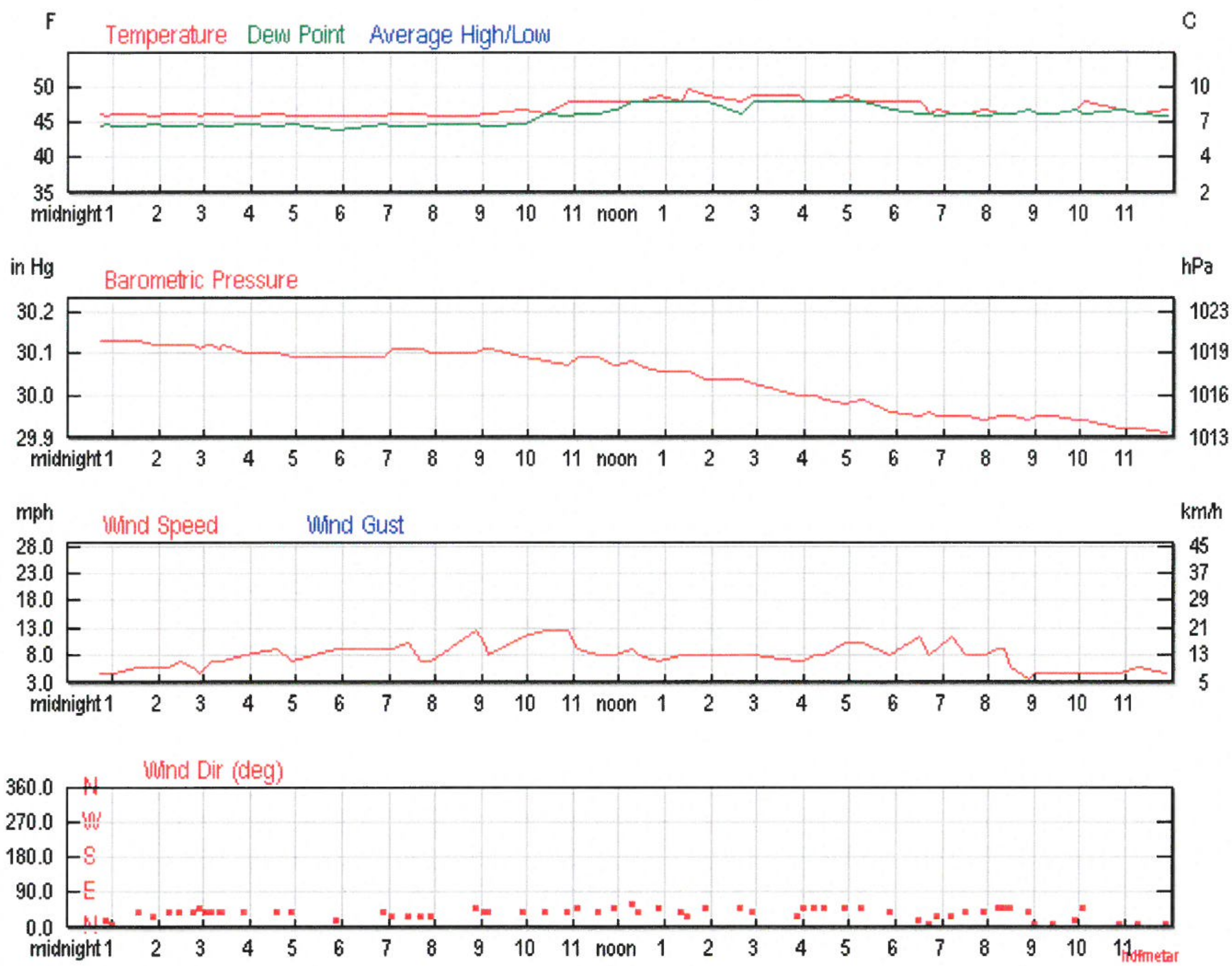
H&H Memo Attachment B

Averages and records for this station are not official NWS values.

T = Trace of Precipitation, MM = Missing Value

Source: NWS Daily Summary

Daily Weather History Graph



Search for Another Location

Airport or City:

KBVY

Submit

Trip Planner

Search our weather history database for the weather conditions in past years. The results will help you decide how hot, cold, wet, or windy it might be!

Date:

H&H Memo Attachment B

Weather History for KBVY - May, 2006

Tuesday, May 16, 2006

Daily Weekly Monthly Custom

	Actual	Average	Record
Temperature			
Mean Temperature	**50** °F	-	
Max Temperature	**55** °F	**62** °F	**84** °F (1980)
Min Temperature	**46** °F	**42** °F	**35** °F (1999)
Degree Days			
Heating Degree Days	14		
Moisture			
Dew Point	**48** °F		
Average Humidity	94		
Maximum Humidity	100		
Minimum Humidity	82		
Precipitation			
Precipitation	**0.56** in	-	- ()
Sea Level Pressure			
Sea Level Pressure	**29.62** in		
Wind			
Wind Speed	**8** mph (North)		
Max Wind Speed	**17** mph		
Max Gust Speed	**21** mph		
Visibility	**6** miles		

Events Fog , Rain

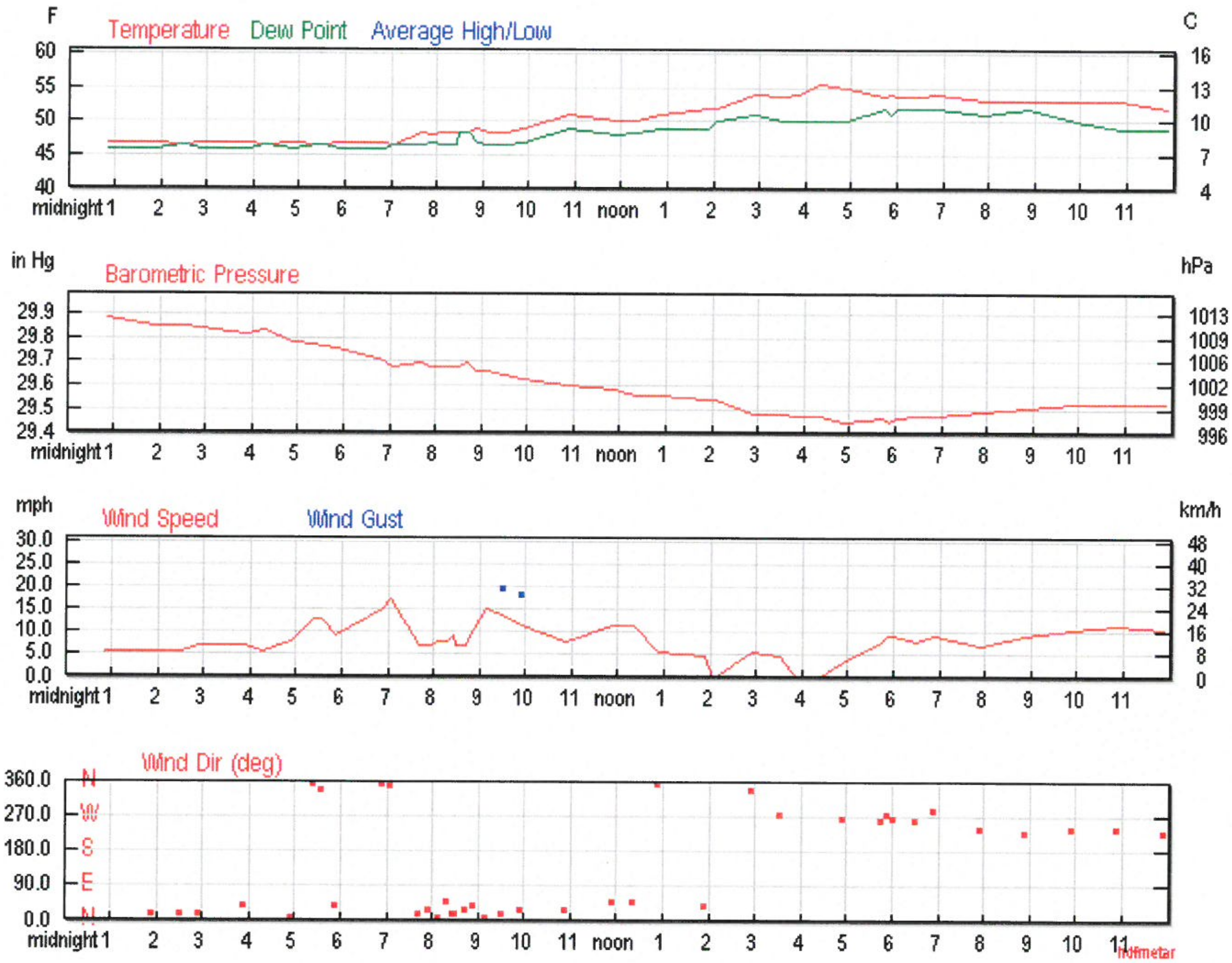
H&H Memo Attachment B

Averages and records for this station are not official NWS values.

T = Trace of Precipitation, MM = Missing Value

Source: NWS Daily Summary

Daily Weather History Graph



Search for Another Location

Airport or City:

KBVY

Submit

Trip Planner

Search our weather history database for the weather conditions in past years. The results will help you decide how hot, cold, wet, or windy it might be!

Date:

H&H Memo Attachment B

Tighe&Bond
Consulting Engineers
Environmental Specialists

Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Antecedent Moisture Conditions Adjustment**
Prepared By: **CRD** Date: **September 22, 2015**

Designation: **Area 1**

Weighted CN: **68** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **83**

Designation: **Area 2**

Weighted CN: **66** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **82**

Designation: **Area 3**

Weighted CN: **60** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **78**

Designation: **Area 4**

Weighted CN: **63** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **80**

Designation: **Area 5**

Weighted CN: **62** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **79**

Tighe&Bond
Consulting Engineers
Environmental Specialists

Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Antecedent Moisture Conditions Adjustment**
Prepared By: **CRD** Date: **September 22, 2015**

Designation: **Area 6**

Weighted CN: **69** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **84**

Designation: **Area 7**

Weighted CN: **68** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **83**

Designation: **Area 8**

Weighted CN: **67** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **82**

Designation: **Area 9**

Weighted CN: **60** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **78**

Designation: **Area 10**

Weighted CN: **61** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **78**

H&H Memo Attachment B

Tighe&Bond
Consulting Engineers
Environmental Specialists

Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Antecedent Moisture Conditions Adjustment**
Prepared By: **CRD** Date: **September 22, 2015**

Designation: **Area 11**

Weighted CN: **63** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **80**

Designation: **Area 12**

Weighted CN: **67** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **82**

Designation: **Area 13**

Weighted CN: **67** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **82**

Designation: **Area 14**

Weighted CN: **68** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **83**

Tighe&Bond
Consulting Engineers
Environmental Specialists

Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Antecedent Moisture Conditions Adjustment**
Prepared By: **CRD** Date: **September 22, 2015**

Designation: **Area 15**

Weighted CN: **66** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **82**

Designation: **Area 16**

Weighted CN: **65** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **81**

Designation: **Area 17**

Weighted CN: **63** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **80**

Designation: **Area 18**

Weighted CN: **62** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **79**

Designation: **Area 19**

Weighted CN: **64** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **80**

H&H Memo Attachment B

Tighe&Bond
Consulting Engineers
Environmental Specialists

Project Name: **Sawmill Brook Watershed Analysis**
Project Number: **M-1476-3-4**
Project Location: **Manchester-by-the-Sea, MA**
Description: **Antecedent Moisture Conditions Adjustment**
Prepared By: **CRD** Date: **September 22, 2015**

Designation: **Area 20**

Weighted CN: **75** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **87**

Designation: **Area 21**

Weighted CN: **66** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **82**

Designation: **Area 22**

Weighted CN: **74** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **87**

Designation: **Area 23**

Weighted CN: **69** (AMC_2)

$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **84**

Designation: **Area 24**

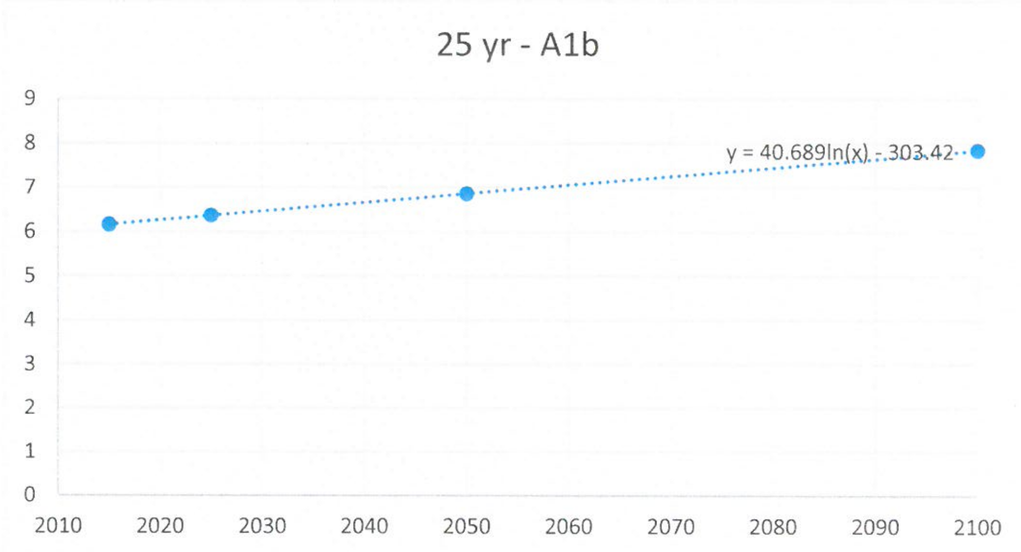
Weighted CN: **73** (AMC_2)

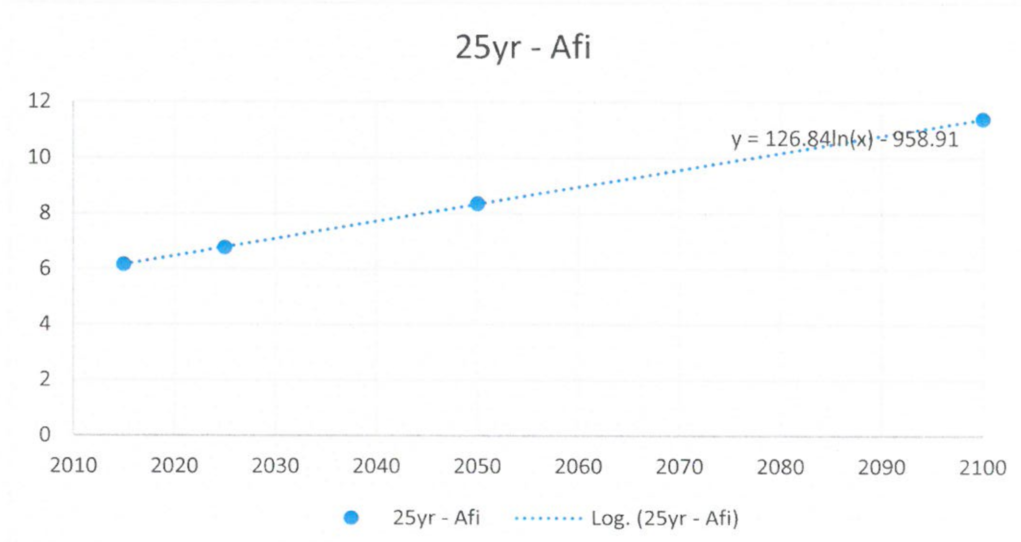
$$RCN_{AMC3} = \frac{23RCN_{AMC2}}{10+0.13RCN_{AMC2}}$$

RCN_{AMC3} = **86**

H&H Memo Attachment B

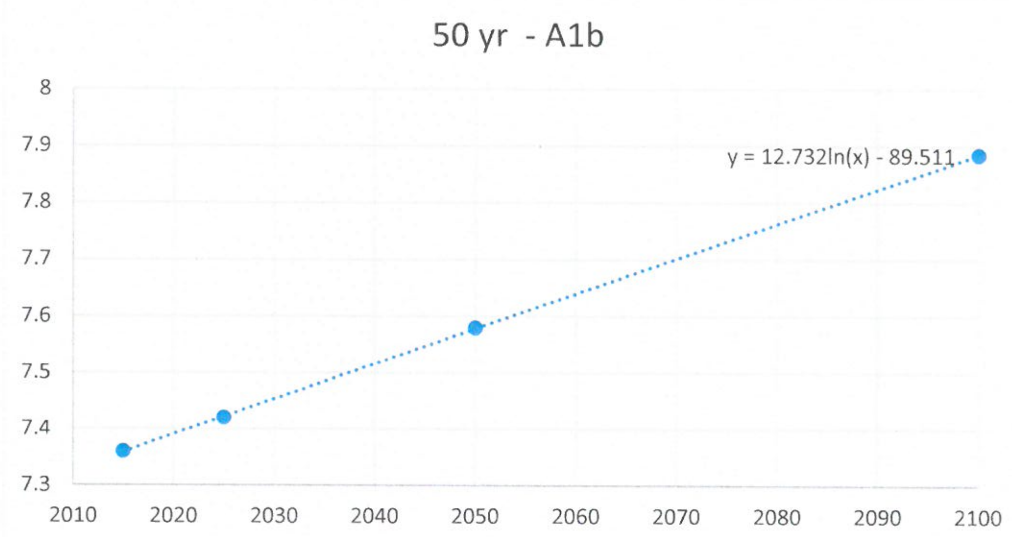
Year	25 yr -A1b	25yr - Afi
2015	6.16	6.16
2025	6.36	6.77
2050	6.86	8.35
2100	7.84	11.39

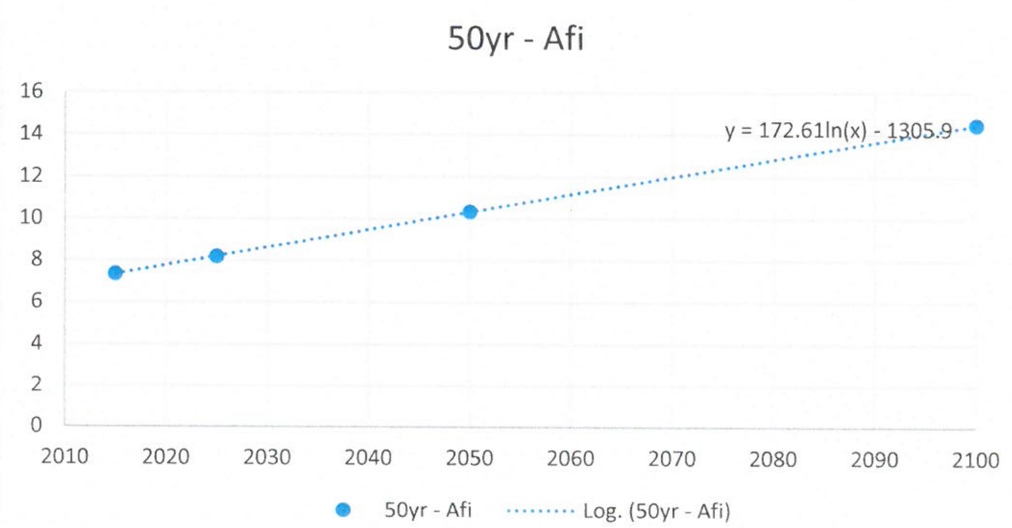




H&H Memo Attachment B

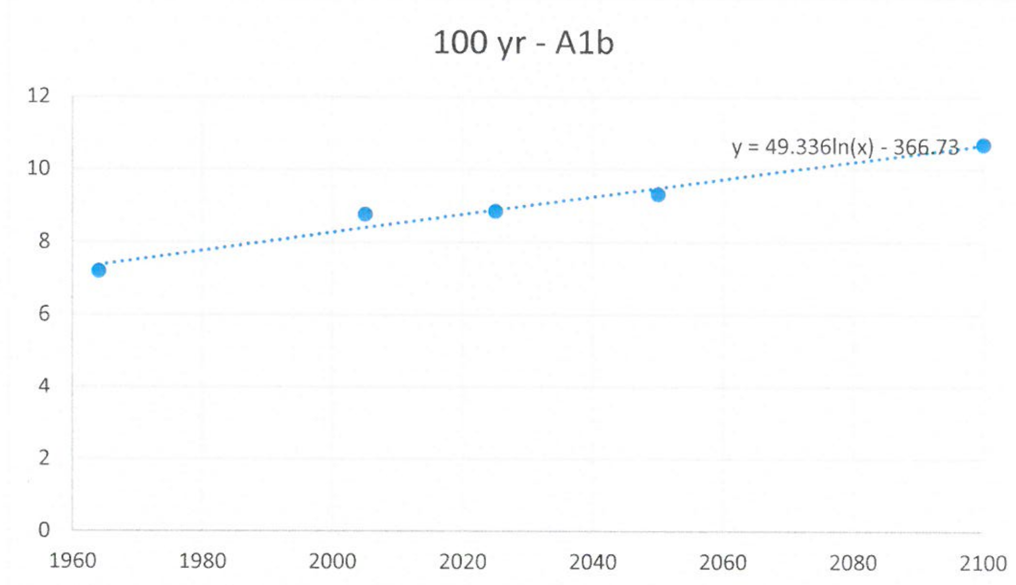
Year	50 yr -A1b	50yr - Afi
2015	7.36	7.36
2025	7.42	8.19
2050	7.58	10.34
2100	7.88	14.48

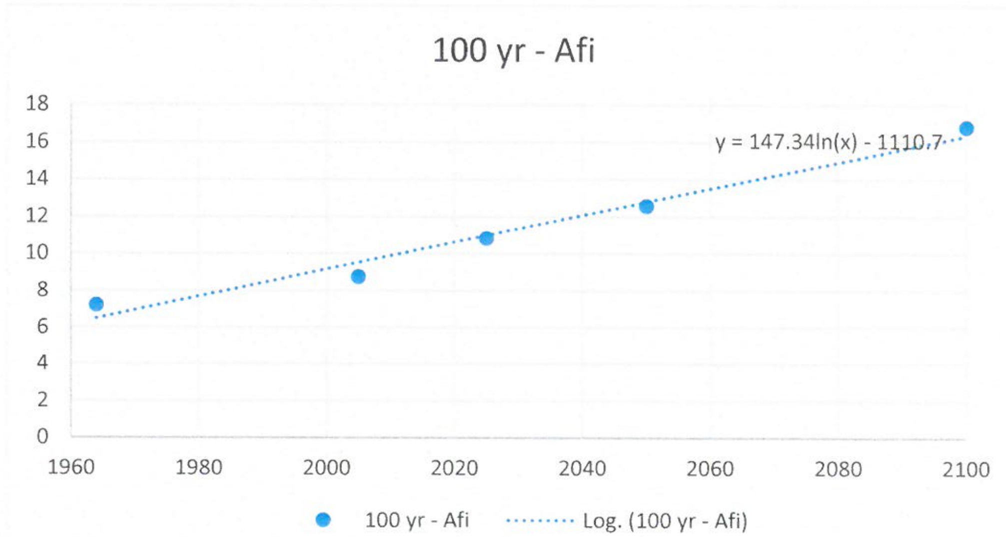




H&H Memo Attachment B

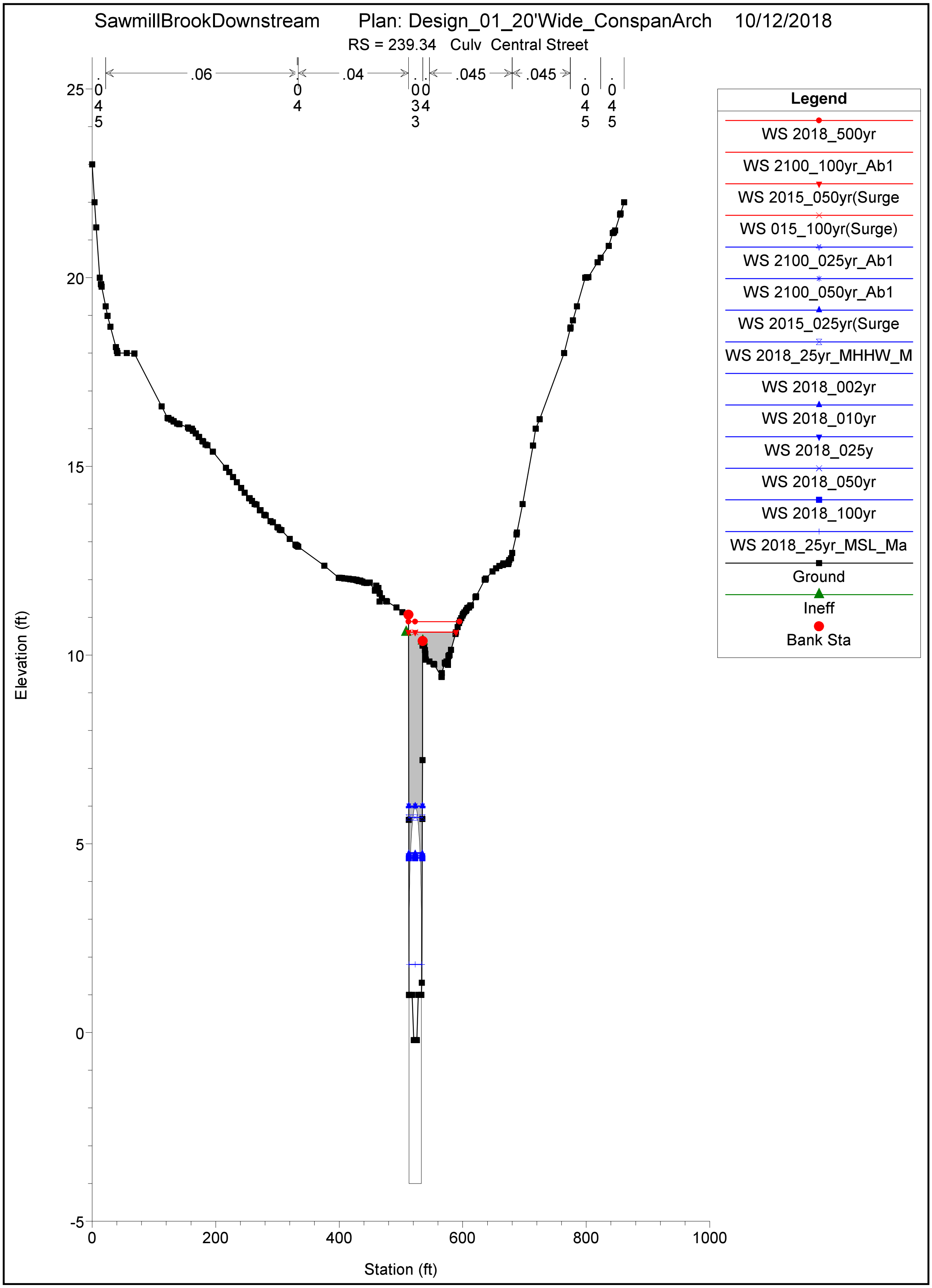
Year	100 yr -A1b	100 yr - Afi
1964	7.2	7.2
2005	8.76	8.76
2025	8.85	10.82
2050	9.31	12.58
2100	10.69	16.82

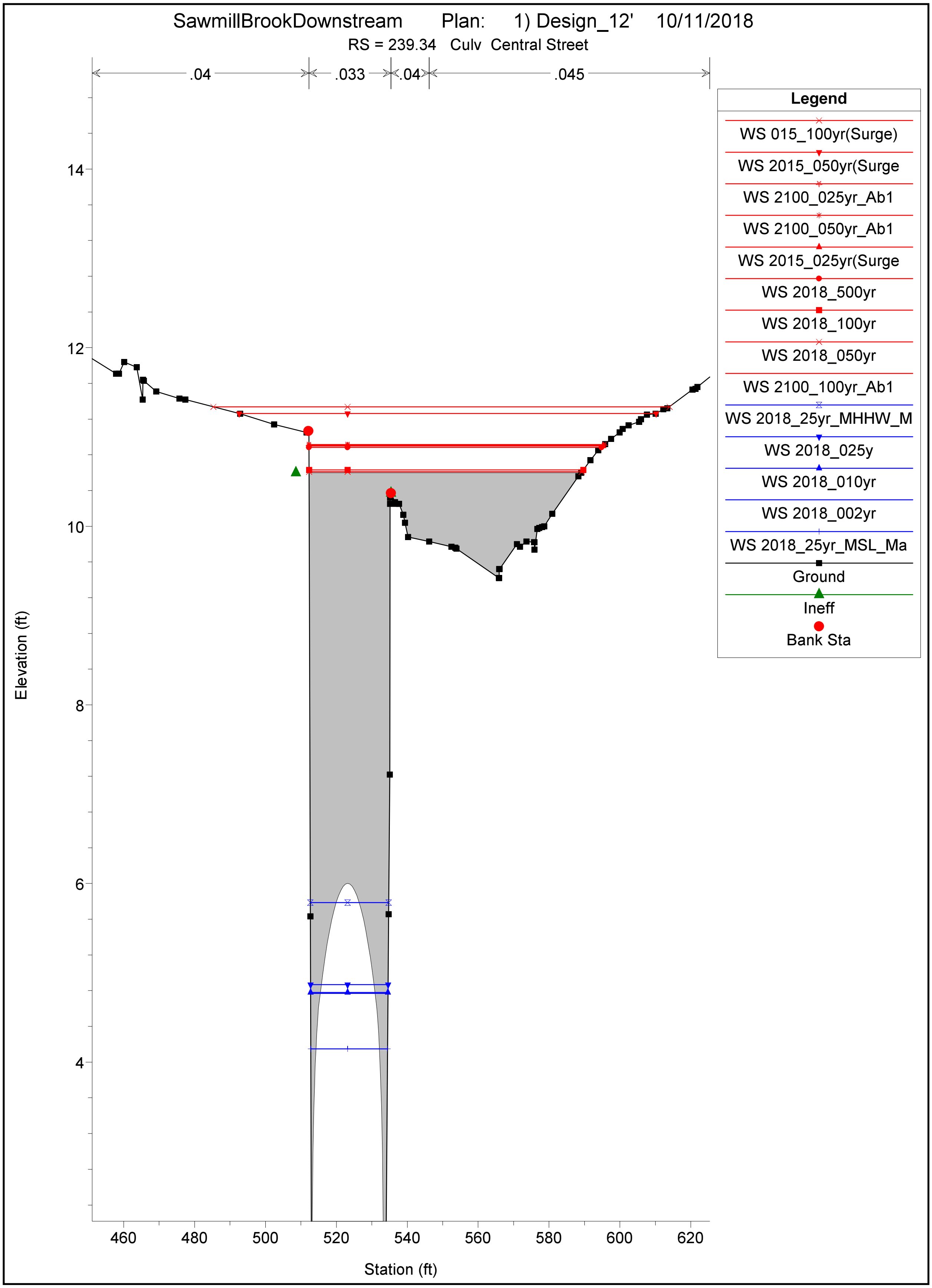


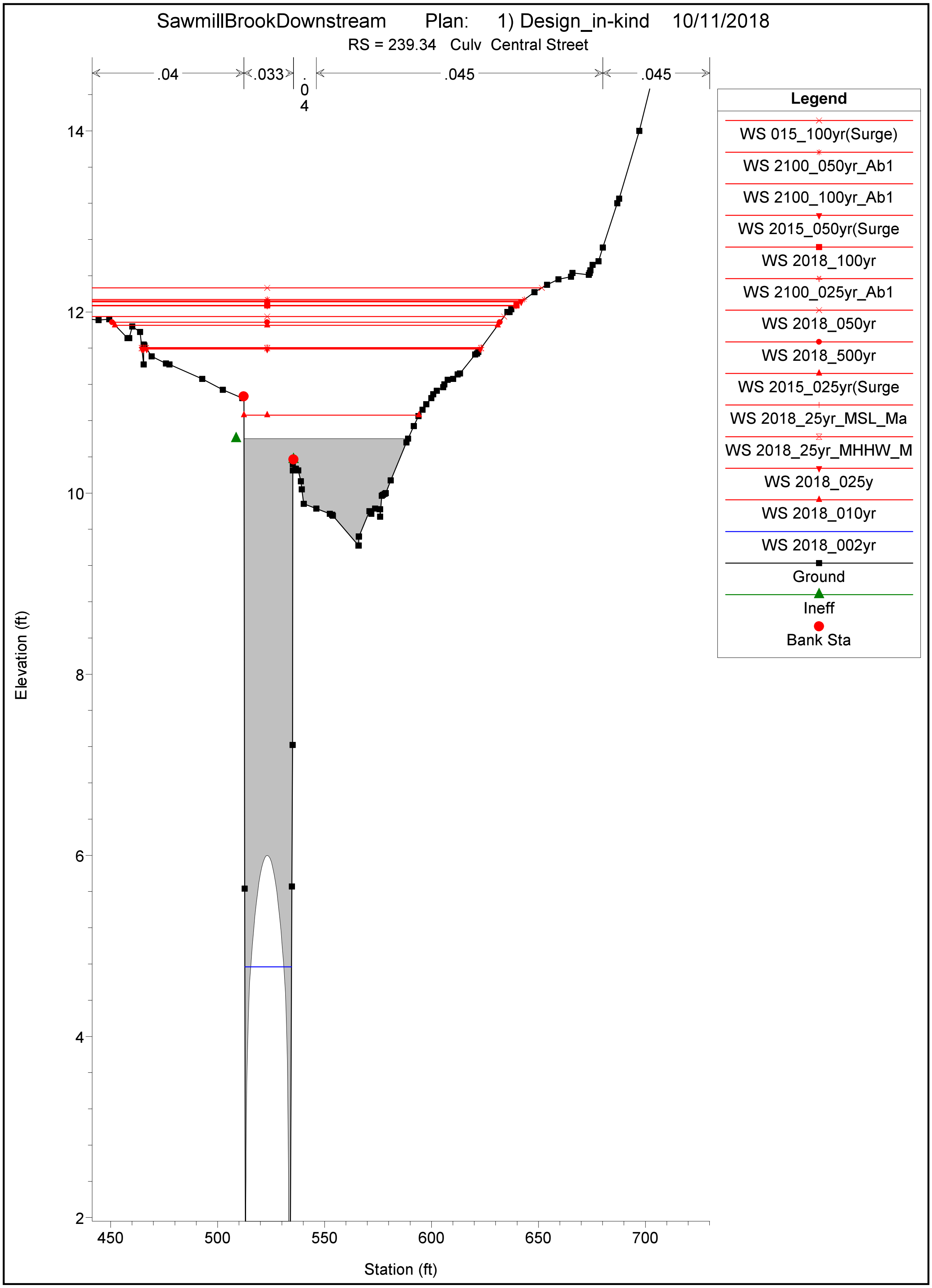


ATTACHMENT C

HEC-RAS Results


SawmillBrookDownstream Plan: Design_01_20'Wide_ConspanArch 10/12/2018
RS = 239.34 Culv Central Street
.06
.04
.045
.045
Legend
WS 2018_500yr
WS 2100_100yr_Ab1
WS 2015_050yr(Surge
WS 015_100yr(Surge)
WS 2100_025yr_Ab1
WS 2100_050yr_Ab1
WS 2015_025yr(Surge
WS 2018_25yr_MHHW_M
WS 2018_002yr
WS 2018_010yr
WS 2018_025y
WS 2018_050yr
WS 2018_100yr
WS 2018_25yr_MSL_Ma
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
25
20
15
10
5
0
-5
0
200
400
600
800
1000


SawmillBrookDownstream Plan: 1) Design_12' 10/11/2018
RS = 239.34 Culv Central Street
.04
.033
.04
.045
Legend
WS 015_100yr(Surge)
WS 2015_050yr(Surge
WS 2100_025yr_Ab1
WS 2100_050yr_Ab1
WS 2015_025yr(Surge
WS 2018_500yr
WS 2018_100yr
WS 2018_050yr
WS 2100_100yr_Ab1
WS 2018_25yr_MHHW_M
WS 2018_025y
WS 2018_010yr
WS 2018_002yr
WS 2018_25yr_MSL_Ma
Ground
Ineff
Bank Sta
Elevation (ft)
14
12
10
8
6
4
Station (ft)
460
480
500
520
540
560
580
600
620


SawmillBrookDownstream Plan: 1) Design_in-kind 10/11/2018
RS = 239.34 Culv Central Street
.04
.033
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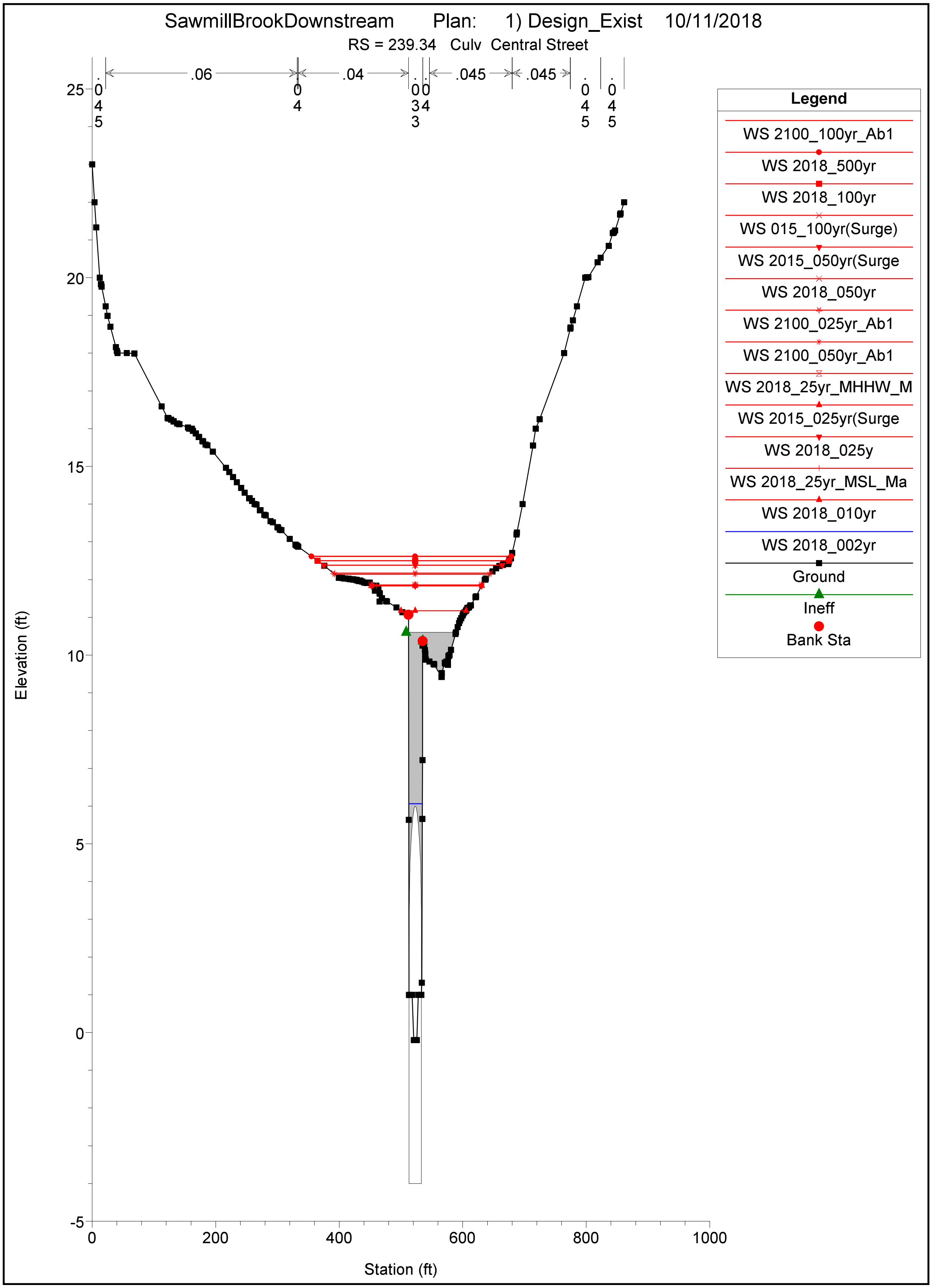
0
4
.045
.045
Legend
WS 015_100yr(Surge)
WS 2100_050yr_Ab1
WS 2100_100yr_Ab1
WS 2015_050yr(Surge
WS 2018_100yr
WS 2100_025yr_Ab1
WS 2018_050yr
WS 2018_500yr
WS 2015_025yr(Surge
WS 2018_25yr_MSL_Ma
WS 2018_25yr_MHHW_M
WS 2018_025y
WS 2018_010yr
WS 2018_002yr
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
14
12
10
8
6
4
2
450
500
550
600
650
700



SawmillBrookDownstream Plan: 1) Design_Exist 10/11/2018
RS = 239.34 Culv Central Street
.06
.04
.045
.045
Legend
WS 2100_100yr_Ab1
WS 2018_500yr
WS 2018_100yr
WS 015_100yr(Surge)
WS 2015_050yr(Surge
WS 2018_050yr
WS 2100_025yr_Ab1
WS 2100_050yr_Ab1
WS 2018_25yr_MHHW_M
WS 2015_025yr(Surge
WS 2018_025y
WS 2018_25yr_MSL_Ma
WS 2018_010yr
WS 2018_002yr
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	2841.083	2018_002yr	Design_20'	232	7.12	12.0851	9.14	12.13	0.000529	1.85	200.94	166.43	0.17
1	2841.083	2018_002yr	Design_12'	232	7.12	12.0851	9.14	12.13	0.000529	1.85	200.94	166.43	0.17
1	2841.083	2018_002yr	Design_in-kind	232	7.12	12.0851	9.14	12.13	0.000529	1.85	200.94	166.43	0.17
1	2841.083	2018_002yr	Design_Exist	232	7.12	12.0843	9.14	12.13	0.000529	1.85	200.81	166.41	0.17
1	2841.083	2018_010yr	Design_20'	845	7.12	15.4289	11.7	15.45	0.000158	1.57	1068.18	357.02	0.1
1	2841.083	2018_010yr	Design_12'	845	7.12	15.4289	11.7	15.45	0.000158	1.57	1068.18	357.02	0.1
1	2841.083	2018_010yr	Design_in-kind	845	7.12	15.4138	11.7	15.43	0.000161	1.57	1062.78	356.61	0.11
1	2841.083	2018_010yr	Design_Exist	845	7.12	15.4322	11.7	15.45	0.000158	1.56	1069.34	357.11	0.1
1	2841.083	2018_025y	Design_20'	1228	7.12	15.7738	12.45	15.8	0.000249	2.03	1192.86	365.98	0.13
1	2841.083	2018_025y	Design_12'	1228	7.12	15.7698	12.45	15.8	0.000249	2.03	1191.41	365.88	0.13
1	2841.083	2018_025y	Design_in-kind	1228	7.12	15.7832	12.45	15.81	0.000247	2.02	1196.31	366.23	0.13
1	2841.083	2018_025y	Design_Exist	1228	7.12	15.8006	12.45	15.83	0.000243	2.01	1202.68	366.68	0.13
1	2841.083	2018_050yr	Design_20'	1565	7.12	16.219	12.76	16.26	0.000295	2.3	1369.34	432.19	0.15
1	2841.083	2018_050yr	Design_12'	1565	7.12	16.2411	12.76	16.28	0.00029	2.28	1378.89	433.44	0.14
1	2841.083	2018_050yr	Design_in-kind	1565	7.12	16.2343	12.76	16.27	0.000292	2.29	1375.95	433.05	0.14
1	2841.083	2018_050yr	Design_Exist	1565	7.12	16.2593	12.76	16.3	0.000286	2.27	1386.78	434.47	0.14
1	2841.083	2018_100yr	Design_20'	2000	7.12	16.7766	13.09	16.82	0.000312	2.47	1619.19	464.08	0.15
1	2841.083	2018_100yr	Design_12'	2000	7.12	16.8017	13.09	16.84	0.000306	2.46	1630.88	465.52	0.15
1	2841.083	2018_100yr	Design_in-kind	2000	7.12	16.775	13.09	16.82	0.000313	2.48	1618.44	463.98	0.15
1	2841.083	2018_100yr	Design_Exist	2000	7.12	16.7826	13.09	16.82	0.000311	2.47	1621.99	464.42	0.15
1	2841.083	2018_500yr	Design_20'	2671	7.12	17.4201	13.55	17.47	0.000344	2.73	1927.38	492.84	0.16
1	2841.083	2018_500yr	Design_12'	2671	7.12	17.4759	13.55	17.52	0.000331	2.69	1954.95	494.89	0.16
1	2841.083	2018_500yr	Design_in-kind	2671	7.12	17.4398	13.55	17.49	0.000339	2.72	1937.11	493.57	0.16
1	2841.083	2018_500yr	Design_Exist	2671	7.12	17.4845	13.55	17.53	0.000329	2.68	1959.19	495.46	0.16
1	2841.083	2018_25yr_MHHW_M	Design_20'	1228	7.12	15.7738	12.45	15.8	0.000249	2.03	1192.86	365.98	0.13
1	2841.083	2018_25yr_MHHW_M	Design_12'	1228	7.12	15.7716	12.45	15.8	0.000249	2.03	1192.04	365.92	0.13
1	2841.083	2018_25yr_MHHW_M	Design_in-kind	1228	7.12	15.7933	12.45	15.82	0.000244	2.01	1200.02	366.49	0.13
1	2841.083	2018_25yr_MHHW_M	Design_Exist	1228	7.12	15.7955	12.45	15.83	0.000244	2.01	1200.79	366.54	0.13
1	2841.083	2018_25yr_MSL_Ma	Design_20'	1228	7.12	15.7738	12.45	15.8	0.000249	2.03	1192.86	365.98	0.13
1	2841.083	2018_25yr_MSL_Ma	Design_12'	1228	7.12	15.7736	12.45	15.8	0.000249	2.03	1192.79	365.98	0.13
1	2841.083	2018_25yr_MSL_Ma	Design_in-kind	1228	7.12	15.8002	12.45	15.83	0.000243	2.01	1202.51	366.67	0.13
1	2841.083	2018_25yr_MSL_Ma	Design_Exist	1228	7.12	15.8008	12.45	15.83	0.000243	2.01	1202.73	366.68	0.13
1	2841.083	2100_025yr_Ab1	Design_20'	1706	7.12	16.4194	12.87	16.46	0.000299	2.35	1457.1	443.6	0.15
1	2841.083	2100_025yr_Ab1	Design_12'	1706	7.12	16.4321	12.87	16.47	0.000296	2.34	1462.7	444.32	0.15
1	2841.083	2100_025yr_Ab1	Design_in-kind	1706	7.12	16.4296	12.87	16.47	0.000297	2.35	1461.63	444.18	0.15
1	2841.083	2100_025yr_Ab1	Design_Exist	1706	7.12	16.4146	12.87	16.45	0.0003	2.36	1454.96	443.32	0.15
1	2841.083	2100_050yr_Ab1	Design_20'	1717	7.12	16.436	12.88	16.48	0.000299	2.36	1464.45	444.55	0.15
1	2841.083	2100_050yr_Ab1	Design_12'	1717	7.12	16.4355	12.88	16.48	0.000299	2.36	1464.23	444.52	0.15
1	2841.083	2100_050yr_Ab1	Design_in-kind	1717	7.12	16.4312	12.88	16.47	0.0003	2.36	1462.32	444.27	0.15
1	2841.083	2100_050yr_Ab1	Design_Exist	1717	7.12	16.4322	12.88	16.47	0.0003	2.36	1462.78	444.33	0.15
1	2841.083	2100_100yr_Ab1	Design_20'	2562	7.12	17.348	13.48	17.4	0.000333	2.67	1891.94	489.27	0.16
1	2841.083	2100_100yr_Ab1	Design_12'	2562	7.12	17.3199	13.48	17.37	0.00034	2.69	1878.21	488.34	0.16
1	2841.083	2100_100yr_Ab1	Design_in-kind	2562	7.12	17.302	13.48	17.35	0.000345	2.71	1869.5	487.75	0.16
1	2841.083	2100_100yr_Ab1	Design_Exist	2562	7.12	17.3406	13.48	17.39	0.000335	2.68	1888.32	489.03	0.16
1	2841.083	2018_025yr(Surge	Design_20'	1228	7.12	15.7698	12.45	15.8	0.000249	2.03	1191.41	365.88	0.13
1	2841.083	2015_025yr(Surge	Design_12'	1228	7.12	15.775	12.45	15.81	0.000248	2.03	1193.31	366.01	0.13
1	2841.083	2015_025yr(Surge	Design_in-kind	1228	7.12	15.7999	12.45	15.83	0.000243	2.01	1202.44	366.66	0.13
1	2841.083	2015_025yr(Surge	Design_Exist	1228	7.12	15.8023	12.45	15.83	0.000243	2.01	1203.29	366.72	0.13
1	2841.083	2018_050yr(Surge	Design_20'	1565	7.12	16.2228	12.76	16.26	0.000294	2.29	1370.96	432.4	0.15
1	2841.083	2015_050yr(Surge	Design_12'	1565	7.12	16.252	12.76	16.29	0.000288	2.27	1383.61	434.05	0.14
1	2841.083	2015_050yr(Surge	Design_in-kind	1565	7.12	16.243	12.76	16.28	0.00029	2.28	1379.71	433.54	0.14
1	2841.083	2015_050yr(Surge	Design_Exist	1565	7.12	16.2507	12.76	16.29	0.000288	2.27	1383.05	433.98	0.14
1	2841.083	015_100yr(Surge)	Design_20'	2000	7.12	16.7691	13.09	16.81	0.000314	2.48	1615.72	463.65	0.15
1	2841.083	015_100yr(Surge)	Design_12'	2000	7.12	16.7641	13.09	16.81	0.000315	2.48	1613.41	463.36	0.15
1	2841.083	015_100yr(Surge)	Design_in-kind	2000	7.12	16.8114	13.09	16.85	0.000304	2.45	1635.38	466.07	0.15
1	2841.083	015_100yr(Surge)	Design_Exist	2000	7.12	16.7743	13.09	16.82	0.000313	2.48	1618.13	463.95	0.15
1	2788.571	2018_002yr	Design_20'	232	7.44	12.0082	9.07	12.09	0.000809	2.33	101.22	80.24	0.2
1	2788.571	2018_002yr	Design_12'	232	7.44	12.0082	9.07	12.09	0.000809	2.33	101.22	80.24	0.2
1	2788.571	2018_002yr	Design_in-kind	232	7.44	12.0082	9.07	12.09	0.000809	2.33	101.22	80.24	0.2
1	2788.571	2018_002yr	Design_Exist	232	7.44	12.0074	9.07	12.09	0.000809	2.33	101.2	80.21	0.2
1	2788.571	2018_010yr	Design_20'	845	7.44	15.348	11.19	15.43	0.000557	2.84	629.69	304.19	0.19
1	2788.571	2018_010yr	Design_12'	845	7.44	15.348	11.19	15.43	0.000557	2.84	629.69	304.19	0.19
1	2788.571	2018_010yr	Design_in-kind	845	7.44	15.3316	11.19	15.41	0.000566	2.85	625.49	303.51	0.19
1	2788.571	2018_010yr	Design_Exist	845	7.44	15.3516	11.19	15.43	0.000555	2.83	630.6	304.34	0.19
1	2788.571	2018_025y	Design_20'	1228	7.44	15.6439	12.31	15.78	0.0009	3.7	706.16	316.5	0.24
1	2788.571	2018_025y	Design_12'	1228	7.44	15.6394	12.31	15.77	0.000903	3.71	704.98	316.31	0.24
1	2788.571	2018_025y	Design_in-kind	1228	7.44	15.6546	12.31	15.78	0.000891	3.69	708.95	316.94	0.24
1	2788.571	2018_025y	Design_Exist	1228	7.44	15.6744	12.31	15.8	0.000876	3.66	714.12	317.76	0.23
1	2788.571	2018_050yr	Design_20'	1565	7.44	16.133	13.04	16.23	0.00074	3.5	987.41	371.21	0.22
1	2788.571	2018_050yr	Design_12'	1565	7.44	16.1572	13.04	16.25	0.000725	3.47	996.4	373.09	0.22
1	2788.571	2018_050yr	Design_in-kind	1565	7.44	16.1497	13.04	16.25	0.000729	3.48	993.6	372.54	0.22

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	2788.571	2018_050yr	Design_Exist	1565	7.44	16.177	13.04	16.27	0.000712	3.45	1003.8	374.54	0.21
1	2788.571	2018_100yr	Design_20'	2000	7.44	16.6892	13.89	16.79	0.000778	3.75	1204.48	407.38	0.23
1	2788.571	2018_100yr	Design_12'	2000	7.44	16.7165	13.89	16.82	0.00076	3.72	1215.65	408.96	0.22
1	2788.571	2018_100yr	Design_in-kind	2000	7.44	16.6874	13.89	16.79	0.000779	3.76	1203.77	407.27	0.23
1	2788.571	2018_100yr	Design_Exist	2000	7.44	16.6958	13.89	16.8	0.000773	3.74	1207.17	407.76	0.23
1	2788.571	2018_500yr	Design_20'	2671	7.44	17.3351	15.06	17.44	0.0008	4	1479.71	444.83	0.23
1	2788.571	2018_500yr	Design_12'	2671	7.44	17.3956	15.06	17.5	0.000761	3.91	1506.71	448.33	0.23
1	2788.571	2018_500yr	Design_in-kind	2671	7.44	17.3565	15.06	17.46	0.000786	3.97	1489.25	446.07	0.23
1	2788.571	2018_500yr	Design_Exist	2671	7.44	17.4048	15.06	17.51	0.000755	3.9	1510.86	448.85	0.23
1	2788.571	2018_25yr_MHHW_M	Design_20'	1228	7.44	15.6439	12.31	15.78	0.0009	3.7	706.16	316.5	0.24
1	2788.571	2018_25yr_MHHW_M	Design_12'	1228	7.44	15.6414	12.31	15.77	0.000902	3.71	705.48	316.39	0.24
1	2788.571	2018_25yr_MHHW_M	Design_in-kind	1228	7.44	15.6661	12.31	15.79	0.000882	3.67	711.96	317.42	0.24
1	2788.571	2018_25yr_MHHW_M	Design_Exist	1228	7.44	15.6685	12.31	15.8	0.00088	3.67	712.59	317.52	0.24
1	2788.571	2018_25yr_MSL_Ma	Design_20'	1228	7.44	15.6439	12.31	15.78	0.0009	3.7	706.16	316.5	0.24
1	2788.571	2018_25yr_MSL_Ma	Design_12'	1228	7.44	15.6437	12.31	15.78	0.0009	3.7	706.09	316.49	0.24
1	2788.571	2018_25yr_MSL_Ma	Design_in-kind	1228	7.44	15.6738	12.31	15.8	0.000876	3.66	713.98	317.74	0.24
1	2788.571	2018_25yr_MSL_Ma	Design_Exist	1228	7.44	15.6745	12.31	15.8	0.000876	3.66	714.16	317.77	0.23
1	2788.571	2100_025yr_Ab1	Design_20'	1706	7.44	16.335	13.33	16.43	0.000739	3.56	1063.88	386.06	0.22
1	2788.571	2100_025yr_Ab1	Design_12'	1706	7.44	16.3487	13.33	16.45	0.00073	3.54	1069.19	387.06	0.22
1	2788.571	2100_025yr_Ab1	Design_in-kind	1706	7.44	16.3461	13.33	16.44	0.000732	3.54	1068.18	386.87	0.22
1	2788.571	2100_025yr_Ab1	Design_Exist	1706	7.44	16.3298	13.33	16.43	0.000742	3.56	1061.87	385.68	0.22
1	2788.571	2100_050yr_Ab1	Design_20'	1717	7.44	16.3518	13.35	16.45	0.000738	3.56	1070.38	387.28	0.22
1	2788.571	2100_050yr_Ab1	Design_12'	1717	7.44	16.3513	13.35	16.45	0.000738	3.56	1070.18	387.25	0.22
1	2788.571	2100_050yr_Ab1	Design_in-kind	1717	7.44	16.3466	13.35	16.45	0.000741	3.57	1068.37	386.91	0.22
1	2788.571	2100_050yr_Ab1	Design_Exist	1717	7.44	16.3477	13.35	16.45	0.00074	3.56	1068.8	386.99	0.22
1	2788.571	2100_100yr_Ab1	Design_20'	2562	7.44	17.2645	14.88	17.37	0.000781	3.93	1448.46	440.73	0.23
1	2788.571	2100_100yr_Ab1	Design_12'	2562	7.44	17.234	14.88	17.34	0.000801	3.97	1435.02	438.96	0.23
1	2788.571	2100_100yr_Ab1	Design_in-kind	2562	7.44	17.2145	14.88	17.32	0.000814	4	1426.49	437.83	0.23
1	2788.571	2100_100yr_Ab1	Design_Exist	2562	7.44	17.2565	14.88	17.36	0.000786	3.94	1444.91	440.27	0.23
1	2788.571	2018_025yr(Surge	Design_20'	1228	7.44	15.6394	12.31	15.77	0.000903	3.71	704.98	316.31	0.24
1	2788.571	2015_025yr(Surge	Design_12'	1228	7.44	15.6453	12.31	15.78	0.000899	3.7	706.52	316.55	0.24
1	2788.571	2015_025yr(Surge	Design_in-kind	1228	7.44	15.6736	12.31	15.8	0.000876	3.66	713.92	317.73	0.24
1	2788.571	2015_025yr(Surge	Design_Exist	1228	7.44	15.6762	12.31	15.8	0.000874	3.66	714.61	317.84	0.23
1	2788.571	2018_050yr(Surge	Design_20'	1565	7.44	16.1371	13.04	16.24	0.000737	3.5	988.92	371.51	0.22
1	2788.571	2015_050yr(Surge	Design_12'	1565	7.44	16.169	13.04	16.26	0.000717	3.46	1000.81	373.95	0.21
1	2788.571	2015_050yr(Surge	Design_in-kind	1565	7.44	16.1591	13.04	16.26	0.000723	3.47	997.12	373.23	0.22
1	2788.571	2015_050yr(Surge	Design_Exist	1565	7.44	16.1677	13.04	16.26	0.000718	3.46	1000.31	373.86	0.21
1	2788.571	015_100yr(Surge)	Design_20'	2000	7.44	16.681	13.89	16.79	0.000783	3.76	1201.17	406.91	0.23
1	2788.571	015_100yr(Surge)	Design_12'	2000	7.44	16.6756	13.89	16.78	0.000787	3.77	1198.96	406.59	0.23
1	2788.571	015_100yr(Surge)	Design_in-kind	2000	7.44	16.727	13.89	16.83	0.000753	3.7	1219.95	409.56	0.22
1	2788.571	015_100yr(Surge)	Design_Exist	2000	7.44	16.6867	13.89	16.79	0.000779	3.76	1203.48	407.23	0.23
1	2767			Culvert									
1	2746.289	2018_002yr	Design_20'	232	7.4	11.6705		11.77	0.00101	2.49	103.83	65.72	0.22
1	2746.289	2018_002yr	Design_12'	232	7.4	11.6705		11.77	0.00101	2.49	103.83	65.72	0.22
1	2746.289	2018_002yr	Design_in-kind	232	7.4	11.6705		11.77	0.00101	2.49	103.83	65.72	0.22
1	2746.289	2018_002yr	Design_Exist	232	7.4	11.6681	8.99	11.77	0.001031	2.51	93.3	65.61	0.23
1	2746.289	2018_010yr	Design_20'	845	7.4	15.2811		15.34	0.000453	2.55	712.82	301.48	0.17
1	2746.289	2018_010yr	Design_12'	845	7.4	15.2811		15.34	0.000453	2.55	712.82	301.48	0.17
1	2746.289	2018_010yr	Design_in-kind	845	7.4	15.2708		15.33	0.000458	2.56	709.71	301.03	0.17
1	2746.289	2018_010yr	Design_Exist	845	7.4	15.3056	11.13	15.36	0.000442	2.53	720.21	302.42	0.17
1	2746.289	2018_025y	Design_20'	1228	7.4	15.5834		15.68	0.000713	3.29	805.84	313.98	0.21
1	2746.289	2018_025y	Design_12'	1228	7.4	15.5819		15.68	0.000714	3.29	805.35	313.92	0.21
1	2746.289	2018_025y	Design_in-kind	1228	7.4	15.6018		15.7	0.000701	3.27	811.62	314.74	0.21
1	2746.289	2018_025y	Design_Exist	1228	7.4	15.6065	12.68	15.7	0.000698	3.26	813.11	314.94	0.21
1	2746.289	2018_050yr	Design_20'	1565	7.4	16.0558		16.16	0.000785	3.59	960.45	365.81	0.22
1	2746.289	2018_050yr	Design_12'	1565	7.4	16.054		16.16	0.000786	3.6	959.78	365.69	0.22
1	2746.289	2018_050yr	Design_in-kind	1565	7.4	16.0628		16.17	0.00078	3.59	963	366.27	0.22
1	2746.289	2018_050yr	Design_Exist	1565	7.4	16.0773	13.11	16.18	0.00077	3.57	968.32	367.23	0.22
1	2746.289	2018_100yr	Design_20'	2000	7.4	16.5919		16.7	0.000838	3.88	1166.61	401.75	0.23
1	2746.289	2018_100yr	Design_12'	2000	7.4	16.5945		16.71	0.000836	3.88	1167.66	401.9	0.23
1	2746.289	2018_100yr	Design_in-kind	2000	7.4	16.6023		16.71	0.000831	3.86	1170.8	402.36	0.23
1	2746.289	2018_100yr	Design_Exist	2000	7.4	16.615	13.97	16.73	0.000822	3.85	1175.92	403.09	0.23
1	2746.289	2018_500yr	Design_20'	2671	7.4	17.2939		17.41	0.000823	4.05	1462.91	442.44	0.24
1	2746.289	2018_500yr	Design_12'	2671	7.4	17.2908		17.4	0.000825	4.05	1461.55	442.26	0.24
1	2746.289	2018_500yr	Design_in-kind	2671	7.4	17.2994		17.41	0.000819	4.04	1465.36	442.76	0.23
1	2746.289	2018_500yr	Design_Exist	2671	7.4	17.2961	14.89	17.41	0.000821	4.05	1463.89	442.56	0.23
1	2746.289	2018_25yr_MHHW_M	Design_20'	1228	7.4	15.5834		15.68	0.000713	3.29	805.84	313.98	0.21
1	2746.289	2018_25yr_MHHW_M	Design_12'	1228	7.4	15.5837		15.68	0.000713	3.29	805.92	313.99	0.21
1	2746.289	2018_25yr_MHHW_M	Design_in-kind	1228	7.4	15.6027		15.7	0.000701	3.27	811.89	314.78	0.21
1	2746.289	2018_25yr_MHHW_M	Design_Exist	1228	7.4	15.6108	12.68	15.7	0.000695	3.26	814.45	315.12	0.21

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	2746.289	2018_25yr_MSL_Ma	Design_20'	1228	7.4	15.5834		15.68	0.000713	3.29	805.84	313.98	0.21
1	2746.289	2018_25yr_MSL_Ma	Design_12'	1228	7.4	15.5834		15.68	0.000713	3.29	805.85	313.98	0.21
1	2746.289	2018_25yr_MSL_Ma	Design_in-kind	1228	7.4	15.6052		15.7	0.000699	3.26	812.68	314.88	0.21
1	2746.289	2018_25yr_MSL_Ma	Design_Exist	1228	7.4	15.6059	12.68	15.7	0.000698	3.26	812.92	314.92	0.21
1	2746.289	2100_025yr_Ab1	Design_20'	1706	7.4	16.2317		16.34	0.0008	3.68	1025.9	378.53	0.23
1	2746.289	2100_025yr_Ab1	Design_12'	1706	7.4	16.248		16.35	0.000789	3.66	1032.06	379.71	0.23
1	2746.289	2100_025yr_Ab1	Design_in-kind	1706	7.4	16.2533		16.36	0.000785	3.65	1034.09	380.1	0.23
1	2746.289	2100_025yr_Ab1	Design_Exist	1706	7.4	16.2544	13.46	16.36	0.000784	3.65	1034.5	380.18	0.22
1	2746.289	2100_050yr_Ab1	Design_20'	1717	7.4	16.2524		16.36	0.000796	3.68	1033.74	380.03	0.23
1	2746.289	2100_050yr_Ab1	Design_12'	1717	7.4	16.2582		16.37	0.000792	3.67	1035.94	380.46	0.23
1	2746.289	2100_050yr_Ab1	Design_in-kind	1717	7.4	16.2695		16.38	0.000784	3.66	1040.25	381.28	0.23
1	2746.289	2100_050yr_Ab1	Design_Exist	1717	7.4	16.2722	13.47	16.38	0.000782	3.65	1041.29	381.48	0.22
1	2746.289	2100_100yr_Ab1	Design_20'	2562	7.4	17.1744		17.29	0.000837	4.05	1410.47	435.51	0.24
1	2746.289	2100_100yr_Ab1	Design_12'	2562	7.4	17.1818		17.29	0.000832	4.04	1413.69	435.93	0.24
1	2746.289	2100_100yr_Ab1	Design_in-kind	2562	7.4	17.1896		17.3	0.000826	4.03	1417.1	436.39	0.24
1	2746.289	2100_100yr_Ab1	Design_Exist	2562	7.4	17.1811	14.82	17.29	0.000832	4.04	1413.39	435.89	0.24
1	2746.289	2018_025yr(Surge	Design_20'	1228	7.4	15.5819		15.68	0.000714	3.29	805.35	313.92	0.21
1	2746.289	2015_025yr(Surge	Design_12'	1228	7.4	15.592		15.69	0.000708	3.28	808.54	314.34	0.21
1	2746.289	2015_025yr(Surge	Design_in-kind	1228	7.4	15.6049		15.7	0.000699	3.26	812.61	314.87	0.21
1	2746.289	2015_025yr(Surge	Design_Exist	1228	7.4	15.6118	12.68	15.7	0.000695	3.25	814.76	315.16	0.21
1	2746.289	2018_050yr(Surge	Design_20'	1565	7.4	16.0499		16.16	0.000789	3.6	958.29	365.42	0.22
1	2746.289	2015_050yr(Surge	Design_12'	1565	7.4	16.055		16.16	0.000786	3.6	960.17	365.76	0.22
1	2746.289	2015_050yr(Surge	Design_in-kind	1565	7.4	16.0724		16.18	0.000773	3.57	966.52	366.91	0.22
1	2746.289	2015_050yr(Surge	Design_Exist	1565	7.4	16.0759	13.11	16.18	0.000771	3.57	967.83	367.14	0.22
1	2746.289	015_100yr(Surge)	Design_20'	2000	7.4	16.6009		16.71	0.000832	3.87	1170.25	402.28	0.23
1	2746.289	015_100yr(Surge)	Design_12'	2000	7.4	16.5959		16.71	0.000835	3.87	1168.23	401.98	0.23
1	2746.289	015_100yr(Surge)	Design_in-kind	2000	7.4	16.611		16.72	0.000825	3.85	1174.32	402.86	0.23
1	2746.289	015_100yr(Surge)	Design_Exist	2000	7.4	16.612	13.97	16.72	0.000824	3.85	1174.71	402.92	0.23
1	2723.129	2018_002yr	Design_20'	232	7.34	11.2416	9.87	11.68	0.00616	5.32	43.58	12.37	0.5
1	2723.129	2018_002yr	Design_12'	232	7.34	11.2416	9.87	11.68	0.00616	5.32	43.58	12.37	0.5
1	2723.129	2018_002yr	Design_in-kind	232	7.34	11.2416	9.87	11.68	0.00616	5.32	43.58	12.37	0.5
1	2723.129	2018_002yr	Design_Exist	232	7.34	11.2416	9.87	11.68	0.00616	5.32	43.58	12.37	0.5
1	2723.129	2018_010yr	Design_20'	845	7.34	13.9544	13.86	15.19	0.011232	9.49	115.04	75.56	0.67
1	2723.129	2018_010yr	Design_12'	845	7.34	13.9544	13.86	15.19	0.011232	9.49	115.04	75.56	0.67
1	2723.129	2018_010yr	Design_in-kind	845	7.34	13.9964	13.86	15.19	0.010817	9.34	118.23	88.58	0.66
1	2723.129	2018_010yr	Design_Exist	845	7.34	13.8649	13.86	15.21	0.012147	9.8	109.31	68.2	0.7
1	2723.129	2018_025y	Design_20'	1228	7.34	15.2678	14.9	15.62	0.004021	6.27	346.01	240.78	0.41
1	2723.129	2018_025y	Design_12'	1228	7.34	15.2644	14.9	15.62	0.00404	6.29	345.31	240.6	0.41
1	2723.129	2018_025y	Design_in-kind	1228	7.34	15.3059	14.9	15.64	0.003816	6.13	353.93	242.85	0.4
1	2723.129	2018_025y	Design_Exist	1228	7.34	15.3153	14.9	15.64	0.003768	6.1	355.88	243.35	0.39
1	2723.129	2018_050yr	Design_20'	1565	7.34	15.8501	15.16	16.11	0.00305	5.75	474.54	274.39	0.36
1	2723.129	2018_050yr	Design_12'	1565	7.34	15.8474	15.16	16.11	0.003061	5.76	473.91	274.25	0.36
1	2723.129	2018_050yr	Design_in-kind	1565	7.34	15.8603	15.16	16.12	0.003012	5.72	476.93	274.93	0.36
1	2723.129	2018_050yr	Design_Exist	1565	7.34	15.8808	15.16	16.13	0.002937	5.65	481.77	276.02	0.35
1	2723.129	2018_100yr	Design_20'	2000	7.34	16.4411	15.43	16.66	0.002451	5.4	618.59	298.21	0.33
1	2723.129	2018_100yr	Design_12'	2000	7.34	16.4443	15.43	16.66	0.002443	5.4	619.4	298.34	0.32
1	2723.129	2018_100yr	Design_in-kind	2000	7.34	16.4538	15.43	16.67	0.002417	5.37	621.8	298.74	0.32
1	2723.129	2018_100yr	Design_Exist	2000	7.34	16.4693	15.43	16.68	0.002375	5.33	625.7	299.56	0.32
1	2723.129	2018_500yr	Design_20'	2671	7.34	17.2124	15.79	17.37	0.00169	4.75	939.26	323.35	0.27
1	2723.129	2018_500yr	Design_12'	2671	7.34	17.2091	15.79	17.37	0.001696	4.76	938.18	323.29	0.27
1	2723.129	2018_500yr	Design_in-kind	2671	7.34	17.2184	15.79	17.38	0.001681	4.74	941.17	323.45	0.27
1	2723.129	2018_500yr	Design_Exist	2671	7.34	17.2148	15.79	17.37	0.001687	4.75	940.03	323.39	0.27
1	2723.129	2018_25yr_MHHW_M	Design_20'	1228	7.34	15.2678	14.9	15.62	0.004021	6.27	346.01	240.78	0.41
1	2723.129	2018_25yr_MHHW_M	Design_12'	1228	7.34	15.2684	14.9	15.62	0.004018	6.27	346.12	240.81	0.41
1	2723.129	2018_25yr_MHHW_M	Design_in-kind	1228	7.34	15.3077	14.9	15.64	0.003807	6.13	354.29	242.94	0.4
1	2723.129	2018_25yr_MHHW_M	Design_Exist	1228	7.34	15.3236	14.9	15.65	0.003725	6.07	357.61	243.8	0.39
1	2723.129	2018_25yr_MSL_Ma	Design_20'	1228	7.34	15.2678	14.9	15.62	0.004021	6.27	346.01	240.78	0.41
1	2723.129	2018_25yr_MSL_Ma	Design_12'	1228	7.34	15.2679	14.9	15.62	0.004021	6.27	346.02	240.78	0.41
1	2723.129	2018_25yr_MSL_Ma	Design_in-kind	1228	7.34	15.3126	14.9	15.64	0.003781	6.11	355.32	243.21	0.39
1	2723.129	2018_25yr_MSL_Ma	Design_Exist	1228	7.34	15.3141	14.9	15.64	0.003774	6.1	355.63	243.29	0.39
1	2723.129	2100_025yr_Ab1	Design_20'	1706	7.34	16.045	15.26	16.29	0.002854	5.65	521.03	283.8	0.35
1	2723.129	2100_025yr_Ab1	Design_12'	1706	7.34	16.0674	15.26	16.31	0.002775	5.58	526.45	284.54	0.34
1	2723.129	2100_025yr_Ab1	Design_in-kind	1706	7.34	16.0746	15.26	16.31	0.00275	5.56	528.21	284.77	0.34
1	2723.129	2100_025yr_Ab1	Design_Exist	1706	7.34	16.0761	15.26	16.31	0.002745	5.56	528.56	284.82	0.34
1	2723.129	2100_050yr_Ab1	Design_20'	1717	7.34	16.0699	15.26	16.31	0.002802	5.61	527.06	284.62	0.35
1	2723.129	2100_050yr_Ab1	Design_12'	1717	7.34	16.0778	15.26	16.32	0.002774	5.59	528.98	284.88	0.34
1	2723.129	2100_050yr_Ab1	Design_in-kind	1717	7.34	16.0931	15.26	16.33	0.002722	5.54	532.7	285.38	0.34
1	2723.129	2100_050yr_Ab1	Design_Exist	1717	7.34	16.0968	15.26	16.33	0.00271	5.53	533.59	285.5	0.34
1	2723.129	2100_100yr_Ab1	Design_20'	2562	7.34	17.0916	15.74	17.25	0.001751	4.8	900.32	321.22	0.28
1	2723.129	2100_100yr_Ab1	Design_12'	2562	7.34	17.0996	15.74	17.26	0.001737	4.78	902.88	321.36	0.28
1	2723.129	2100_100yr_Ab1	Design_in-kind	2562	7.34	17.108	15.74	17.27	0.001723	4.76	905.59	321.5	0.28

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	2723.129	2100_100yr_Ab1	Design_Exist	2562	7.34	17.0989	15.74	17.26	0.001739	4.78	902.65	321.34	0.28
1	2723.129	2018_025yr(Surge	Design_20'	1228	7.34	15.2644	14.9	15.62	0.00404	6.29	345.31	240.6	0.41
1	2723.129	2015_025yr(Surge	Design_12'	1228	7.34	15.286	14.9	15.63	0.003922	6.21	349.78	241.77	0.4
1	2723.129	2015_025yr(Surge	Design_in-kind	1228	7.34	15.3122	14.9	15.64	0.003784	6.11	355.23	243.19	0.4
1	2723.129	2015_025yr(Surge	Design_Exist	1228	7.34	15.3254	14.9	15.65	0.003716	6.06	358	243.91	0.39
1	2723.129	2018_050yr(Surge	Design_20'	1565	7.34	15.8414	15.16	16.1	0.003084	5.78	472.49	273.93	0.36
1	2723.129	2015_050yr(Surge	Design_12'	1565	7.34	15.849	15.16	16.11	0.003055	5.75	474.27	274.33	0.36
1	2723.129	2015_050yr(Surge	Design_in-kind	1565	7.34	15.8739	15.16	16.13	0.002962	5.68	480.14	275.65	0.35
1	2723.129	2015_050yr(Surge	Design_Exist	1565	7.34	15.879	15.16	16.13	0.002944	5.66	481.32	275.92	0.35
1	2723.129	015_100yr(Surge)	Design_20'	2000	7.34	16.4521	15.43	16.67	0.002421	5.38	621.38	298.67	0.32
1	2723.129	015_100yr(Surge)	Design_12'	2000	7.34	16.446	15.43	16.66	0.002438	5.39	619.84	298.42	0.32
1	2723.129	015_100yr(Surge)	Design_in-kind	2000	7.34	16.4645	15.43	16.68	0.002388	5.34	624.48	299.27	0.32
1	2723.129	015_100yr(Surge)	Design_Exist	2000	7.34	16.4656	15.43	16.68	0.002385	5.34	624.78	299.34	0.32
1	2594.622	2018_002yr	Design_20'	232	6.84	11.1335		11.27	0.001295	2.97	89.89	43.86	0.29
1	2594.622	2018_002yr	Design_12'	232	6.84	11.1335		11.27	0.001295	2.97	89.89	43.86	0.29
1	2594.622	2018_002yr	Design_in-kind	232	6.84	11.1335		11.27	0.001295	2.97	89.89	43.86	0.29
1	2594.622	2018_002yr	Design_Exist	232	6.84	11.1335		11.27	0.001295	2.97	89.89	43.86	0.29
1	2594.622	2018_010yr	Design_20'	845	6.84	14.3182		14.54	0.00111	4.31	381.61	191.95	0.3
1	2594.622	2018_010yr	Design_12'	845	6.84	14.3182		14.54	0.00111	4.31	381.61	191.95	0.3
1	2594.622	2018_010yr	Design_in-kind	845	6.84	14.3474		14.56	0.001082	4.27	387.22	192.92	0.29
1	2594.622	2018_010yr	Design_Exist	845	6.84	14.3827	11.46	14.59	0.001049	4.22	394.05	194.09	0.29
1	2594.622	2018_025y	Design_20'	1228	6.84	15.06		15.32	0.001247	4.91	534.44	222.57	0.32
1	2594.622	2018_025y	Design_12'	1228	6.84	15.0562		15.31	0.001251	4.92	533.6	222.46	0.32
1	2594.622	2018_025y	Design_in-kind	1228	6.84	15.1028		15.35	0.001203	4.84	543.99	223.74	0.32
1	2594.622	2018_025y	Design_Exist	1228	6.84	15.1133		15.36	0.001193	4.82	546.34	224.03	0.31
1	2594.622	2018_050yr	Design_20'	1565	6.84	15.5784		15.85	0.001325	5.3	653.51	236.82	0.34
1	2594.622	2018_050yr	Design_12'	1565	6.84	15.5752		15.85	0.001329	5.3	652.74	236.73	0.34
1	2594.622	2018_050yr	Design_in-kind	1565	6.84	15.5906		15.86	0.001313	5.28	656.41	237.15	0.33
1	2594.622	2018_050yr	Design_Exist	1565	6.84	15.6152		15.88	0.001287	5.24	662.25	237.83	0.33
1	2594.622	2018_100yr	Design_20'	2000	6.84	16.0997		16.4	0.00145	5.79	781.47	259.19	0.35
1	2594.622	2018_100yr	Design_12'	2000	6.84	16.104		16.41	0.001445	5.78	782.59	259.31	0.35
1	2594.622	2018_100yr	Design_in-kind	2000	6.84	16.117		16.42	0.001431	5.76	785.95	259.67	0.35
1	2594.622	2018_100yr	Design_Exist	2000	6.84	16.1378		16.43	0.001408	5.72	791.37	260.24	0.35
1	2594.622	2018_500yr	Design_20'	2671	6.84	16.8095		17.14	0.001539	6.3	972.19	277.81	0.37
1	2594.622	2018_500yr	Design_12'	2671	6.84	16.8048		17.14	0.001544	6.31	970.89	277.69	0.37
1	2594.622	2018_500yr	Design_in-kind	2671	6.84	16.8178		17.15	0.00153	6.29	974.51	278.02	0.37
1	2594.622	2018_500yr	Design_Exist	2671	6.84	16.8128		17.14	0.001536	6.29	973.12	277.9	0.37
1	2594.622	2018_25yr_MHHW_M	Design_20'	1228	6.84	15.06		15.32	0.001247	4.91	534.44	222.57	0.32
1	2594.622	2018_25yr_MHHW_M	Design_12'	1228	6.84	15.0606		15.32	0.001247	4.91	534.58	222.58	0.32
1	2594.622	2018_25yr_MHHW_M	Design_in-kind	1228	6.84	15.1047		15.35	0.001201	4.84	544.42	223.8	0.32
1	2594.622	2018_25yr_MHHW_M	Design_Exist	1228	6.84	15.1226		15.36	0.001183	4.81	548.42	224.29	0.31
1	2594.622	2018_25yr_MSL_Ma	Design_20'	1228	6.84	15.06		15.32	0.001247	4.91	534.44	222.57	0.32
1	2594.622	2018_25yr_MSL_Ma	Design_12'	1228	6.84	15.06		15.32	0.001247	4.91	534.45	222.57	0.32
1	2594.622	2018_25yr_MSL_Ma	Design_in-kind	1228	6.84	15.1102		15.35	0.001196	4.83	545.66	223.95	0.32
1	2594.622	2018_25yr_MSL_Ma	Design_Exist	1228	6.84	15.112		15.36	0.001194	4.83	546.04	223.99	0.32
1	2594.622	2100_025yr_Ab1	Design_20'	1706	6.84	15.7415		16.03	0.001386	5.49	692.51	241.2	0.34
1	2594.622	2100_025yr_Ab1	Design_12'	1706	6.84	15.7694		16.05	0.001356	5.45	699.25	241.94	0.34
1	2594.622	2100_025yr_Ab1	Design_in-kind	1706	6.84	15.7785		16.06	0.001347	5.43	701.43	242.17	0.34
1	2594.622	2100_025yr_Ab1	Design_Exist	1706	6.84	15.7803		16.06	0.001345	5.43	701.87	242.22	0.34
1	2594.622	2100_050yr_Ab1	Design_20'	1717	6.84	15.7667		16.05	0.001377	5.49	698.59	241.86	0.34
1	2594.622	2100_050yr_Ab1	Design_12'	1717	6.84	15.7766		16.06	0.001366	5.47	700.99	242.13	0.34
1	2594.622	2100_050yr_Ab1	Design_in-kind	1717	6.84	15.7958		16.08	0.001346	5.44	705.63	242.63	0.34
1	2594.622	2100_050yr_Ab1	Design_Exist	1717	6.84	15.8003		16.08	0.001342	5.43	706.74	242.75	0.34
1	2594.622	2100_100yr_Ab1	Design_20'	2562	6.84	16.688		17.02	0.001542	6.25	938.64	274.75	0.37
1	2594.622	2100_100yr_Ab1	Design_12'	2562	6.84	16.6993		17.03	0.00153	6.23	941.74	275.03	0.37
1	2594.622	2100_100yr_Ab1	Design_in-kind	2562	6.84	16.7112		17.04	0.001517	6.21	945.01	275.33	0.37
1	2594.622	2100_100yr_Ab1	Design_Exist	2562	6.84	16.6983		17.03	0.001531	6.23	941.45	275.01	0.37
1	2594.622	2018_025yr(Surge	Design_20'	1228	6.84	15.0562		15.31	0.001251	4.92	533.6	222.46	0.32
1	2594.622	2015_025yr(Surge	Design_12'	1228	6.84	15.0804		15.33	0.001226	4.88	538.99	223.13	0.32
1	2594.622	2015_025yr(Surge	Design_in-kind	1228	6.84	15.1098		15.35	0.001196	4.83	545.55	223.93	0.32
1	2594.622	2015_025yr(Surge	Design_Exist	1228	6.84	15.1247		15.37	0.001181	4.81	548.89	224.34	0.31
1	2594.622	2018_050yr(Surge	Design_20'	1565	6.84	15.5679		15.84	0.001336	5.32	651.03	236.53	0.34
1	2594.622	2015_050yr(Surge	Design_12'	1565	6.84	15.577		15.85	0.001327	5.3	653.18	236.78	0.34
1	2594.622	2015_050yr(Surge	Design_in-kind	1565	6.84	15.6069		15.88	0.001296	5.25	660.28	237.6	0.33
1	2594.622	2015_050yr(Surge	Design_Exist	1565	6.84	15.613		15.88	0.00129	5.24	661.71	237.77	0.33
1	2594.622	015_100yr(Surge)	Design_20'	2000	6.84	16.1147		16.42	0.001433	5.76	785.36	259.6	0.35
1	2594.622	015_100yr(Surge)	Design_12'	2000	6.84	16.1064		16.41	0.001442	5.78	783.21	259.38	0.35
1	2594.622	015_100yr(Surge)	Design_in-kind	2000	6.84	16.1313		16.43	0.001415	5.73	789.68	260.07	0.35
1	2594.622	015_100yr(Surge)	Design_Exist	2000	6.84	16.1329		16.43	0.001413	5.73	790.09	260.11	0.35
1	2470.57	2018_002yr	Design_20'	232	6.6	10.9721		11.09	0.001394	3.04	138.47	98.95	0.29

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	2470.57	2018_002yr	Design_12'	232	6.6	10.9721		11.09	0.001394	3.04	138.47	98.95	0.29
1	2470.57	2018_002yr	Design_in-kind	232	6.6	10.9721		11.09	0.001394	3.04	138.47	98.95	0.29
1	2470.57	2018_002yr	Design_Exist	232	6.6	10.9721		11.09	0.001394	3.04	138.47	98.95	0.29
1	2470.57	2018_010yr	Design_20'	845	6.6	14.3316		14.4	0.000523	2.94	668.24	227.03	0.2
1	2470.57	2018_010yr	Design_12'	845	6.6	14.3316		14.4	0.000523	2.94	668.24	227.03	0.2
1	2470.57	2018_010yr	Design_in-kind	845	6.6	14.3604		14.42	0.00051	2.91	674.79	227.73	0.2
1	2470.57	2018_010yr	Design_Exist	845	6.6	14.3953		14.46	0.000495	2.88	682.74	228.57	0.19
1	2470.57	2018_025y	Design_20'	1228	6.6	15.0728		15.15	0.000604	3.39	843.19	245.05	0.22
1	2470.57	2018_025y	Design_12'	1228	6.6	15.0691		15.15	0.000606	3.39	842.28	244.96	0.22
1	2470.57	2018_025y	Design_in-kind	1228	6.6	15.1147		15.19	0.000585	3.34	853.46	246.06	0.21
1	2470.57	2018_025y	Design_Exist	1228	6.6	15.1249		15.2	0.00058	3.33	855.99	246.31	0.21
1	2470.57	2018_050yr	Design_20'	1565	6.6	15.5858		15.68	0.00067	3.73	972.08	257.4	0.23
1	2470.57	2018_050yr	Design_12'	1565	6.6	15.5827		15.67	0.000672	3.73	971.27	257.33	0.23
1	2470.57	2018_050yr	Design_in-kind	1565	6.6	15.5979		15.69	0.000665	3.72	975.18	257.69	0.23
1	2470.57	2018_050yr	Design_Exist	1565	6.6	15.622		15.71	0.000653	3.69	981.41	258.27	0.23
1	2470.57	2018_100yr	Design_20'	2000	6.6	16.1007		16.21	0.000768	4.16	1107.77	269.68	0.25
1	2470.57	2018_100yr	Design_12'	2000	6.6	16.1049		16.21	0.000766	4.15	1108.92	269.77	0.25
1	2470.57	2018_100yr	Design_in-kind	2000	6.6	16.1176		16.22	0.000759	4.14	1112.35	270.07	0.25
1	2470.57	2018_100yr	Design_Exist	2000	6.6	16.1381		16.24	0.000749	4.12	1117.87	270.52	0.25
1	2470.57	2018_500yr	Design_20'	2671	6.6	16.7966		16.93	0.00088	4.69	1300.9	285.62	0.27
1	2470.57	2018_500yr	Design_12'	2671	6.6	16.7919		16.92	0.000882	4.69	1299.57	285.51	0.27
1	2470.57	2018_500yr	Design_in-kind	2671	6.6	16.8048		16.94	0.000875	4.68	1303.26	285.82	0.27
1	2470.57	2018_500yr	Design_Exist	2671	6.6	16.7999		16.93	0.000878	4.69	1301.85	285.7	0.27
1	2470.57	2018_25yr_MHHW_M	Design_20'	1228	6.6	15.0728		15.15	0.000604	3.39	843.19	245.05	0.22
1	2470.57	2018_25yr_MHHW_M	Design_12'	1228	6.6	15.0734		15.15	0.000604	3.38	843.34	245.06	0.22
1	2470.57	2018_25yr_MHHW_M	Design_in-kind	1228	6.6	15.1166		15.19	0.000584	3.34	853.93	246.11	0.21
1	2470.57	2018_25yr_MHHW_M	Design_Exist	1228	6.6	15.134		15.21	0.000576	3.32	858.23	246.53	0.21
1	2470.57	2018_25yr_MSL_Ma	Design_20'	1228	6.6	15.0728		15.15	0.000604	3.39	843.19	245.05	0.22
1	2470.57	2018_25yr_MSL_Ma	Design_12'	1228	6.6	15.0729		15.15	0.000604	3.39	843.2	245.05	0.22
1	2470.57	2018_25yr_MSL_Ma	Design_in-kind	1228	6.6	15.122		15.2	0.000582	3.34	855.26	246.24	0.21
1	2470.57	2018_25yr_MSL_Ma	Design_Exist	1228	6.6	15.1236		15.2	0.000581	3.33	855.67	246.28	0.21
1	2470.57	2100_025yr_Ab1	Design_20'	1706	6.6	15.7473		15.84	0.000711	3.89	1013.97	261.26	0.24
1	2470.57	2100_025yr_Ab1	Design_12'	1706	6.6	15.7748		15.87	0.000697	3.86	1021.15	261.92	0.24
1	2470.57	2100_025yr_Ab1	Design_in-kind	1706	6.6	15.7837		15.88	0.000693	3.85	1023.47	262.13	0.24
1	2470.57	2100_025yr_Ab1	Design_Exist	1706	6.6	15.7855		15.88	0.000692	3.85	1023.94	262.17	0.24
1	2470.57	2100_050yr_Ab1	Design_20'	1717	6.6	15.7722		15.87	0.000708	3.89	1020.47	261.86	0.24
1	2470.57	2100_050yr_Ab1	Design_12'	1717	6.6	15.782		15.88	0.000703	3.88	1023.02	262.09	0.24
1	2470.57	2100_050yr_Ab1	Design_in-kind	1717	6.6	15.8008		15.9	0.000694	3.86	1027.96	262.54	0.24
1	2470.57	2100_050yr_Ab1	Design_Exist	1717	6.6	15.8053		15.9	0.000692	3.85	1029.14	262.65	0.24
1	2470.57	2100_100yr_Ab1	Design_20'	2562	6.6	16.6774		16.81	0.00087	4.62	1267.05	282.79	0.27
1	2470.57	2100_100yr_Ab1	Design_12'	2562	6.6	16.6886		16.82	0.000864	4.61	1270.21	283.06	0.27
1	2470.57	2100_100yr_Ab1	Design_in-kind	2562	6.6	16.7003		16.83	0.000858	4.6	1273.53	283.34	0.27
1	2470.57	2100_100yr_Ab1	Design_Exist	2562	6.6	16.6876		16.81	0.000865	4.61	1269.91	283.03	0.27
1	2470.57	2018_025yr(Surge	Design_20'	1228	6.6	15.0691		15.15	0.000606	3.39	842.28	244.96	0.22
1	2470.57	2015_025yr(Surge	Design_12'	1228	6.6	15.0928		15.17	0.000595	3.37	848.09	245.53	0.22
1	2470.57	2015_025yr(Surge	Design_in-kind	1228	6.6	15.1215		15.2	0.000582	3.34	855.14	246.23	0.21
1	2470.57	2015_025yr(Surge	Design_Exist	1228	6.6	15.1361		15.21	0.000575	3.32	858.73	246.58	0.21
1	2470.57	2018_050yr(Surge	Design_20'	1565	6.6	15.5755		15.67	0.000675	3.74	969.43	257.16	0.23
1	2470.57	2015_050yr(Surge	Design_12'	1565	6.6	15.5845		15.67	0.000671	3.73	971.74	257.37	0.23
1	2470.57	2015_050yr(Surge	Design_in-kind	1565	6.6	15.6139		15.7	0.000657	3.7	979.31	258.07	0.23
1	2470.57	2015_050yr(Surge	Design_Exist	1565	6.6	15.6198		15.71	0.000654	3.69	980.84	258.21	0.23
1	2470.57	015_100yr(Surge)	Design_20'	2000	6.6	16.1154		16.22	0.00076	4.14	1111.74	270.01	0.25
1	2470.57	015_100yr(Surge)	Design_12'	2000	6.6	16.1073		16.21	0.000765	4.15	1109.55	269.83	0.25
1	2470.57	015_100yr(Surge)	Design_in-kind	2000	6.6	16.1317		16.24	0.000752	4.12	1116.15	270.38	0.25
1	2470.57	015_100yr(Surge)	Design_Exist	2000	6.6	16.1333		16.24	0.000751	4.12	1116.57	270.42	0.25
1	2308.278	2018_002yr	Design_20'	232	5.87	10.8477		10.91	0.000699	2.33	151.21	90.82	0.21
1	2308.278	2018_002yr	Design_12'	232	5.87	10.8477		10.91	0.000699	2.33	151.21	90.82	0.21
1	2308.278	2018_002yr	Design_in-kind	232	5.87	10.8477		10.91	0.000699	2.33	151.21	90.82	0.21
1	2308.278	2018_002yr	Design_Exist	232	5.87	10.8477		10.91	0.000699	2.33	151.21	90.82	0.21
1	2308.278	2018_010yr	Design_20'	845	5.87	14.2854		14.32	0.000283	2.28	719.06	240.4	0.15
1	2308.278	2018_010yr	Design_12'	845	5.87	14.2854		14.32	0.000283	2.28	719.06	240.4	0.15
1	2308.278	2018_010yr	Design_in-kind	845	5.87	14.3154		14.35	0.000275	2.26	726.29	241.22	0.15
1	2308.278	2018_010yr	Design_Exist	845	5.87	14.3516		14.39	0.000267	2.23	735.05	242.21	0.15
1	2308.278	2018_025y	Design_20'	1228	5.87	15.0189		15.07	0.000329	2.63	902.75	260.43	0.16
1	2308.278	2018_025y	Design_12'	1228	5.87	15.0151		15.06	0.00033	2.63	901.75	260.33	0.16
1	2308.278	2018_025y	Design_in-kind	1228	5.87	15.0625		15.11	0.000319	2.59	914.13	261.62	0.16
1	2308.278	2018_025y	Design_Exist	1228	5.87	15.0732		15.12	0.000316	2.59	916.93	261.91	0.16
1	2308.278	2018_050yr	Design_20'	1565	5.87	15.5252		15.58	0.00037	2.9	1038.12	274.5	0.18
1	2308.278	2018_050yr	Design_12'	1565	5.87	15.5219		15.58	0.000371	2.91	1037.21	274.4	0.18
1	2308.278	2018_050yr	Design_in-kind	1565	5.87	15.5378		15.59	0.000367	2.89	1041.57	274.86	0.18
1	2308.278	2018_050yr	Design_Exist	1565	5.87	15.563		15.62	0.000361	2.87	1048.51	275.59	0.17

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	2308.278	2018_100yr	Design_20'	2000	5.87	16.03		16.1	0.000432	3.26	1180.4	289.33	0.19
1	2308.278	2018_100yr	Design_12'	2000	5.87	16.0344		16.1	0.000431	3.25	1181.69	289.48	0.19
1	2308.278	2018_100yr	Design_in-kind	2000	5.87	16.0477		16.12	0.000427	3.24	1185.54	289.9	0.19
1	2308.278	2018_100yr	Design_Exist	2000	5.87	16.0692		16.14	0.000421	3.23	1191.76	290.58	0.19
1	2308.278	2018_500yr	Design_20'	2671	5.87	16.715		16.8	0.000502	3.69	1386.04	311.69	0.21
1	2308.278	2018_500yr	Design_12'	2671	5.87	16.7101		16.8	0.000503	3.69	1384.52	311.51	0.21
1	2308.278	2018_500yr	Design_in-kind	2671	5.87	16.7237		16.81	0.000499	3.68	1388.75	312.02	0.21
1	2308.278	2018_500yr	Design_Exist	2671	5.87	16.7185		16.8	0.000501	3.69	1387.13	311.82	0.21
1	2308.278	2018_25yr_MHHW_M	Design_20'	1228	5.87	15.0189		15.07	0.000329	2.63	902.75	260.43	0.16
1	2308.278	2018_25yr_MHHW_M	Design_12'	1228	5.87	15.0196		15.07	0.000329	2.63	902.91	260.45	0.16
1	2308.278	2018_25yr_MHHW_M	Design_in-kind	1228	5.87	15.0645		15.11	0.000318	2.59	914.65	261.68	0.16
1	2308.278	2018_25yr_MHHW_M	Design_Exist	1228	5.87	15.0827		15.13	0.000314	2.58	919.42	262.17	0.16
1	2308.278	2018_25yr_MSL_Ma	Design_20'	1228	5.87	15.0189		15.07	0.000329	2.63	902.75	260.43	0.16
1	2308.278	2018_25yr_MSL_Ma	Design_12'	1228	5.87	15.019		15.07	0.000329	2.63	902.77	260.43	0.16
1	2308.278	2018_25yr_MSL_Ma	Design_in-kind	1228	5.87	15.0701		15.12	0.000317	2.59	916.12	261.83	0.16
1	2308.278	2018_25yr_MSL_Ma	Design_Exist	1228	5.87	15.0719		15.12	0.000317	2.59	916.58	261.88	0.16
1	2308.278	2100_025yr_Ab1	Design_20'	1706	5.87	15.6826		15.74	0.000395	3.04	1081.69	279.07	0.18
1	2308.278	2100_025yr_Ab1	Design_12'	1706	5.87	15.7114		15.77	0.000388	3.01	1089.72	279.92	0.18
1	2308.278	2100_025yr_Ab1	Design_in-kind	1706	5.87	15.7206		15.78	0.000385	3.01	1092.32	280.19	0.18
1	2308.278	2100_025yr_Ab1	Design_Exist	1706	5.87	15.7225		15.78	0.000385	3	1092.84	280.24	0.18
1	2308.278	2100_050yr_Ab1	Design_20'	1717	5.87	15.7078		15.77	0.000394	3.04	1088.72	279.81	0.18
1	2308.278	2100_050yr_Ab1	Design_12'	1717	5.87	15.718		15.78	0.000391	3.03	1091.57	280.11	0.18
1	2308.278	2100_050yr_Ab1	Design_in-kind	1717	5.87	15.7376		15.8	0.000386	3.01	1097.09	280.69	0.18
1	2308.278	2100_050yr_Ab1	Design_Exist	1717	5.87	15.7423		15.8	0.000385	3.01	1098.41	280.82	0.18
1	2308.278	2100_100yr_Ab1	Design_20'	2562	5.87	16.5969		16.68	0.000495	3.63	1349.49	307.28	0.21
1	2308.278	2100_100yr_Ab1	Design_12'	2562	5.87	16.6086		16.69	0.000491	3.62	1353.11	307.72	0.21
1	2308.278	2100_100yr_Ab1	Design_in-kind	2562	5.87	16.621		16.7	0.000488	3.61	1356.91	308.18	0.21
1	2308.278	2100_100yr_Ab1	Design_Exist	2562	5.87	16.6075		16.69	0.000492	3.62	1352.77	307.67	0.21
1	2308.278	2018_025yr(Surge	Design_20'	1228	5.87	15.0151		15.06	0.00033	2.63	901.75	260.33	0.16
1	2308.278	2015_025yr(Surge	Design_12'	1228	5.87	15.0397		15.09	0.000324	2.61	908.18	261	0.16
1	2308.278	2015_025yr(Surge	Design_in-kind	1228	5.87	15.0697		15.11	0.000317	2.59	916	261.82	0.16
1	2308.278	2015_025yr(Surge	Design_Exist	1228	5.87	15.0848		15.13	0.000314	2.58	919.97	262.23	0.16
1	2308.278	2018_050yr(Surge	Design_20'	1565	5.87	15.5145		15.57	0.000373	2.91	1035.17	274.18	0.18
1	2308.278	2015_050yr(Surge	Design_12'	1565	5.87	15.5238		15.58	0.000371	2.9	1037.73	274.46	0.18
1	2308.278	2015_050yr(Surge	Design_in-kind	1565	5.87	15.5545		15.61	0.000363	2.88	1046.17	275.35	0.17
1	2308.278	2015_050yr(Surge	Design_Exist	1565	5.87	15.5607		15.62	0.000361	2.88	1047.87	275.53	0.17
1	2308.278	015_100yr(Surge)	Design_20'	2000	5.87	16.0454		16.11	0.000428	3.25	1184.86	289.82	0.19
1	2308.278	015_100yr(Surge)	Design_12'	2000	5.87	16.0369		16.11	0.00043	3.25	1182.39	289.55	0.19
1	2308.278	015_100yr(Surge)	Design_in-kind	2000	5.87	16.0625		16.13	0.000423	3.23	1189.82	290.37	0.19
1	2308.278	015_100yr(Surge)	Design_Exist	2000	5.87	16.0641		16.13	0.000423	3.23	1190.29	290.42	0.19
1	2105.615	2018_002yr	Design_20'	232	6.26	10.6379		10.73	0.000972	2.68	135.69	96.83	0.26
1	2105.615	2018_002yr	Design_12'	232	6.26	10.6379		10.73	0.000972	2.68	135.69	96.83	0.26
1	2105.615	2018_002yr	Design_in-kind	232	6.26	10.6379		10.73	0.000972	2.68	135.69	96.83	0.26
1	2105.615	2018_002yr	Design_Exist	232	6.26	10.6379		10.73	0.000972	2.68	135.69	96.83	0.26
1	2105.615	2018_010yr	Design_20'	845	6.26	14.2039		14.26	0.000328	2.52	706.26	222.97	0.17
1	2105.615	2018_010yr	Design_12'	845	6.26	14.2039		14.26	0.000328	2.52	706.26	222.97	0.17
1	2105.615	2018_010yr	Design_in-kind	845	6.26	14.236		14.29	0.000319	2.49	713.43	223.93	0.17
1	2105.615	2018_010yr	Design_Exist	845	6.26	14.2746		14.32	0.00031	2.46	722.11	225.09	0.16
1	2105.615	2018_025y	Design_20'	1228	6.26	14.9184		14.99	0.000398	2.96	873.25	244.32	0.19
1	2105.615	2018_025y	Design_12'	1228	6.26	14.9143		14.98	0.000399	2.96	872.24	244.22	0.19
1	2105.615	2018_025y	Design_in-kind	1228	6.26	14.9654		15.03	0.000385	2.92	884.74	245.47	0.19
1	2105.615	2018_025y	Design_Exist	1228	6.26	14.9768		15.04	0.000381	2.91	887.56	245.75	0.18
1	2105.615	2018_050yr	Design_20'	1565	6.26	15.4086		15.49	0.000457	3.31	995.97	256.81	0.2
1	2105.615	2018_050yr	Design_12'	1565	6.26	15.405		15.49	0.000458	3.31	995.05	256.7	0.2
1	2105.615	2018_050yr	Design_in-kind	1565	6.26	15.4222		15.5	0.000453	3.3	999.46	257.21	0.2
1	2105.615	2018_050yr	Design_Exist	1565	6.26	15.4495		15.53	0.000445	3.27	1006.5	258.03	0.2
1	2105.615	2018_100yr	Design_20'	2000	6.26	15.8913		15.99	0.000538	3.73	1122.82	268.44	0.22
1	2105.615	2018_100yr	Design_12'	2000	6.26	15.8962		16	0.000536	3.72	1124.14	268.55	0.22
1	2105.615	2018_100yr	Design_in-kind	2000	6.26	15.9108		16.01	0.000531	3.71	1128.07	268.89	0.22
1	2105.615	2018_100yr	Design_Exist	2000	6.26	15.9344		16.03	0.000522	3.69	1134.41	269.44	0.22
1	2105.615	2018_500yr	Design_20'	2671	6.26	16.5509		16.68	0.000624	4.22	1304.71	282.91	0.24
1	2105.615	2018_500yr	Design_12'	2671	6.26	16.5455		16.67	0.000626	4.22	1303.18	282.79	0.24
1	2105.615	2018_500yr	Design_in-kind	2671	6.26	16.5605		16.69	0.00062	4.21	1307.44	283.11	0.24
1	2105.615	2018_500yr	Design_Exist	2671	6.26	16.5548		16.68	0.000623	4.21	1305.81	282.99	0.24
1	2105.615	2018_25yr_MHHW_M	Design_20'	1228	6.26	14.9184		14.99	0.000398	2.96	873.25	244.32	0.19
1	2105.615	2018_25yr_MHHW_M	Design_12'	1228	6.26	14.9191		14.99	0.000398	2.96	873.42	244.34	0.19
1	2105.615	2018_25yr_MHHW_M	Design_in-kind	1228	6.26	14.9675		15.03	0.000384	2.92	885.26	245.52	0.19
1	2105.615	2018_25yr_MHHW_M	Design_Exist	1228	6.26	14.987		15.05	0.000379	2.91	890.06	246	0.18
1	2105.615	2018_25yr_MSL_Ma	Design_20'	1228	6.26	14.9184		14.99	0.000398	2.96	873.25	244.32	0.19
1	2105.615	2018_25yr_MSL_Ma	Design_12'	1228	6.26	14.9185		14.99	0.000398	2.96	873.27	244.33	0.19
1	2105.615	2018_25yr_MSL_Ma	Design_in-kind	1228	6.26	14.9735		15.04	0.000382	2.92	886.75	245.67	0.19

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	2105.615	2018_25yr_MSL_Ma	Design_Exist	1228	6.26	14.9754		15.04	0.000382	2.91	887.21	245.72	0.18
1	2105.615	2100_025yr_Ab1	Design_20'	1706	6.26	15.5568		15.65	0.000492	3.47	1034.35	260.66	0.21
1	2105.615	2100_025yr_Ab1	Design_12'	1706	6.26	15.5881		15.68	0.000482	3.44	1042.5	261.39	0.21
1	2105.615	2100_025yr_Ab1	Design_in-kind	1706	6.26	15.5982		15.69	0.000478	3.44	1045.14	261.63	0.21
1	2105.615	2100_025yr_Ab1	Design_Exist	1706	6.26	15.6002		15.69	0.000478	3.43	1045.68	261.68	0.21
1	2105.615	2100_050yr_Ab1	Design_20'	1717	6.26	15.5825		15.67	0.00049	3.47	1041.03	261.26	0.21
1	2105.615	2100_050yr_Ab1	Design_12'	1717	6.26	15.5936		15.68	0.000486	3.46	1043.93	261.52	0.21
1	2105.615	2100_050yr_Ab1	Design_in-kind	1717	6.26	15.6149		15.7	0.000479	3.44	1049.53	262.02	0.21
1	2105.615	2100_050yr_Ab1	Design_Exist	1717	6.26	15.6201		15.71	0.000477	3.44	1050.87	262.14	0.21
1	2105.615	2100_100yr_Ab1	Design_20'	2562	6.26	16.4352		16.56	0.000617	4.16	1272.12	280.4	0.24
1	2105.615	2100_100yr_Ab1	Design_12'	2562	6.26	16.4482		16.57	0.000612	4.15	1275.77	280.68	0.24
1	2105.615	2100_100yr_Ab1	Design_in-kind	2562	6.26	16.4619		16.58	0.000607	4.13	1279.61	280.98	0.24
1	2105.615	2100_100yr_Ab1	Design_Exist	2562	6.26	16.447		16.57	0.000613	4.15	1275.43	280.66	0.24
1	2105.615	2018_025yr(Surge	Design_20'	1228	6.26	14.9143		14.98	0.000399	2.96	872.24	244.22	0.19
1	2105.615	2015_025yr(Surge	Design_12'	1228	6.26	14.9409		15.01	0.000392	2.94	878.74	244.87	0.19
1	2105.615	2015_025yr(Surge	Design_in-kind	1228	6.26	14.973		15.04	0.000383	2.92	886.62	245.66	0.19
1	2105.615	2015_025yr(Surge	Design_Exist	1228	6.26	14.9893		15.05	0.000378	2.9	890.62	246.06	0.18
1	2105.615	2018_050yr(Surge	Design_20'	1565	6.26	15.3969		15.48	0.000461	3.32	992.97	256.46	0.2
1	2105.615	2015_050yr(Surge	Design_12'	1565	6.26	15.4071		15.49	0.000458	3.31	995.58	256.77	0.2
1	2105.615	2015_050yr(Surge	Design_in-kind	1565	6.26	15.4403		15.52	0.000448	3.28	1004.13	257.75	0.2
1	2105.615	2015_050yr(Surge	Design_Exist	1565	6.26	15.447		15.53	0.000446	3.28	1005.85	257.95	0.2
1	2105.615	015_100yr(Surge)	Design_20'	2000	6.26	15.9082		16.01	0.000532	3.71	1127.38	268.83	0.22
1	2105.615	015_100yr(Surge)	Design_12'	2000	6.26	15.8989		16	0.000535	3.72	1124.86	268.62	0.22
1	2105.615	015_100yr(Surge)	Design_in-kind	2000	6.26	15.927		16.03	0.000525	3.69	1132.44	269.27	0.22
1	2105.615	015_100yr(Surge)	Design_Exist	2000	6.26	15.9288		16.03	0.000524	3.69	1132.92	269.31	0.22
1	1967.196	2018_002yr	Design_20'	232	5.6	9.691	9.69	10.35	0.011412	6.91	45.17	41.27	0.67
1	1967.196	2018_002yr	Design_12'	232	5.6	9.691	9.69	10.35	0.011412	6.91	45.17	41.27	0.67
1	1967.196	2018_002yr	Design_in-kind	232	5.6	9.691	9.69	10.35	0.011412	6.91	45.17	41.27	0.67
1	1967.196	2018_002yr	Design_Exist	232	5.6	9.691	9.69	10.35	0.011412	6.91	45.17	41.27	0.67
1	1967.196	2018_010yr	Design_20'	845	5.6	14.1055		14.19	0.000772	3.17	441.44	140.83	0.2
1	1967.196	2018_010yr	Design_12'	845	5.6	14.1055		14.19	0.000772	3.17	441.44	140.83	0.2
1	1967.196	2018_010yr	Design_in-kind	845	5.6	14.1401		14.22	0.000751	3.14	446.31	141.4	0.2
1	1967.196	2018_010yr	Design_Exist	845	5.6	14.1815		14.26	0.000727	3.1	452.19	142.08	0.2
1	1967.196	2018_025y	Design_20'	1228	5.6	14.7881		14.9	0.00097	3.77	541.4	152.08	0.23
1	1967.196	2018_025y	Design_12'	1228	5.6	14.7836		14.9	0.000973	3.77	540.71	152.01	0.23
1	1967.196	2018_025y	Design_in-kind	1228	5.6	14.8394		14.95	0.000935	3.71	549.22	152.92	0.23
1	1967.196	2018_025y	Design_Exist	1228	5.6	14.8518		14.96	0.000927	3.7	551.13	153.13	0.22
1	1967.196	2018_050yr	Design_20'	1565	5.6	15.25		15.39	0.001141	4.23	613.44	159.86	0.25
1	1967.196	2018_050yr	Design_12'	1565	5.6	15.246		15.39	0.001144	4.24	612.8	159.8	0.25
1	1967.196	2018_050yr	Design_in-kind	1565	5.6	15.265		15.4	0.001129	4.21	615.85	160.11	0.25
1	1967.196	2018_050yr	Design_Exist	1565	5.6	15.2952		15.43	0.001106	4.18	620.69	160.61	0.25
1	1967.196	2018_100yr	Design_20'	2000	5.6	15.691		15.87	0.001392	4.83	685.54	167.13	0.28
1	1967.196	2018_100yr	Design_12'	2000	5.6	15.6965		15.88	0.001387	4.82	686.47	167.23	0.28
1	1967.196	2018_100yr	Design_in-kind	2000	5.6	15.7131		15.89	0.001373	4.8	689.24	167.5	0.28
1	1967.196	2018_100yr	Design_Exist	2000	5.6	15.7396		15.92	0.00135	4.77	693.69	167.94	0.28
1	1967.196	2018_500yr	Design_20'	2671	5.6	16.2941		16.53	0.001771	5.68	792.31	192.57	0.32
1	1967.196	2018_500yr	Design_12'	2671	5.6	16.2877		16.53	0.001778	5.69	791.09	192.23	0.32
1	1967.196	2018_500yr	Design_in-kind	2671	5.6	16.3054		16.54	0.00176	5.67	794.49	193.17	0.32
1	1967.196	2018_500yr	Design_Exist	2671	5.6	16.2986		16.53	0.001767	5.67	793.19	192.81	0.32
1	1967.196	2018_25yr_MHHW_M	Design_20'	1228	5.6	14.7881		14.9	0.00097	3.77	541.4	152.08	0.23
1	1967.196	2018_25yr_MHHW_M	Design_12'	1228	5.6	14.7889		14.9	0.00097	3.76	541.52	152.09	0.23
1	1967.196	2018_25yr_MHHW_M	Design_in-kind	1228	5.6	14.8417		14.95	0.000933	3.71	549.57	152.96	0.23
1	1967.196	2018_25yr_MHHW_M	Design_Exist	1228	5.6	14.8629		14.97	0.000919	3.69	552.83	153.31	0.22
1	1967.196	2018_25yr_MSL_Ma	Design_20'	1228	5.6	14.7881		14.9	0.00097	3.77	541.4	152.08	0.23
1	1967.196	2018_25yr_MSL_Ma	Design_12'	1228	5.6	14.7882		14.9	0.00097	3.77	541.42	152.08	0.23
1	1967.196	2018_25yr_MSL_Ma	Design_in-kind	1228	5.6	14.8483		14.96	0.000929	3.7	550.58	153.07	0.22
1	1967.196	2018_25yr_MSL_Ma	Design_Exist	1228	5.6	14.8503		14.96	0.000928	3.7	550.89	153.1	0.22
1	1967.196	2100_025yr_Ab1	Design_20'	1706	5.6	15.3827		15.54	0.00124	4.45	634.8	162.05	0.26
1	1967.196	2100_025yr_Ab1	Design_12'	1706	5.6	15.4176		15.57	0.001211	4.41	640.46	162.63	0.26
1	1967.196	2100_025yr_Ab1	Design_in-kind	1706	5.6	15.4288		15.58	0.001202	4.4	642.29	162.81	0.26
1	1967.196	2100_025yr_Ab1	Design_Exist	1706	5.6	15.4311		15.58	0.0012	4.4	642.66	162.85	0.26
1	1967.196	2100_050yr_Ab1	Design_20'	1717	5.6	15.4088		15.56	0.001234	4.45	639.03	162.48	0.26
1	1967.196	2100_050yr_Ab1	Design_12'	1717	5.6	15.4212		15.57	0.001224	4.44	641.05	162.69	0.26
1	1967.196	2100_050yr_Ab1	Design_in-kind	1717	5.6	15.445		15.6	0.001205	4.41	644.93	163.08	0.26
1	1967.196	2100_050yr_Ab1	Design_Exist	1717	5.6	15.4507		15.6	0.0012	4.41	645.86	163.17	0.26
1	1967.196	2100_100yr_Ab1	Design_20'	2562	5.6	16.1839		16.41	0.001731	5.57	771.41	186.71	0.31
1	1967.196	2100_100yr_Ab1	Design_12'	2562	5.6	16.1991		16.43	0.001717	5.56	774.25	187.51	0.31
1	1967.196	2100_100yr_Ab1	Design_in-kind	2562	5.6	16.215		16.44	0.001702	5.54	777.24	188.36	0.31
1	1967.196	2100_100yr_Ab1	Design_Exist	2562	5.6	16.1977		16.43	0.001718	5.56	773.99	187.44	0.31
1	1967.196	2018_025yr(Surge	Design_20'	1228	5.6	14.7836		14.9	0.000973	3.77	540.71	152.01	0.23
1	1967.196	2015_025yr(Surge	Design_12'	1228	5.6	14.8126		14.92	0.000953	3.74	545.14	152.48	0.23

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1	1967.196	2015_025yr(Surge	Design_in-kind	1228	5.6	14.8477		14.96	0.000929	3.7	550.49	153.06	0.22
1	1967.196	2015_025yr(Surge	Design_Exist	1228	5.6	14.8654		14.97	0.000918	3.68	553.2	153.35	0.22
1	1967.196	2018_050yr(Surge	Design_20'	1565	5.6	15.237		15.38	0.001151	4.25	611.37	159.65	0.25
1	1967.196	2015_050yr(Surge	Design_12'	1565	5.6	15.2483		15.39	0.001142	4.23	613.17	159.83	0.25
1	1967.196	2015_050yr(Surge	Design_in-kind	1565	5.6	15.2851		15.42	0.001114	4.19	619.06	160.44	0.25
1	1967.196	2015_050yr(Surge	Design_Exist	1565	5.6	15.2925		15.43	0.001108	4.18	620.25	160.56	0.25
1	1967.196	015_100yr(Surge)	Design_20'	2000	5.6	15.7102		15.89	0.001375	4.81	688.75	167.45	0.28
1	1967.196	015_100yr(Surge)	Design_12'	2000	5.6	15.6996		15.88	0.001385	4.82	686.98	167.28	0.28
1	1967.196	015_100yr(Surge)	Design_in-kind	2000	5.6	15.7314		15.91	0.001357	4.78	692.31	167.8	0.28
1	1967.196	015_100yr(Surge)	Design_Exist	2000	5.6	15.7334		15.91	0.001355	4.78	692.65	167.83	0.28
1	1801.551	2018_002yr	Design_20'	232	4	8.6655	5.83	8.78	0.001011	2.74	84.8	20.21	0.24
1	1801.551	2018_002yr	Design_12'	232	4	8.6664	5.83	8.78	0.00101	2.74	84.82	20.21	0.24
1	1801.551	2018_002yr	Design_in-kind	232	4	8.6716	5.83	8.79	0.001006	2.73	84.92	20.21	0.23
1	1801.551	2018_002yr	Design_Exist	232	4	8.7535	5.83	8.87	0.000952	2.68	86.58	20.28	0.23
1	1801.551	2018_010yr	Design_20'	845	4	13.9181	8.23	14.07	0.000575	3.44	392.35	142.79	0.2
1	1801.551	2018_010yr	Design_12'	845	4	13.9181	8.23	14.07	0.000575	3.44	392.35	142.79	0.2
1	1801.551	2018_010yr	Design_in-kind	845	4	13.957	8.23	14.1	0.000561	3.41	397.95	145.2	0.2
1	1801.551	2018_010yr	Design_Exist	845	4	14.0033	8.23	14.14	0.000547	3.38	404.74	148.61	0.19
1	1801.551	2018_025y	Design_20'	1228	4	14.5094	9.37	14.73	0.000853	4.37	486.41	173.18	0.24
1	1801.551	2018_025y	Design_12'	1228	4	14.5039	9.37	14.73	0.000856	4.37	485.45	172.9	0.25
1	1801.551	2018_025y	Design_in-kind	1228	4	14.5716	9.37	14.79	0.000822	4.3	497.27	176.32	0.24
1	1801.551	2018_025y	Design_Exist	1228	4	14.5867	9.37	14.8	0.000814	4.29	499.94	177.08	0.24
1	1801.551	2018_050yr	Design_20'	1565	4	14.8952	10.42	15.18	0.001095	5.08	557	193.23	0.28
1	1801.551	2018_050yr	Design_12'	1565	4	14.8901	10.42	15.18	0.001098	5.08	555.99	192.93	0.28
1	1801.551	2018_050yr	Design_in-kind	1565	4	14.9149	10.42	15.2	0.001082	5.05	560.8	194.42	0.28
1	1801.551	2018_050yr	Design_Exist	1565	4	14.954	10.42	15.23	0.001057	5.01	568.45	196.79	0.27
1	1801.551	2018_100yr	Design_20'	2000	4	15.2204	11.67	15.61	0.001465	5.99	623.1	212.67	0.32
1	1801.551	2018_100yr	Design_12'	2000	4	15.2288	11.67	15.61	0.001457	5.98	624.89	213.07	0.32
1	1801.551	2018_100yr	Design_in-kind	2000	4	15.2536	11.67	15.63	0.001434	5.94	630.19	214.25	0.32
1	1801.551	2018_100yr	Design_Exist	2000	4	15.293	11.67	15.66	0.001398	5.88	638.67	216.12	0.32
1	1801.551	2018_500yr	Design_20'	2671	4	15.6648	12.82	16.18	0.001973	7.15	722.98	238.05	0.38
1	1801.551	2018_500yr	Design_12'	2671	4	15.6535	12.82	16.17	0.001988	7.17	720.28	237.35	0.38
1	1801.551	2018_500yr	Design_in-kind	2671	4	15.6848	12.82	16.19	0.001949	7.12	727.75	239.29	0.38
1	1801.551	2018_500yr	Design_Exist	2671	4	15.6729	12.82	16.19	0.001963	7.14	724.9	238.55	0.38
1	1801.551	2018_25yr_MHHW_M	Design_20'	1228	4	14.5094	9.37	14.73	0.000853	4.37	486.41	173.18	0.24
1	1801.551	2018_25yr_MHHW_M	Design_12'	1228	4	14.5103	9.37	14.73	0.000853	4.37	486.56	173.22	0.24
1	1801.551	2018_25yr_MHHW_M	Design_in-kind	1228	4	14.5744	9.37	14.79	0.00082	4.3	497.76	176.46	0.24
1	1801.551	2018_25yr_MHHW_M	Design_Exist	1228	4	14.6001	9.37	14.81	0.000808	4.28	502.31	177.76	0.24
1	1801.551	2018_25yr_MSL_Ma	Design_20'	1228	4	14.5094	9.37	14.73	0.000853	4.37	486.41	173.18	0.24
1	1801.551	2018_25yr_MSL_Ma	Design_12'	1228	4	14.5095	9.37	14.73	0.000853	4.37	486.42	173.18	0.24
1	1801.551	2018_25yr_MSL_Ma	Design_in-kind	1228	4	14.5823	9.37	14.8	0.000816	4.29	499.17	176.86	0.24
1	1801.551	2018_25yr_MSL_Ma	Design_Exist	1228	4	14.5848	9.37	14.8	0.000815	4.29	499.61	176.98	0.24
1	1801.551	2100_025yr_Ab1	Design_20'	1706	4	14.9836	11.03	15.31	0.001233	5.42	574.31	198.54	0.3
1	1801.551	2100_025yr_Ab1	Design_12'	1706	4	15.0306	11.03	15.35	0.001199	5.36	583.71	201.59	0.29
1	1801.551	2100_025yr_Ab1	Design_in-kind	1706	4	15.0456	11.03	15.36	0.001188	5.34	586.75	202.56	0.29
1	1801.551	2100_025yr_Ab1	Design_Exist	1706	4	15.0487	11.03	15.36	0.001186	5.34	587.37	202.76	0.29
1	1801.551	2100_050yr_Ab1	Design_20'	1717	4	15.0118	11.05	15.33	0.001228	5.42	579.93	200.37	0.3
1	1801.551	2100_050yr_Ab1	Design_12'	1717	4	15.0285	11.05	15.35	0.001216	5.4	583.29	201.45	0.29
1	1801.551	2100_050yr_Ab1	Design_in-kind	1717	4	15.0606	11.05	15.37	0.001192	5.35	589.78	203.53	0.29
1	1801.551	2100_050yr_Ab1	Design_Exist	1717	4	15.0682	11.05	15.38	0.001187	5.34	591.34	204.03	0.29
1	1801.551	2100_100yr_Ab1	Design_20'	2562	4	15.5663	12.65	16.07	0.001932	7.03	699.82	231.97	0.37
1	1801.551	2100_100yr_Ab1	Design_12'	2562	4	15.5926	12.65	16.09	0.0019	6.99	705.95	233.59	0.37
1	1801.551	2100_100yr_Ab1	Design_in-kind	2562	4	15.6199	12.65	16.11	0.001868	6.94	712.34	235.28	0.37
1	1801.551	2100_100yr_Ab1	Design_Exist	2562	4	15.5902	12.65	16.09	0.001903	6.99	705.38	233.44	0.37
1	1801.551	2018_025yr(Surge	Design_20'	1228	4	14.5039	9.37	14.73	0.000856	4.37	485.45	172.9	0.25
1	1801.551	2015_025yr(Surge	Design_12'	1228	4	14.5392	9.37	14.76	0.000838	4.34	491.59	174.68	0.24
1	1801.551	2015_025yr(Surge	Design_in-kind	1228	4	14.5816	9.37	14.8	0.000817	4.29	499.05	176.83	0.24
1	1801.551	2015_025yr(Surge	Design_Exist	1228	4	14.603	9.37	14.81	0.000806	4.27	502.84	177.91	0.24
1	1801.551	2018_050yr(Surge	Design_20'	1565	4	14.8783	10.42	15.17	0.001106	5.1	553.73	192.24	0.28
1	1801.551	2015_050yr(Surge	Design_12'	1565	4	14.893	10.42	15.18	0.001096	5.08	556.57	193.1	0.28
1	1801.551	2015_050yr(Surge	Design_in-kind	1565	4	14.9409	10.42	15.22	0.001065	5.02	565.88	196.01	0.28
1	1801.551	2015_050yr(Surge	Design_Exist	1565	4	14.9504	10.42	15.23	0.001059	5.01	567.75	196.59	0.27
1	1801.551	015_100yr(Surge)	Design_20'	2000	4	15.2493	11.67	15.63	0.001438	5.95	629.26	214.04	0.32
1	1801.551	015_100yr(Surge)	Design_12'	2000	4	15.2334	11.67	15.62	0.001453	5.97	625.86	213.29	0.32
1	1801.551	015_100yr(Surge)	Design_in-kind	2000	4	15.2809	11.67	15.65	0.001409	5.9	636.04	215.54	0.32
1	1801.551	015_100yr(Surge)	Design_Exist	2000	4	15.2838	11.67	15.65	0.001406	5.9	636.68	215.68	0.32
1	1776			Culvert									
1	1748.775	2018_002yr	Design_20'	232	4.1	8.1271	6.61	8.33	0.002331	3.59	64.58	22.76	0.38
1	1748.775	2018_002yr	Design_12'	232	4.1	8.1283	6.61	8.33	0.002328	3.59	64.61	22.76	0.38

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	1748.775	2018_002yr	Design_in-kind	232	4.1	8.1363	6.61	8.34	0.002309	3.58	64.79	22.77	0.37
1	1748.775	2018_002yr	Design_Exist	232	4.1	8.2363	6.84	8.45	0.002613	3.7	62.74	22.96	0.39
1	1748.775	2018_010yr	Design_20'	845	4.1	11.1604	8.83	11.67	0.002783	5.82	152.96	52.94	0.43
1	1748.775	2018_010yr	Design_12'	845	4.1	11.1604	8.83	11.67	0.002783	5.82	152.96	52.94	0.43
1	1748.775	2018_010yr	Design_in-kind	845	4.1	11.341	8.83	11.81	0.002497	5.61	158.82	55.47	0.41
1	1748.775	2018_010yr	Design_Exist	845	4.1	11.5198	9.03	11.98	0.002497	5.56	160.32	58.54	0.41
1	1748.775	2018_025y	Design_20'	1228	4.1	11.5151	9.97	12.44	0.004805	7.88	164.51	58.46	0.57
1	1748.775	2018_025y	Design_12'	1228	4.1	11.5154	9.97	12.44	0.004804	7.88	164.52	58.46	0.57
1	1748.775	2018_025y	Design_in-kind	1228	4.1	12.0361	9.97	12.77	0.003931	7.05	183.31	72.51	0.53
1	1748.775	2018_025y	Design_Exist	1228	4.1	12.1524	10.14	12.89	0.003969	7.05	183.33	81.13	0.53
1	1748.775	2018_050yr	Design_20'	1565	4.1	11.8487	10.7	13.14	0.007213	9.33	176.29	68.03	0.71
1	1748.775	2018_050yr	Design_12'	1565	4.1	11.8462	10.7	13.14	0.007225	9.34	176.2	67.99	0.71
1	1748.775	2018_050yr	Design_in-kind	1565	4.1	12.3167	10.7	13.39	0.005357	8.5	193.84	104.53	0.62
1	1748.775	2018_050yr	Design_Exist	1565	4.1	12.5304	10.85	13.56	0.005095	8.35	197.51	111.42	0.6
1	1748.775	2018_100yr	Design_20'	2000	4.1	11.8844	11.74	13.96	0.011506	11.84	177.63	68.62	0.9
1	1748.775	2018_100yr	Design_12'	2000	4.1	11.9987	11.74	13.98	0.01068	11.57	181.91	70.44	0.87
1	1748.775	2018_100yr	Design_in-kind	2000	4.1	12.3637	11.74	14.08	0.008503	10.77	195.6	106.89	0.78
1	1748.775	2018_100yr	Design_Exist	2000	4.1	12.5114	11.79	14.2	0.008417	10.7	196.8	110.92	0.78
1	1748.775	2018_500yr	Design_20'	2671	4.1	13.4089	13.21	14.61	0.005842	9.95	389.58	162.4	0.66
1	1748.775	2018_500yr	Design_12'	2671	4.1	13.4089	13.21	14.61	0.005842	9.95	389.58	162.4	0.66
1	1748.775	2018_500yr	Design_in-kind	2671	4.1	13.2068	13.21	14.6	0.006846	10.56	361.53	149.64	0.72
1	1748.775	2018_500yr	Design_Exist	2671	4.1	13.3591	13.26	14.63	0.006424	10.22	378.21	159.25	0.69
1	1748.775	2018_25yr_MHHW_M	Design_20'	1228	4.1	11.5151	9.97	12.44	0.004805	7.88	164.51	58.46	0.57
1	1748.775	2018_25yr_MHHW_M	Design_12'	1228	4.1	11.5153	9.97	12.44	0.004804	7.88	164.52	58.46	0.57
1	1748.775	2018_25yr_MHHW_M	Design_in-kind	1228	4.1	12.0407	9.97	12.78	0.003919	7.04	183.49	72.63	0.53
1	1748.775	2018_25yr_MHHW_M	Design_Exist	1228	4.1	12.1632	10.14	12.89	0.003942	7.03	183.74	82.53	0.53
1	1748.775	2018_25yr_MSL_Ma	Design_20'	1228	4.1	11.5151	9.97	12.44	0.004805	7.88	164.51	58.46	0.57
1	1748.775	2018_25yr_MSL_Ma	Design_12'	1228	4.1	11.5153	9.97	12.44	0.004804	7.88	164.52	58.46	0.57
1	1748.775	2018_25yr_MSL_Ma	Design_in-kind	1228	4.1	12.0434	9.97	12.78	0.003912	7.04	183.59	72.68	0.52
1	1748.775	2018_25yr_MSL_Ma	Design_Exist	1228	4.1	12.1467	10.14	12.88	0.003983	7.06	183.12	80.4	0.53
1	1748.775	2100_025yr_Ab1	Design_20'	1706	4.1	11.915	10.97	13.41	0.008205	10.04	178.77	69.13	0.76
1	1748.775	2100_025yr_Ab1	Design_12'	1706	4.1	12.0332	10.97	13.46	0.0076	9.8	183.2	72.44	0.73
1	1748.775	2100_025yr_Ab1	Design_in-kind	1706	4.1	12.3918	10.97	13.63	0.006083	9.14	196.65	107.75	0.66
1	1748.775	2100_025yr_Ab1	Design_Exist	1706	4.1	12.4038	11.11	13.69	0.006539	9.32	192.76	108.07	0.68
1	1748.775	2100_050yr_Ab1	Design_20'	1717	4.1	11.9196	10.99	13.43	0.008287	10.09	178.94	69.21	0.76
1	1748.775	2100_050yr_Ab1	Design_12'	1717	4.1	12.0359	10.99	13.47	0.007686	9.86	183.3	72.51	0.74
1	1748.775	2100_050yr_Ab1	Design_in-kind	1717	4.1	12.4274	10.99	13.66	0.006032	9.13	197.99	108.72	0.66
1	1748.775	2100_050yr_Ab1	Design_Exist	1717	4.1	12.3852	11.14	13.69	0.0067	9.41	192.06	107.57	0.69
1	1748.775	2100_100yr_Ab1	Design_20'	2562	4.1	13.2217	13.11	14.49	0.006224	10.08	363.56	150.55	0.68
1	1748.775	2100_100yr_Ab1	Design_12'	2562	4.1	13.2213	13.11	14.49	0.006226	10.09	363.51	150.52	0.68
1	1748.775	2100_100yr_Ab1	Design_in-kind	2562	4.1	13.1583	13.11	14.48	0.006549	10.28	354.95	146.69	0.7
1	1748.775	2100_100yr_Ab1	Design_Exist	2562	4.1	13.3003	13.15	14.52	0.006191	9.98	370.03	155.33	0.68
1	1748.775	2018_025yr(Surge	Design_20'	1228	4.1	11.5154	9.97	12.44	0.004804	7.88	164.52	58.46	0.57
1	1748.775	2015_025yr(Surge	Design_12'	1228	4.1	11.7163	9.97	12.56	0.004771	7.53	171.39	64.77	0.57
1	1748.775	2015_025yr(Surge	Design_in-kind	1228	4.1	12.1769	9.97	12.87	0.003596	6.85	188.59	84.3	0.5
1	1748.775	2015_025yr(Surge	Design_Exist	1228	4.1	12.1569	10.14	12.89	0.003958	7.04	183.5	81.71	0.53
1	1748.775	2018_050yr(Surge	Design_20'	1565	4.1	11.7979	10.7	13.12	0.007461	9.43	174.4	67.19	0.72
1	1748.775	2015_050yr(Surge	Design_12'	1565	4.1	12.0782	10.7	13.25	0.006215	8.91	184.89	74.14	0.66
1	1748.775	2015_050yr(Surge	Design_in-kind	1565	4.1	12.4034	10.7	13.44	0.005084	8.36	197.09	108.06	0.6
1	1748.775	2015_050yr(Surge	Design_Exist	1565	4.1	12.5332	10.85	13.56	0.005087	8.34	197.62	111.49	0.6
1	1748.775	015_100yr(Surge)	Design_20'	2000	4.1	11.9251	11.74	13.97	0.011202	11.74	179.15	69.3	0.88
1	1748.775	015_100yr(Surge)	Design_12'	2000	4.1	12.1579	11.74	14.02	0.009652	11.21	187.88	81.85	0.83
1	1748.775	015_100yr(Surge)	Design_in-kind	2000	4.1	12.4512	11.74	14.11	0.008069	10.59	198.88	109.36	0.76
1	1748.775	015_100yr(Surge)	Design_Exist	2000	4.1	12.5093	11.79	14.2	0.008428	10.71	196.72	110.87	0.78
1	1600.008	2018_002yr	Design_20'	232	4.45	7.148		7.69	0.008013	5.9	39.31	15.31	0.65
1	1600.008	2018_002yr	Design_12'	232	4.45	7.1532		7.69	0.007965	5.89	39.39	15.31	0.65
1	1600.008	2018_002yr	Design_in-kind	232	4.45	7.1856		7.71	0.007675	5.82	39.89	15.33	0.64
1	1600.008	2018_002yr	Design_Exist	232	4.45	7.3782		7.83	0.00621	5.41	42.85	15.44	0.57
1	1600.008	2018_010yr	Design_20'	845	4.45	9.6979	9.7	10.89	0.009119	9.29	117.11	61.29	0.74
1	1600.008	2018_010yr	Design_12'	845	4.45	9.6979	9.7	10.89	0.009119	9.29	117.11	61.29	0.74
1	1600.008	2018_010yr	Design_in-kind	845	4.45	11.1984		11.43	0.001695	4.78	314.67	181.55	0.33
1	1600.008	2018_010yr	Design_Exist	845	4.45	11.4627		11.63	0.001248	4.21	364.44	195.09	0.29
1	1600.008	2018_025y	Design_20'	1228	4.45	10.7924	10.79	11.59	0.005839	8.49	245.07	161.31	0.61
1	1600.008	2018_025y	Design_12'	1228	4.45	10.7924	10.79	11.59	0.005839	8.49	245.07	161.31	0.61
1	1600.008	2018_025y	Design_in-kind	1228	4.45	12.0711		12.26	0.001448	4.81	498.78	266.44	0.31
1	1600.008	2018_025y	Design_Exist	1228	4.45	12.2616		12.41	0.00115	4.36	549.96	270.99	0.28
1	1600.008	2018_050yr	Design_20'	1565	4.45	11.1437	11.14	11.98	0.006203	9.09	304.81	178.81	0.63
1	1600.008	2018_050yr	Design_12'	1565	4.45	11.7834		12.19	0.003034	6.77	430.39	218.49	0.45
1	1600.008	2018_050yr	Design_in-kind	1565	4.45	12.5901		12.76	0.001284	4.74	640.38	279.38	0.3
1	1600.008	2018_050yr	Design_Exist	1565	4.45	12.877		13	0.000946	4.16	721.57	286.61	0.26
1	1600.008	2018_100yr	Design_20'	2000	4.45	11.9277		12.49	0.004268	8.14	462.79	230.7	0.54

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	1600.008	2018_100yr	Design_12'	2000	4.45	12.5355		12.83	0.002228	6.21	625.14	277.99	0.39
1	1600.008	2018_100yr	Design_in-kind	2000	4.45	13.0157		13.19	0.001342	5.02	761.55	290.06	0.31
1	1600.008	2018_100yr	Design_Exist	2000	4.45	13.2293		13.38	0.001089	4.6	824.08	295.37	0.28
1	1600.008	2018_500yr	Design_20'	2671	4.45	13.7936		13.96	0.001168	4.97	994.74	309.41	0.29
1	1600.008	2018_500yr	Design_12'	2671	4.45	13.7936		13.96	0.001168	4.97	994.73	309.41	0.29
1	1600.008	2018_500yr	Design_in-kind	2671	4.45	13.6547	11.89	13.84	0.001317	5.22	951.98	305.95	0.31
1	1600.008	2018_500yr	Design_Exist	2671	4.45	13.7746		13.94	0.001187	5	988.86	308.93	0.29
1	1600.008	2018_25yr_MHHW_M	Design_20'	1228	4.45	10.7924	10.79	11.59	0.005839	8.49	245.07	161.31	0.61
1	1600.008	2018_25yr_MHHW_M	Design_12'	1228	4.45	10.7924	10.79	11.59	0.005839	8.49	245.07	161.31	0.61
1	1600.008	2018_25yr_MHHW_M	Design_in-kind	1228	4.45	12.0783		12.27	0.001435	4.79	500.72	266.6	0.31
1	1600.008	2018_25yr_MHHW_M	Design_Exist	1228	4.45	12.2759		12.43	0.00113	4.32	553.85	271.36	0.28
1	1600.008	2018_25yr_MSL_Ma	Design_20'	1228	4.45	10.7924	10.79	11.59	0.005839	8.49	245.07	161.31	0.61
1	1600.008	2018_25yr_MSL_Ma	Design_12'	1228	4.45	10.7924	10.79	11.59	0.005839	8.49	245.07	161.31	0.61
1	1600.008	2018_25yr_MSL_Ma	Design_in-kind	1228	4.45	12.0825		12.27	0.001428	4.78	501.83	266.7	0.31
1	1600.008	2018_25yr_MSL_Ma	Design_Exist	1228	4.45	12.254		12.41	0.00116	4.37	547.92	270.8	0.28
1	1600.008	2100_025yr_Ab1	Design_20'	1706	4.45	11.2939	11.29	12.12	0.006178	9.21	332.23	186.44	0.63
1	1600.008	2100_025yr_Ab1	Design_12'	1706	4.45	12.2124		12.52	0.002352	6.2	536.67	269.74	0.4
1	1600.008	2100_025yr_Ab1	Design_in-kind	1706	4.45	12.7738		12.94	0.001252	4.75	692.12	284.04	0.3
1	1600.008	2100_025yr_Ab1	Design_Exist	1706	4.45	12.8335		12.99	0.001176	4.63	709.14	285.53	0.29
1	1600.008	2100_050yr_Ab1	Design_20'	1717	4.45	11.3042	11.3	12.13	0.006183	9.23	334.17	186.97	0.63
1	1600.008	2100_050yr_Ab1	Design_12'	1717	4.45	12.2277		12.54	0.002339	6.2	540.79	270.13	0.4
1	1600.008	2100_050yr_Ab1	Design_in-kind	1717	4.45	12.8238		12.98	0.001204	4.68	706.36	285.29	0.29
1	1600.008	2100_050yr_Ab1	Design_Exist	1717	4.45	12.8255		12.98	0.001202	4.67	706.85	285.33	0.29
1	1600.008	2100_100yr_Ab1	Design_20'	2562	4.45	13.6183		13.79	0.001251	5.08	940.85	305.05	0.3
1	1600.008	2100_100yr_Ab1	Design_12'	2562	4.45	13.618		13.79	0.001251	5.08	940.76	305.04	0.3
1	1600.008	2100_100yr_Ab1	Design_in-kind	2562	4.45	13.5759		13.75	0.001299	5.15	927.97	303.99	0.31
1	1600.008	2100_100yr_Ab1	Design_Exist	2562	4.45	13.6876		13.85	0.001177	4.95	962.08	306.77	0.29
1	1600.008	2018_025yr(Surge	Design_20'	1228	4.45	10.7924	10.79	11.59	0.005839	8.49	245.07	161.31	0.61
1	1600.008	2015_025yr(Surge	Design_12'	1228	4.45	11.6168		11.91	0.002222	5.71	395.15	204.47	0.38
1	1600.008	2015_025yr(Surge	Design_in-kind	1228	4.45	12.2726		12.42	0.001135	4.33	552.96	271.28	0.28
1	1600.008	2015_025yr(Surge	Design_Exist	1228	4.45	12.2675		12.42	0.001141	4.34	551.58	271.15	0.28
1	1600.008	2018_050yr(Surge	Design_20'	1565	4.45	11.3366	11.15	12	0.004947	8.28	340.25	188.63	0.57
1	1600.008	2015_050yr(Surge	Design_12'	1565	4.45	12.23		12.49	0.001938	5.64	541.42	270.19	0.36
1	1600.008	2015_050yr(Surge	Design_in-kind	1565	4.45	12.6977		12.85	0.001143	4.51	670.57	282.11	0.28
1	1600.008	2015_050yr(Surge	Design_Exist	1565	4.45	12.8801		13	0.000943	4.16	722.46	286.69	0.26
1	1600.008	015_100yr(Surge)	Design_20'	2000	4.45	12.1647		12.62	0.003424	7.45	523.83	268.6	0.48
1	1600.008	015_100yr(Surge)	Design_12'	2000	4.45	12.7795		13	0.001711	5.56	693.76	284.19	0.35
1	1600.008	015_100yr(Surge)	Design_in-kind	2000	4.45	13.1061		13.27	0.001227	4.83	787.88	292.31	0.29
1	1600.008	015_100yr(Surge)	Design_Exist	2000	4.45	13.2273		13.37	0.001091	4.6	823.51	295.32	0.28
1	1456.522	2018_002yr	Design_20'	232	3.05	6.4314		6.79	0.004281	4.78	48.52	16.66	0.49
1	1456.522	2018_002yr	Design_12'	232	3.05	6.4483		6.8	0.004209	4.75	48.8	16.67	0.49
1	1456.522	2018_002yr	Design_in-kind	232	3.05	6.543		6.87	0.003835	4.6	50.38	16.74	0.47
1	1456.522	2018_002yr	Design_Exist	232	3.05	6.9401		7.2	0.002672	4.06	57.08	17.01	0.39
1	1456.522	2018_010yr	Design_20'	845	3.05	9.0051	8.25	9.61	0.004367	6.96	162.88	65.28	0.53
1	1456.522	2018_010yr	Design_12'	845	3.05	9.0051	8.25	9.61	0.004367	6.96	162.88	65.28	0.53
1	1456.522	2018_010yr	Design_in-kind	845	3.05	11.1957		11.26	0.000448	2.8	586.74	304.9	0.18
1	1456.522	2018_010yr	Design_Exist	845	3.05	11.4584		11.51	0.000337	2.49	669.12	322.48	0.16
1	1456.522	2018_025y	Design_20'	1228	3.05	9.8078	8.98	10.49	0.004464	7.72	236.09	126.8	0.55
1	1456.522	2018_025y	Design_12'	1228	3.05	10.3116	8.98	10.73	0.002703	6.33	340.81	256.8	0.43
1	1456.522	2018_025y	Design_in-kind	1228	3.05	12.0675		12.12	0.000388	2.8	878.71	371.9	0.17
1	1456.522	2018_025y	Design_Exist	1228	3.05	12.2549		12.3	0.000318	2.58	948.66	374.88	0.16
1	1456.522	2018_050yr	Design_20'	1565	3.05	10.9522	9.69	11.25	0.002024	5.83	514.46	288.56	0.38
1	1456.522	2018_050yr	Design_12'	1565	3.05	11.7673		11.89	0.000837	4.02	771.93	343.14	0.25
1	1456.522	2018_050yr	Design_in-kind	1565	3.05	12.5762		12.63	0.000376	2.87	1069.93	379.87	0.17
1	1456.522	2018_050yr	Design_Exist	1565	3.05	12.8638		12.91	0.000288	2.57	1179.83	384.32	0.15
1	1456.522	2018_100yr	Design_20'	2000	3.05	11.9027		12.07	0.001192	4.85	819.02	352.2	0.3
1	1456.522	2018_100yr	Design_12'	2000	3.05	12.5108		12.61	0.000654	3.77	1045.12	378.85	0.22
1	1456.522	2018_100yr	Design_in-kind	2000	3.05	12.9945		13.06	0.000418	3.12	1230.19	386.35	0.18
1	1456.522	2018_100yr	Design_Exist	2000	3.05	13.2104		13.26	0.000348	2.89	1313.97	389.82	0.17
1	1456.522	2018_500yr	Design_20'	2671	3.05	13.7691		13.83	0.000399	3.22	1534.37	399.15	0.18
1	1456.522	2018_500yr	Design_12'	2671	3.05	13.7691		13.83	0.000399	3.22	1534.37	399.15	0.18
1	1456.522	2018_500yr	Design_in-kind	2671	3.05	13.6277		13.7	0.000445	3.36	1478.09	396.79	0.19
1	1456.522	2018_500yr	Design_Exist	2671	3.05	13.7498		13.81	0.000405	3.24	1526.66	398.82	0.18
1	1456.522	2018_25yr_MHHW_M	Design_20'	1228	3.05	9.8078	8.98	10.49	0.004464	7.72	236.09	126.8	0.55
1	1456.522	2018_25yr_MHHW_M	Design_12'	1228	3.05	10.6418	8.98	10.91	0.001799	5.34	427.93	270.88	0.36
1	1456.522	2018_25yr_MHHW_M	Design_in-kind	1228	3.05	12.0746		12.13	0.000385	2.8	881.35	372.02	0.17
1	1456.522	2018_25yr_MHHW_M	Design_Exist	1228	3.05	12.269		12.31	0.000314	2.56	953.97	375.1	0.15
1	1456.522	2018_25yr_MSL_Ma	Design_20'	1228	3.05	9.8078	8.98	10.49	0.004464	7.72	236.09	126.8	0.55
1	1456.522	2018_25yr_MSL_Ma	Design_12'	1228	3.05	10.6278	8.98	10.9	0.00183	5.38	424.15	270.28	0.36
1	1456.522	2018_25yr_MSL_Ma	Design_in-kind	1228	3.05	12.0787		12.13	0.000383	2.79	882.86	372.08	0.17
1	1456.522	2018_25yr_MSL_Ma	Design_Exist	1228	3.05	12.2474		12.29	0.000321	2.59	945.85	374.76	0.16

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	1456.522	2100_025yr_Ab1	Design_20'	1706	3.05	11.1824	9.78	11.45	0.001854	5.7	582.69	304.01	0.37
1	1456.522	2100_025yr_Ab1	Design_12'	1706	3.05	12.1987		12.29	0.000651	3.67	927.64	374.01	0.22
1	1456.522	2100_025yr_Ab1	Design_in-kind	1706	3.05	12.7574		12.81	0.000377	2.91	1139.01	382.67	0.17
1	1456.522	2100_025yr_Ab1	Design_Exist	1706	3.05	12.8174		12.87	0.000357	2.85	1162.01	383.6	0.17
1	1456.522	2100_050yr_Ab1	Design_20'	1717	3.05	11.2118	9.79	11.48	0.001818	5.65	591.64	305.97	0.36
1	1456.522	2100_050yr_Ab1	Design_12'	1717	3.05	12.2134		12.31	0.00065	3.67	933.14	374.24	0.22
1	1456.522	2100_050yr_Ab1	Design_in-kind	1717	3.05	12.8074		12.86	0.000364	2.88	1158.18	383.45	0.17
1	1456.522	2100_050yr_Ab1	Design_Exist	1717	3.05	12.8092		12.86	0.000364	2.88	1158.83	383.47	0.17
1	1456.522	2100_100yr_Ab1	Design_20'	2562	3.05	13.593		13.66	0.00042	3.26	1464.33	396.21	0.18
1	1456.522	2100_100yr_Ab1	Design_12'	2562	3.05	13.5927		13.66	0.00042	3.26	1464.21	396.2	0.18
1	1456.522	2100_100yr_Ab1	Design_in-kind	2562	3.05	13.55		13.62	0.000434	3.31	1447.29	395.49	0.19
1	1456.522	2100_100yr_Ab1	Design_Exist	2562	3.05	13.6636		13.73	0.000398	3.19	1492.33	397.39	0.18
1	1456.522	2018_025yr(Surge	Design_20'	1228	3.05	10.3252	8.98	10.74	0.002658	6.29	344.32	257.38	0.43
1	1456.522	2015_025yr(Surge	Design_12'	1228	3.05	11.6064		11.69	0.000608	3.38	717.59	332.38	0.21
1	1456.522	2015_025yr(Surge	Design_in-kind	1228	3.05	12.2658		12.31	0.000315	2.57	952.76	375.05	0.15
1	1456.522	2015_025yr(Surge	Design_Exist	1228	3.05	12.2608		12.31	0.000316	2.57	950.87	374.97	0.15
1	1456.522	2018_050yr(Surge	Design_20'	1565	3.05	11.3181		11.51	0.001344	4.91	624.54	313.09	0.31
1	1456.522	2015_050yr(Surge	Design_12'	1565	3.05	12.2188		12.3	0.000537	3.34	935.13	374.32	0.2
1	1456.522	2015_050yr(Surge	Design_in-kind	1565	3.05	12.6839		12.73	0.000339	2.75	1110.92	381.53	0.16
1	1456.522	2015_050yr(Surge	Design_Exist	1565	3.05	12.867		12.91	0.000287	2.56	1181.03	384.37	0.15
1	1456.522	015_100yr(Surge)	Design_20'	2000	3.05	12.1446		12.28	0.000947	4.41	907.41	373.14	0.27
1	1456.522	015_100yr(Surge)	Design_12'	2000	3.05	12.7562		12.83	0.000518	3.42	1138.53	382.65	0.2
1	1456.522	015_100yr(Surge)	Design_in-kind	2000	3.05	13.0859		13.14	0.000387	3.02	1265.56	387.76	0.17
1	1456.522	015_100yr(Surge)	Design_Exist	2000	3.05	13.2085		13.26	0.000349	2.9	1313.2	389.79	0.17
1	1331.074	2018_002yr	Design_20'	232	1.92	6.0011		6.29	0.003158	4.34	53.45	15.56	0.41
1	1331.074	2018_002yr	Design_12'	232	1.92	6.0277		6.32	0.003086	4.31	53.87	15.86	0.4
1	1331.074	2018_002yr	Design_in-kind	232	1.92	6.1647		6.43	0.002807	4.14	56.55	23.38	0.38
1	1331.074	2018_002yr	Design_Exist	232	1.92	6.7325		6.91	0.001596	3.44	78.09	52.57	0.3
1	1331.074	2018_010yr	Design_20'	845	1.92	8.8162		9.12	0.002262	5.37	237.73	97.05	0.38
1	1331.074	2018_010yr	Design_12'	845	1.92	8.8162		9.12	0.002262	5.37	237.73	97.05	0.38
1	1331.074	2018_010yr	Design_in-kind	845	1.92	11.1799		11.21	0.000223	2.09	757.18	356.78	0.13
1	1331.074	2018_010yr	Design_Exist	845	1.92	11.4455		11.47	0.000171	1.87	854.03	372.49	0.11
1	1331.074	2018_025y	Design_20'	1228	1.92	9.6956		10	0.002064	5.6	336.13	127.69	0.37
1	1331.074	2018_025y	Design_12'	1228	1.92	10.2451		10.43	0.001259	4.6	449.79	299.61	0.29
1	1331.074	2018_025y	Design_in-kind	1228	1.92	12.0509		12.08	0.000205	2.13	1090.31	405.93	0.12
1	1331.074	2018_025y	Design_Exist	1228	1.92	12.2403		12.27	0.000172	1.98	1167.41	408.29	0.11
1	1331.074	2018_050yr	Design_20'	1565	1.92	10.8743		11.02	0.001051	4.42	650.91	338.7	0.27
1	1331.074	2018_050yr	Design_12'	1565	1.92	11.7306		11.79	0.000447	3.08	962.61	389.36	0.18
1	1331.074	2018_050yr	Design_in-kind	1565	1.92	12.5571		12.59	0.000211	2.24	1297.38	412.21	0.13
1	1331.074	2018_050yr	Design_Exist	1565	1.92	12.8483		12.87	0.000166	2.03	1417.96	415.82	0.11
1	1331.074	2018_100yr	Design_20'	2000	1.92	11.8465		11.94	0.000655	3.76	1008.14	396.22	0.22
1	1331.074	2018_100yr	Design_12'	2000	1.92	12.4772		12.53	0.000369	2.95	1264.49	411.22	0.17
1	1331.074	2018_100yr	Design_in-kind	2000	1.92	12.9712		13.01	0.000246	2.49	1469.12	417.34	0.14
1	1331.074	2018_100yr	Design_Exist	2000	1.92	13.1904		13.22	0.000208	2.32	1560.93	420.06	0.13
1	1331.074	2018_500yr	Design_20'	2671	1.92	13.7446		13.79	0.000249	2.62	1795.51	426.42	0.14
1	1331.074	2018_500yr	Design_12'	2671	1.92	13.7446		13.79	0.000249	2.62	1795.51	426.42	0.14
1	1331.074	2018_500yr	Design_in-kind	2671	1.92	13.6007		13.65	0.000275	2.73	1734.26	424.83	0.15
1	1331.074	2018_500yr	Design_Exist	2671	1.92	13.7249		13.77	0.000252	2.64	1787.13	426.2	0.14
1	1331.074	2018_25yr_MHHW_M	Design_20'	1228	1.92	9.6956		10	0.002064	5.6	336.13	127.69	0.37
1	1331.074	2018_25yr_MHHW_M	Design_12'	1228	1.92	10.5865		10.71	0.000877	3.95	555.87	321.66	0.25
1	1331.074	2018_25yr_MHHW_M	Design_in-kind	1228	1.92	12.0581		12.09	0.000203	2.13	1093.23	406.02	0.12
1	1331.074	2018_25yr_MHHW_M	Design_Exist	1228	1.92	12.2546		12.28	0.00017	1.97	1173.25	408.47	0.11
1	1331.074	2018_25yr_MSL_Ma	Design_20'	1228	1.92	9.6956		10	0.002064	5.6	336.13	127.69	0.37
1	1331.074	2018_25yr_MSL_Ma	Design_12'	1228	1.92	10.572		10.7	0.000891	3.98	551.21	320.81	0.25
1	1331.074	2018_25yr_MSL_Ma	Design_in-kind	1228	1.92	12.0622		12.09	0.000202	2.12	1094.9	406.07	0.12
1	1331.074	2018_25yr_MSL_Ma	Design_Exist	1228	1.92	12.2327		12.26	0.000173	1.99	1164.32	408.19	0.11
1	1331.074	2100_025yr_Ab1	Design_20'	1706	1.92	11.1059		11.24	0.000982	4.36	730.94	352.4	0.26
1	1331.074	2100_025yr_Ab1	Design_12'	1706	1.92	12.1685		12.22	0.000354	2.83	1138.11	407.39	0.16
1	1331.074	2100_025yr_Ab1	Design_in-kind	1706	1.92	12.7374		12.77	0.000216	2.3	1371.9	414.45	0.13
1	1331.074	2100_025yr_Ab1	Design_Exist	1706	1.92	12.7983		12.83	0.000205	2.25	1397.17	415.2	0.12
1	1331.074	2100_050yr_Ab1	Design_20'	1717	1.92	11.1363		11.27	0.000964	4.33	741.68	354.2	0.26
1	1331.074	2100_050yr_Ab1	Design_12'	1717	1.92	12.1831		12.23	0.000354	2.83	1144.07	407.58	0.16
1	1331.074	2100_050yr_Ab1	Design_in-kind	1717	1.92	12.7879		12.82	0.00021	2.27	1392.85	415.07	0.13
1	1331.074	2100_050yr_Ab1	Design_Exist	1717	1.92	12.7897		12.82	0.00021	2.27	1393.57	415.09	0.13
1	1331.074	2100_100yr_Ab1	Design_20'	2562	1.92	13.5676		13.61	0.000259	2.65	1720.21	424.46	0.14
1	1331.074	2100_100yr_Ab1	Design_12'	2562	1.92	13.5673		13.61	0.000259	2.65	1720.08	424.46	0.14
1	1331.074	2100_100yr_Ab1	Design_in-kind	2562	1.92	13.5238		13.57	0.000267	2.68	1701.62	423.98	0.14
1	1331.074	2100_100yr_Ab1	Design_Exist	2562	1.92	13.6394		13.68	0.000246	2.59	1750.7	425.26	0.14
1	1331.074	2018_025yr(Surge	Design_20'	1228	1.92	10.2591		10.44	0.001241	4.57	454	300.52	0.29
1	1331.074	2015_025yr(Surge	Design_12'	1228	1.92	11.5815		11.63	0.000317	2.57	905.2	380.53	0.15
1	1331.074	2015_025yr(Surge	Design_in-kind	1228	1.92	12.2513		12.28	0.00017	1.97	1171.92	408.43	0.11

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	1331.074	2015_025yr(Surge	Design_Exist	1228	1.92	12.2463		12.27	0.000171	1.98	1169.84	408.36	0.11
1	1331.074	2018_050yr(Surge	Design_20'	1565	1.92	11.2625		11.36	0.000705	3.74	786.86	361.67	0.22
1	1331.074	2015_050yr(Surge	Design_12'	1565	1.92	12.1939		12.24	0.000291	2.57	1148.49	407.71	0.15
1	1331.074	2015_050yr(Surge	Design_in-kind	1565	1.92	12.6662		12.7	0.000193	2.16	1342.43	413.57	0.12
1	1331.074	2015_050yr(Surge	Design_Exist	1565	1.92	12.8515		12.88	0.000166	2.02	1419.28	415.86	0.11
1	1331.074	015_100yr(Surge)	Design_20'	2000	1.92	12.1		12.17	0.000518	3.41	1110.23	406.54	0.19
1	1331.074	015_100yr(Surge)	Design_12'	2000	1.92	12.7283		12.77	0.000299	2.7	1368.12	414.33	0.15
1	1331.074	015_100yr(Surge)	Design_in-kind	2000	1.92	13.0641		13.1	0.000229	2.41	1507.95	418.49	0.13
1	1331.074	015_100yr(Surge)	Design_Exist	2000	1.92	13.1885		13.22	0.000208	2.32	1560.1	420.03	0.13
1	1255.24	2018_002yr	Design_20'	232	1.66	5.3612		5.91	0.007194	5.95	39.02	12.34	0.59
1	1255.24	2018_002yr	Design_12'	232	1.66	5.4142		5.95	0.006875	5.85	39.68	12.41	0.58
1	1255.24	2018_002yr	Design_in-kind	232	1.66	5.6513		6.11	0.005653	5.43	42.94	16.57	0.53
1	1255.24	2018_002yr	Design_Exist	232	1.66	6.5411		6.76	0.002164	3.92	72.53	48.23	0.34
1	1255.24	2018_010yr	Design_20'	845	1.66	8.4464		8.9	0.003527	6.44	188.99	71.54	0.46
1	1255.24	2018_010yr	Design_12'	845	1.66	8.4464		8.9	0.003527	6.44	188.99	71.54	0.46
1	1255.24	2018_010yr	Design_in-kind	845	1.66	11.1422		11.19	0.000345	2.57	682.82	352.4	0.15
1	1255.24	2018_010yr	Design_Exist	845	1.66	11.4201		11.45	0.000248	2.23	782.2	362.05	0.13
1	1255.24	2018_025y	Design_20'	1228	1.66	9.2539		9.77	0.003655	7.12	248.86	76.79	0.48
1	1255.24	2018_025y	Design_12'	1228	1.66	9.9634	8.23	10.29	0.002125	5.8	305.34	82.43	0.37
1	1255.24	2018_025y	Design_in-kind	1228	1.66	12.025		12.06	0.000273	2.44	1006.92	380.3	0.14
1	1255.24	2018_025y	Design_Exist	1228	1.66	12.2193		12.25	0.000225	2.25	1081.05	382.78	0.13
1	1255.24	2018_050yr	Design_20'	1565	1.66	10.327	8.67	10.85	0.003471	7.65	409.63	315	0.48
1	1255.24	2018_050yr	Design_12'	1565	1.66	11.665		11.75	0.000647	3.66	871.84	369.86	0.21
1	1255.24	2018_050yr	Design_in-kind	1565	1.66	12.5319		12.57	0.000272	2.52	1201.35	386.78	0.14
1	1255.24	2018_050yr	Design_Exist	1565	1.66	12.8291		12.86	0.00021	2.26	1316.88	390.58	0.12
1	1255.24	2018_100yr	Design_20'	2000	1.66	11.7475		11.88	0.000966	4.5	902.44	372.35	0.26
1	1255.24	2018_100yr	Design_12'	2000	1.66	12.4313		12.5	0.000487	3.35	1162.49	385.5	0.19
1	1255.24	2018_100yr	Design_in-kind	2000	1.66	12.9425		12.99	0.000311	2.77	1361.23	392.03	0.15
1	1255.24	2018_100yr	Design_Exist	2000	1.66	13.1666		13.21	0.00026	2.56	1449.43	394.9	0.14
1	1255.24	2018_500yr	Design_20'	2671	1.66	13.7162		13.77	0.000307	2.88	1668.46	402.64	0.15
1	1255.24	2018_500yr	Design_12'	2671	1.66	13.7162		13.77	0.000307	2.88	1668.46	402.64	0.15
1	1255.24	2018_500yr	Design_in-kind	2671	1.66	13.5691		13.62	0.000341	3.01	1609.43	400.29	0.16
1	1255.24	2018_500yr	Design_Exist	2671	1.66	13.6961		13.75	0.000311	2.9	1660.39	402.21	0.15
1	1255.24	2018_25yr_MHHW_M	Design_20'	1228	1.66	9.2539		9.77	0.003655	7.12	248.86	76.79	0.48
1	1255.24	2018_25yr_MHHW_M	Design_12'	1228	1.66	10.1237	8.23	10.57	0.002831	6.79	346.75	303.78	0.43
1	1255.24	2018_25yr_MHHW_M	Design_in-kind	1228	1.66	12.0324		12.07	0.000271	2.43	1009.73	380.39	0.14
1	1255.24	2018_25yr_MHHW_M	Design_Exist	1228	1.66	12.2339		12.26	0.000222	2.23	1086.65	382.97	0.13
1	1255.24	2018_25yr_MSL_Ma	Design_20'	1228	1.66	9.2539		9.77	0.003655	7.12	248.86	76.79	0.48
1	1255.24	2018_25yr_MSL_Ma	Design_12'	1228	1.66	10.0133	8.23	10.54	0.003286	7.25	313.58	293.86	0.46
1	1255.24	2018_25yr_MSL_Ma	Design_in-kind	1228	1.66	12.0366		12.07	0.00027	2.43	1011.35	380.45	0.14
1	1255.24	2018_25yr_MSL_Ma	Design_Exist	1228	1.66	12.2115		12.24	0.000227	2.25	1078.09	382.69	0.13
1	1255.24	2100_025yr_Ab1	Design_20'	1706	1.66	10.8371		11.12	0.002068	6.15	577.31	340.33	0.37
1	1255.24	2100_025yr_Ab1	Design_12'	1706	1.66	12.1227		12.19	0.000478	3.25	1044.16	381.55	0.18
1	1255.24	2100_025yr_Ab1	Design_in-kind	1706	1.66	12.712		12.75	0.000275	2.57	1271.22	389.09	0.14
1	1255.24	2100_025yr_Ab1	Design_Exist	1706	1.66	12.7743		12.81	0.000261	2.51	1295.48	389.88	0.14
1	1255.24	2100_050yr_Ab1	Design_20'	1717	1.66	10.8822		11.16	0.001975	6.04	592.71	341.82	0.37
1	1255.24	2100_050yr_Ab1	Design_12'	1717	1.66	12.1375		12.2	0.000477	3.25	1049.79	381.74	0.18
1	1255.24	2100_050yr_Ab1	Design_in-kind	1717	1.66	12.7633		12.8	0.000267	2.54	1291.21	389.74	0.14
1	1255.24	2100_050yr_Ab1	Design_Exist	1717	1.66	12.7651		12.8	0.000266	2.53	1291.9	389.76	0.14
1	1255.24	2100_100yr_Ab1	Design_20'	2562	1.66	13.5379		13.59	0.000321	2.92	1596.95	399.85	0.15
1	1255.24	2100_100yr_Ab1	Design_12'	2562	1.66	13.5376		13.59	0.000321	2.92	1596.83	399.84	0.15
1	1255.24	2100_100yr_Ab1	Design_in-kind	2562	1.66	13.4931		13.55	0.000332	2.96	1579.05	399.21	0.16
1	1255.24	2100_100yr_Ab1	Design_Exist	2562	1.66	13.6113		13.66	0.000304	2.85	1626.31	400.89	0.15
1	1255.24	2018_025yr(Surge	Design_20'	1228	1.66	9.9791	8.23	10.3	0.002101	5.78	306.64	82.56	0.37
1	1255.24	2015_025yr(Surge	Design_12'	1228	1.66	11.5345		11.6	0.00046	3.06	823.83	365.72	0.18
1	1255.24	2015_025yr(Surge	Design_in-kind	1228	1.66	12.2306		12.26	0.000222	2.24	1085.38	382.93	0.13
1	1255.24	2015_025yr(Surge	Design_Exist	1228	1.66	12.2254		12.26	0.000224	2.24	1083.38	382.86	0.13
1	1255.24	2018_050yr(Surge	Design_20'	1565	1.66	11.1215		11.29	0.001214	4.82	675.51	351.42	0.29
1	1255.24	2015_050yr(Surge	Design_12'	1565	1.66	12.1571		12.21	0.000388	2.94	1057.26	381.99	0.17
1	1255.24	2015_050yr(Surge	Design_in-kind	1565	1.66	12.6435		12.68	0.000246	2.42	1244.61	388.21	0.13
1	1255.24	2015_050yr(Surge	Design_Exist	1565	1.66	12.8324		12.86	0.000209	2.25	1318.14	390.62	0.12
1	1255.24	015_100yr(Surge)	Design_20'	2000	1.66	12.0292		12.13	0.000721	3.97	1008.54	380.35	0.23
1	1255.24	015_100yr(Surge)	Design_12'	2000	1.66	12.6925		12.75	0.000385	3.03	1263.63	388.84	0.17
1	1255.24	015_100yr(Surge)	Design_in-kind	2000	1.66	13.0376		13.08	0.000288	2.68	1398.58	393.25	0.14
1	1255.24	015_100yr(Surge)	Design_Exist	2000	1.66	13.1646		13.2	0.00026	2.57	1448.62	394.87	0.14
1	1169.738	2018_002yr	Design_20'	232	1	4.792		5.3	0.006351	5.73	40.47	13.3	0.57
1	1169.738	2018_002yr	Design_12'	232	1	4.8937		5.37	0.005811	5.55	41.88	14.19	0.54
1	1169.738	2018_002yr	Design_in-kind	232	1	5.2839		5.66	0.004144	4.93	47.89	16.34	0.46
1	1169.738	2018_002yr	Design_Exist	232	1	6.3998		6.58	0.001697	3.53	78.18	45.88	0.3
1	1169.738	2018_010yr	Design_20'	845	1	7.2412	7.24	8.36	0.009238	9.27	122.07	58.46	0.72

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	1169.738	2018_010yr	Design_12'	845	1	7.2412	7.24	8.36	0.009238	9.27	122.07	58.46	0.72
1	1169.738	2018_010yr	Design_in-kind	845	1	11.1197		11.16	0.000279	2.34	684.25	332.43	0.14
1	1169.738	2018_010yr	Design_Exist	845	1	11.4022		11.43	0.000211	2.08	779.82	344.16	0.12
1	1169.738	2018_025y	Design_20'	1228	1	8.6155		9.36	0.005344	8.26	216.13	77.74	0.57
1	1169.738	2018_025y	Design_12'	1228	1	9.7611		10.1	0.002176	5.87	313.71	93.37	0.37
1	1169.738	2018_025y	Design_in-kind	1228	1	12.0016		12.04	0.000256	2.39	993.58	369.05	0.13
1	1169.738	2018_025y	Design_Exist	1228	1	12.1992		12.23	0.000215	2.22	1067.22	376.8	0.12
1	1169.738	2018_050yr	Design_20'	1565	1	10.1498		10.55	0.002586	6.61	381.61	292.15	0.41
1	1169.738	2018_050yr	Design_12'	1565	1	11.6118		11.7	0.000593	3.54	852.87	352.87	0.2
1	1169.738	2018_050yr	Design_in-kind	1565	1	12.5059		12.55	0.00027	2.53	1184.61	388.77	0.14
1	1169.738	2018_050yr	Design_Exist	1565	1	12.8084		12.84	0.000212	2.29	1304	400.55	0.12
1	1169.738	2018_100yr	Design_20'	2000	1	11.6603		11.79	0.000925	4.43	870.03	354.88	0.25
1	1169.738	2018_100yr	Design_12'	2000	1	12.3837		12.46	0.000487	3.38	1137.39	384.05	0.19
1	1169.738	2018_100yr	Design_in-kind	2000	1	12.9107		12.96	0.00032	2.83	1345.2	404.83	0.15
1	1169.738	2018_100yr	Design_Exist	2000	1	13.1397		13.18	0.000269	2.63	1438.98	414.09	0.14
1	1169.738	2018_500yr	Design_20'	2671	1	13.6829		13.74	0.000328	3	1669.82	435.96	0.16
1	1169.738	2018_500yr	Design_12'	2671	1	13.6829		13.74	0.000328	3	1669.81	435.96	0.16
1	1169.738	2018_500yr	Design_in-kind	2671	1	13.5323		13.59	0.000363	3.13	1604.57	429.85	0.16
1	1169.738	2018_500yr	Design_Exist	2671	1	13.6624		13.72	0.000332	3.01	1660.87	435.21	0.16
1	1169.738	2018_25yr_MHHW_M	Design_20'	1228	1	8.6155		9.36	0.005344	8.26	216.13	77.74	0.57
1	1169.738	2018_25yr_MHHW_M	Design_12'	1228	1	10.0469		10.33	0.00175	5.39	351.71	289.23	0.34
1	1169.738	2018_25yr_MHHW_M	Design_in-kind	1228	1	12.0091		12.05	0.000254	2.38	996.36	369.32	0.13
1	1169.738	2018_25yr_MHHW_M	Design_Exist	1228	1	12.2141		12.25	0.000212	2.2	1072.82	377.39	0.12
1	1169.738	2018_25yr_MSL_Ma	Design_20'	1228	1	8.6155		9.36	0.005344	8.26	216.13	77.74	0.57
1	1169.738	2018_25yr_MSL_Ma	Design_12'	1228	1	9.8204		10.15	0.00209	5.78	319.39	98.18	0.37
1	1169.738	2018_25yr_MSL_Ma	Design_in-kind	1228	1	12.0135		12.05	0.000253	2.37	997.96	369.47	0.13
1	1169.738	2018_25yr_MSL_Ma	Design_Exist	1228	1	12.1913		12.22	0.000216	2.22	1064.26	376.42	0.12
1	1169.738	2100_025yr_Ab1	Design_20'	1706	1	10.6882		10.95	0.001778	5.72	544.67	314.47	0.34
1	1169.738	2100_025yr_Ab1	Design_12'	1706	1	12.0792		12.15	0.000461	3.22	1022.32	371.84	0.18
1	1169.738	2100_025yr_Ab1	Design_in-kind	1706	1	12.6849		12.73	0.000277	2.6	1254.82	395.7	0.14
1	1169.738	2100_025yr_Ab1	Design_Exist	1706	1	12.7484		12.79	0.000264	2.54	1280.05	398.16	0.14
1	1169.738	2100_050yr_Ab1	Design_20'	1717	1	10.7379		10.99	0.00171	5.63	560.35	316.56	0.34
1	1169.738	2100_050yr_Ab1	Design_12'	1717	1	12.0939		12.16	0.000461	3.22	1027.78	372.37	0.18
1	1169.738	2100_050yr_Ab1	Design_in-kind	1717	1	12.7369		12.78	0.00027	2.57	1275.46	397.72	0.14
1	1169.738	2100_050yr_Ab1	Design_Exist	1717	1	12.7387		12.78	0.000269	2.57	1276.18	397.79	0.14
1	1169.738	2100_100yr_Ab1	Design_20'	2562	1	13.5034		13.56	0.000341	3.02	1592.19	428.65	0.16
1	1169.738	2100_100yr_Ab1	Design_12'	2562	1	13.5031		13.56	0.000341	3.02	1592.05	428.64	0.16
1	1169.738	2100_100yr_Ab1	Design_in-kind	2562	1	13.4575		13.51	0.000352	3.06	1572.54	426.74	0.16
1	1169.738	2100_100yr_Ab1	Design_Exist	2562	1	13.5785		13.63	0.000324	2.96	1624.48	431.77	0.15
1	1169.738	2018_025yr(Surge	Design_20'	1228	1	9.9189		10.23	0.001942	5.62	329.24	100.92	0.35
1	1169.738	2015_025yr(Surge	Design_12'	1228	1	11.499		11.56	0.000406	2.9	813.33	348.18	0.17
1	1169.738	2015_025yr(Surge	Design_in-kind	1228	1	12.2107		12.24	0.000213	2.21	1071.54	377.26	0.12
1	1169.738	2015_025yr(Surge	Design_Exist	1228	1	12.2054		12.24	0.000214	2.21	1069.55	377.05	0.12
1	1169.738	2018_050yr(Surge	Design_20'	1565	1	11.0316		11.18	0.001048	4.51	655.12	328.77	0.27
1	1169.738	2015_050yr(Surge	Design_12'	1565	1	12.1219		12.18	0.000373	2.9	1038.24	373.38	0.16
1	1169.738	2015_050yr(Surge	Design_in-kind	1565	1	12.6196		12.66	0.000246	2.43	1229.1	393.17	0.13
1	1169.738	2015_050yr(Surge	Design_Exist	1565	1	12.8117		12.84	0.000211	2.28	1305.31	400.68	0.12
1	1169.738	015_100yr(Surge)	Design_20'	2000	1	11.962		12.06	0.000702	3.94	978.99	367.41	0.22
1	1169.738	015_100yr(Surge)	Design_12'	2000	1	12.6539		12.71	0.000391	3.08	1242.61	394.5	0.17
1	1169.738	015_100yr(Surge)	Design_in-kind	2000	1	13.008		13.05	0.000297	2.74	1384.79	408.76	0.15
1	1169.738	015_100yr(Surge)	Design_Exist	2000	1	13.1377		13.18	0.00027	2.63	1438.12	414.01	0.14
1	1065.804	2018_002yr	Design_20'	232	1.11	4.9233		5	0.000725	2.19	105.71	34.28	0.22
1	1065.804	2018_002yr	Design_12'	232	1.11	5.0219		5.09	0.000657	2.13	109.09	34.28	0.21
1	1065.804	2018_002yr	Design_in-kind	232	1.11	5.3909		5.45	0.000495	1.9	122.32	36.82	0.18
1	1065.804	2018_002yr	Design_Exist	232	1.11	6.4568		6.49	0.000206	1.43	164.78	63.41	0.12
1	1065.804	2018_010yr	Design_20'	845	1.11	7.0333	4.49	7.33	0.001688	4.44	213.79	96.96	0.36
1	1065.804	2018_010yr	Design_12'	845	1.11	7.3521	4.49	7.59	0.001289	4.05	246.73	109.84	0.32
1	1065.804	2018_010yr	Design_in-kind	845	1.11	11.1206		11.14	0.000073	1.39	1019.03	319.03	0.08
1	1065.804	2018_010yr	Design_Exist	845	1.11	11.4013		11.42	0.00006	1.28	1109.79	327.48	0.07
1	1065.804	2018_025y	Design_20'	1228	1.11	8.8213		9.01	0.000828	3.84	452.07	168.27	0.26
1	1065.804	2018_025y	Design_12'	1228	1.11	9.8504		9.95	0.000389	2.9	648.29	212.68	0.18
1	1065.804	2018_025y	Design_in-kind	1228	1.11	11.9969		12.02	0.000084	1.59	1310.39	346.04	0.09
1	1065.804	2018_025y	Design_Exist	1228	1.11	12.1942		12.21	0.000074	1.51	1379.68	356.49	0.08
1	1065.804	2018_050yr	Design_20'	1565	1.11	10.2402		10.37	0.000496	3.38	750.14	291.7	0.21
1	1065.804	2018_050yr	Design_12'	1565	1.11	11.6061		11.65	0.000177	2.24	1177.52	333.91	0.13
1	1065.804	2018_050yr	Design_in-kind	1565	1.11	12.4978		12.53	0.0001	1.79	1490.35	372.44	0.1
1	1065.804	2018_050yr	Design_Exist	1565	1.11	12.8009		12.82	0.000083	1.67	1605.53	387.46	0.09
1	1065.804	2018_100yr	Design_20'	2000	1.11	11.6501		11.72	0.00028	2.83	1192.24	335.29	0.16
1	1065.804	2018_100yr	Design_12'	2000	1.11	12.3702		12.42	0.000176	2.36	1443.26	365.88	0.13
1	1065.804	2018_100yr	Design_in-kind	2000	1.11	12.8987		12.94	0.000128	2.08	1643.68	392.08	0.11
1	1065.804	2018_100yr	Design_Exist	2000	1.11	13.1287		13.16	0.000112	1.98	1735.09	402.93	0.11

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	1065.804	2018_500yr	Design_20'	2671	1.11	13.6671		13.71	0.000148	2.35	1958.88	428.33	0.12
1	1065.804	2018_500yr	Design_12'	2671	1.11	13.6671		13.71	0.000148	2.35	1958.88	428.33	0.12
1	1065.804	2018_500yr	Design_in-kind	2671	1.11	13.5154		13.56	0.000161	2.42	1894.42	421.17	0.13
1	1065.804	2018_500yr	Design_Exist	2671	1.11	13.6465		13.69	0.00015	2.36	1950.04	427.36	0.12
1	1065.804	2018_25yr_MHHW_M	Design_20'	1228	1.11	8.8213		9.01	0.000828	3.84	452.08	168.27	0.26
1	1065.804	2018_25yr_MHHW_M	Design_12'	1228	1.11	10.1108		10.2	0.00034	2.77	712.64	287.62	0.17
1	1065.804	2018_25yr_MHHW_M	Design_in-kind	1228	1.11	12.0045		12.03	0.000083	1.58	1312.99	346.37	0.09
1	1065.804	2018_25yr_MHHW_M	Design_Exist	1228	1.11	12.2091		12.23	0.000073	1.51	1384.98	357.29	0.08
1	1065.804	2018_25yr_MSL_Ma	Design_20'	1228	1.11	8.8213		9.01	0.000828	3.84	452.07	168.27	0.26
1	1065.804	2018_25yr_MSL_Ma	Design_12'	1228	1.11	9.9074		10	0.000373	2.85	660.47	215.11	0.18
1	1065.804	2018_25yr_MSL_Ma	Design_in-kind	1228	1.11	12.0088		12.03	0.000083	1.58	1314.49	346.6	0.09
1	1065.804	2018_25yr_MSL_Ma	Design_Exist	1228	1.11	12.1864		12.21	0.000074	1.51	1376.89	356.08	0.08
1	1065.804	2100_025yr_Ab1	Design_20'	1706	1.11	10.7189		10.82	0.000403	3.17	893.36	306.65	0.19
1	1065.804	2100_025yr_Ab1	Design_12'	1706	1.11	12.0698		12.11	0.000154	2.16	1335.74	349.85	0.12
1	1065.804	2100_025yr_Ab1	Design_in-kind	1706	1.11	12.6756		12.71	0.000107	1.87	1557.37	381.46	0.1
1	1065.804	2100_025yr_Ab1	Design_Exist	1706	1.11	12.7393		12.77	0.000103	1.84	1581.77	384.56	0.1
1	1065.804	2100_050yr_Ab1	Design_20'	1717	1.11	10.7646		10.87	0.000394	3.14	907.43	308.05	0.19
1	1065.804	2100_050yr_Ab1	Design_12'	1717	1.11	12.0843		12.13	0.000155	2.17	1340.82	350.63	0.12
1	1065.804	2100_050yr_Ab1	Design_in-kind	1717	1.11	12.7276		12.76	0.000105	1.86	1577.28	384.01	0.1
1	1065.804	2100_050yr_Ab1	Design_Exist	1717	1.11	12.7294		12.76	0.000105	1.86	1577.98	384.09	0.1
1	1065.804	2100_100yr_Ab1	Design_20'	2562	1.11	13.4877		13.53	0.000151	2.34	1882.78	419.87	0.12
1	1065.804	2100_100yr_Ab1	Design_12'	2562	1.11	13.4874		13.53	0.000151	2.34	1882.64	419.85	0.12
1	1065.804	2100_100yr_Ab1	Design_in-kind	2562	1.11	13.4414		13.49	0.000155	2.36	1863.41	417.68	0.12
1	1065.804	2100_100yr_Ab1	Design_Exist	2562	1.11	13.5632		13.61	0.000145	2.3	1914.64	423.43	0.12
1	1065.804	2018_025yr(Surge	Design_20'	1228	1.11	9.9915		10.09	0.000375	2.88	678.79	255.55	0.18
1	1065.804	2015_025yr(Surge	Design_12'	1228	1.11	11.4963		11.53	0.000118	1.82	1141.03	330.46	0.11
1	1065.804	2015_025yr(Surge	Design_in-kind	1228	1.11	12.2057		12.23	0.000074	1.51	1383.77	357.11	0.08
1	1065.804	2015_025yr(Surge	Design_Exist	1228	1.11	12.2004		12.22	0.000074	1.51	1381.89	356.82	0.08
1	1065.804	2018_050yr(Surge	Design_20'	1565	1.11	11.0377		11.11	0.000266	2.64	992.68	316.46	0.16
1	1065.804	2015_050yr(Surge	Design_12'	1565	1.11	12.114		12.15	0.000126	1.96	1351.23	352.21	0.11
1	1065.804	2015_050yr(Surge	Design_in-kind	1565	1.11	12.6117		12.64	0.000093	1.74	1533.11	378.22	0.1
1	1065.804	2015_050yr(Surge	Design_Exist	1565	1.11	12.8041		12.83	0.000083	1.67	1606.8	387.62	0.09
1	1065.804	015_100yr(Surge)	Design_20'	2000	1.11	11.9495		12.01	0.000229	2.62	1294.01	344.57	0.15
1	1065.804	015_100yr(Surge)	Design_12'	2000	1.11	12.6411		12.68	0.00015	2.21	1544.23	379.71	0.12
1	1065.804	015_100yr(Surge)	Design_in-kind	2000	1.11	12.9964		13.03	0.000121	2.04	1682.21	396.69	0.11
1	1065.804	015_100yr(Surge)	Design_Exist	2000	1.11	13.1266		13.16	0.000113	1.98	1734.25	402.83	0.11
1	950.2366	2018_002yr	Design_20'	232	1.6	4.9548		4.96	0.000056	0.65	359.38	116.19	0.06
1	950.2366	2018_002yr	Design_12'	232	1.6	5.052		5.06	0.000051	0.63	370.68	116.34	0.06
1	950.2366	2018_002yr	Design_in-kind	232	1.6	5.4158		5.42	0.000036	0.56	413.1	116.86	0.05
1	950.2366	2018_002yr	Design_Exist	232	1.6	6.4723		6.48	0.000015	0.43	545.75	147.09	0.04
1	950.2366	2018_010yr	Design_20'	845	1.6	7.1863		7.21	0.000121	1.34	663.77	179.93	0.1
1	950.2366	2018_010yr	Design_12'	845	1.6	7.475		7.5	0.0001	1.26	717.19	190.15	0.09
1	950.2366	2018_010yr	Design_in-kind	845	1.6	11.127		11.13	0.000013	0.64	1708.77	349.67	0.04
1	950.2366	2018_010yr	Design_Exist	845	1.6	11.4062		11.41	0.000012	0.61	1807.97	361.49	0.04
1	950.2366	2018_025y	Design_20'	1228	1.6	8.909		8.94	0.000088	1.38	1034.05	252.88	0.09
1	950.2366	2018_025y	Design_12'	1228	1.6	9.8912		9.91	0.000052	1.16	1304.93	296.1	0.07
1	950.2366	2018_025y	Design_in-kind	1228	1.6	12.0028		12.01	0.000019	0.81	2029.12	423.07	0.05
1	950.2366	2018_025y	Design_Exist	1228	1.6	12.1992		12.21	0.000017	0.79	2112.81	428.94	0.04
1	950.2366	2018_050yr	Design_20'	1565	1.6	10.293		10.32	0.000069	1.37	1429.75	320.2	0.08
1	950.2366	2018_050yr	Design_12'	1565	1.6	11.6201		11.64	0.000036	1.09	1885.99	368.02	0.06
1	950.2366	2018_050yr	Design_in-kind	1565	1.6	12.5041		12.52	0.000024	0.96	2244.97	438	0.05
1	950.2366	2018_050yr	Design_Exist	1565	1.6	12.8058		12.82	0.000021	0.91	2378.45	446.93	0.05
1	950.2366	2018_100yr	Design_20'	2000	1.6	11.672		11.7	0.000057	1.39	1905.13	369.57	0.08
1	950.2366	2018_100yr	Design_12'	2000	1.6	12.3817		12.4	0.000042	1.25	2191.6	434.36	0.07
1	950.2366	2018_100yr	Design_in-kind	2000	1.6	12.9062		12.92	0.000033	1.15	2423.5	449.92	0.06
1	950.2366	2018_100yr	Design_Exist	2000	1.6	13.1348		13.15	0.00003	1.11	2527.13	456.77	0.06
1	950.2366	2018_500yr	Design_20'	2671	1.6	13.6742		13.7	0.000043	1.37	2777.97	473.43	0.07
1	950.2366	2018_500yr	Design_12'	2671	1.6	13.6742		13.7	0.000043	1.37	2777.97	473.43	0.07
1	950.2366	2018_500yr	Design_in-kind	2671	1.6	13.5234		13.55	0.000046	1.4	2706.93	468.61	0.07
1	950.2366	2018_500yr	Design_Exist	2671	1.6	13.6537		13.68	0.000044	1.37	2768.24	472.78	0.07
1	950.2366	2018_25yr_MHHW_M	Design_20'	1228	1.6	8.909		8.94	0.000088	1.38	1034.05	252.88	0.09
1	950.2366	2018_25yr_MHHW_M	Design_12'	1228	1.6	10.1476		10.16	0.000046	1.11	1383.54	315.34	0.07
1	950.2366	2018_25yr_MHHW_M	Design_in-kind	1228	1.6	12.0102		12.02	0.000019	0.81	2032.29	423.3	0.05
1	950.2366	2018_25yr_MHHW_M	Design_Exist	1228	1.6	12.214		12.22	0.000017	0.79	2119.16	429.38	0.04
1	950.2366	2018_25yr_MSL_Ma	Design_20'	1228	1.6	8.909		8.94	0.000088	1.38	1034.05	252.88	0.09
1	950.2366	2018_25yr_MSL_Ma	Design_12'	1228	1.6	9.9465		9.96	0.00005	1.14	1321.36	298.05	0.07
1	950.2366	2018_25yr_MSL_Ma	Design_in-kind	1228	1.6	12.0145		12.02	0.000019	0.81	2034.11	423.43	0.05
1	950.2366	2018_25yr_MSL_Ma	Design_Exist	1228	1.6	12.1914		12.2	0.000017	0.79	2109.46	428.71	0.04
1	950.2366	2100_025yr_Ab1	Design_20'	1706	1.6	10.7579		10.78	0.000064	1.38	1582.25	336.02	0.08
1	950.2366	2100_025yr_Ab1	Design_12'	1706	1.6	12.0805		12.1	0.000035	1.12	2062.09	425.41	0.06
1	950.2366	2100_025yr_Ab1	Design_in-kind	1706	1.6	12.6821		12.69	0.000027	1.02	2323.39	443.27	0.05

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	950.2366	2100_025yr_Ab1	Design_Exist	1706	1.6	12.7454		12.76	0.000026	1.01	2351.54	445.14	0.05
1	950.2366	2100_050yr_Ab1	Design_20'	1717	1.6	10.8024		10.83	0.000064	1.38	1597.25	337.58	0.08
1	950.2366	2100_050yr_Ab1	Design_12'	1717	1.6	12.095		12.11	0.000035	1.12	2068.27	425.84	0.06
1	950.2366	2100_050yr_Ab1	Design_in-kind	1717	1.6	12.7339		12.75	0.000027	1.01	2346.41	444.8	0.05
1	950.2366	2100_050yr_Ab1	Design_Exist	1717	1.6	12.7357		12.75	0.000027	1.01	2347.21	444.86	0.05
1	950.2366	2100_100yr_Ab1	Design_20'	2562	1.6	13.4953		13.52	0.000043	1.35	2693.75	467.74	0.07
1	950.2366	2100_100yr_Ab1	Design_12'	2562	1.6	13.495		13.52	0.000043	1.35	2693.6	467.73	0.07
1	950.2366	2100_100yr_Ab1	Design_in-kind	2562	1.6	13.4493		13.47	0.000044	1.36	2672.28	466.34	0.07
1	950.2366	2100_100yr_Ab1	Design_Exist	2562	1.6	13.5704		13.59	0.000042	1.33	2728.96	470.12	0.07
1	950.2366	2018_025yr(Surge	Design_20'	1228	1.6	10.0284		10.05	0.000049	1.13	1346.2	311.49	0.07
1	950.2366	2015_025yr(Surge	Design_12'	1228	1.6	11.5058		11.52	0.000023	0.87	1844.12	364.61	0.05
1	950.2366	2015_025yr(Surge	Design_in-kind	1228	1.6	12.2106		12.22	0.000017	0.79	2117.71	429.28	0.04
1	950.2366	2015_025yr(Surge	Design_Exist	1228	1.6	12.2054		12.21	0.000017	0.79	2115.45	429.12	0.04
1	950.2366	2018_050yr(Surge	Design_20'	1565	1.6	11.0614		11.08	0.000047	1.2	1685.9	347.4	0.07
1	950.2366	2015_050yr(Surge	Design_12'	1565	1.6	12.1226		12.14	0.000029	1.02	2080.04	426.67	0.06
1	950.2366	2015_050yr(Surge	Design_in-kind	1565	1.6	12.6175		12.63	0.000023	0.94	2294.82	441.36	0.05
1	950.2366	2015_050yr(Surge	Design_Exist	1565	1.6	12.809		12.82	0.000021	0.91	2379.92	447.03	0.05
1	950.2366	015_100yr(Surge)	Design_20'	2000	1.6	11.9662		11.99	0.00005	1.32	2015.16	378.32	0.07
1	950.2366	015_100yr(Surge)	Design_12'	2000	1.6	12.6503		12.67	0.000037	1.2	2309.32	442.33	0.06
1	950.2366	015_100yr(Surge)	Design_in-kind	2000	1.6	13.0033		13.02	0.000032	1.13	2467.33	452.8	0.06
1	950.2366	015_100yr(Surge)	Design_Exist	2000	1.6	13.1328		13.15	0.00003	1.11	2526.18	456.71	0.06
1	892.5984	2018_002yr	Design_20'	232	1.22	4.953		4.96	0.000047	0.55	422.07	154.09	0.06
1	892.5984	2018_002yr	Design_12'	232	1.22	5.0505		5.05	0.000042	0.53	437.09	154.23	0.06
1	892.5984	2018_002yr	Design_in-kind	232	1.22	5.4149		5.42	0.000028	0.47	493.4	154.73	0.05
1	892.5984	2018_002yr	Design_Exist	232	1.22	6.4722		6.47	0.000011	0.35	657.87	156.72	0.03
1	892.5984	2018_010yr	Design_20'	845	1.22	7.1864		7.21	0.000087	1.1	779.41	190.7	0.09
1	892.5984	2018_010yr	Design_12'	845	1.22	7.4753		7.49	0.000072	1.03	836.65	205.47	0.08
1	892.5984	2018_010yr	Design_in-kind	845	1.22	11.1269		11.13	0.000011	0.56	1774.46	352.53	0.03
1	892.5984	2018_010yr	Design_Exist	845	1.22	11.4061		11.41	0.000009	0.54	1874.11	361	0.03
1	892.5984	2018_025y	Design_20'	1228	1.22	8.9099		8.93	0.000065	1.15	1153.76	227.39	0.08
1	892.5984	2018_025y	Design_12'	1228	1.22	9.8915		9.91	0.000039	0.98	1380.48	238.68	0.06
1	892.5984	2018_025y	Design_in-kind	1228	1.22	12.0025		12.01	0.000015	0.72	2094.76	457.21	0.04
1	892.5984	2018_025y	Design_Exist	1228	1.22	12.1989		12.21	0.000014	0.7	2184.93	460.77	0.04
1	892.5984	2018_050yr	Design_20'	1565	1.22	10.2931		10.31	0.000053	1.18	1497.11	307.88	0.07
1	892.5984	2018_050yr	Design_12'	1565	1.22	11.6196		11.63	0.000029	0.97	1951.88	367.32	0.06
1	892.5984	2018_050yr	Design_in-kind	1565	1.22	12.5037		12.51	0.00002	0.86	2326.19	466.3	0.05
1	892.5984	2018_050yr	Design_Exist	1565	1.22	12.8054		12.81	0.000018	0.82	2467.71	471.77	0.04
1	892.5984	2018_100yr	Design_20'	2000	1.22	11.6713		11.69	0.000046	1.23	1970.88	368.7	0.07
1	892.5984	2018_100yr	Design_12'	2000	1.22	12.3811		12.4	0.000035	1.12	2269.15	464.08	0.06
1	892.5984	2018_100yr	Design_in-kind	2000	1.22	12.9056		12.92	0.000028	1.03	2515.08	473.59	0.06
1	892.5984	2018_100yr	Design_Exist	2000	1.22	13.1343		13.15	0.000025	1	2623.84	477.77	0.05
1	892.5984	2018_500yr	Design_20'	2671	1.22	13.6734		13.69	0.000036	1.23	2884.16	487.88	0.06
1	892.5984	2018_500yr	Design_12'	2671	1.22	13.6734		13.69	0.000036	1.23	2884.15	487.88	0.06
1	892.5984	2018_500yr	Design_in-kind	2671	1.22	13.5226		13.54	0.000038	1.26	2810.76	485.05	0.07
1	892.5984	2018_500yr	Design_Exist	2671	1.22	13.6529		13.67	0.000036	1.24	2874.13	487.5	0.06
1	892.5984	2018_25yr_MHHW_M	Design_20'	1228	1.22	8.9099		8.93	0.000065	1.15	1153.77	227.39	0.08
1	892.5984	2018_25yr_MHHW_M	Design_12'	1228	1.22	10.1477		10.16	0.000035	0.95	1452.95	299.28	0.06
1	892.5984	2018_25yr_MHHW_M	Design_in-kind	1228	1.22	12.01		12.02	0.000015	0.72	2098.18	457.34	0.04
1	892.5984	2018_25yr_MHHW_M	Design_Exist	1228	1.22	12.2137		12.22	0.000014	0.7	2191.75	461.04	0.04
1	892.5984	2018_25yr_MSL_Ma	Design_20'	1228	1.22	8.9099		8.93	0.000065	1.15	1153.76	227.39	0.08
1	892.5984	2018_25yr_MSL_Ma	Design_12'	1228	1.22	9.9467		9.96	0.000038	0.98	1394.4	273.4	0.06
1	892.5984	2018_25yr_MSL_Ma	Design_in-kind	1228	1.22	12.0143		12.02	0.000015	0.72	2100.15	457.42	0.04
1	892.5984	2018_25yr_MSL_Ma	Design_Exist	1228	1.22	12.1911		12.2	0.000014	0.7	2181.33	460.63	0.04
1	892.5984	2100_025yr_Ab1	Design_20'	1706	1.22	10.7575		10.78	0.000051	1.2	1646.83	336.77	0.07
1	892.5984	2100_025yr_Ab1	Design_12'	1706	1.22	12.08		12.09	0.000029	1	2130.24	458.61	0.06
1	892.5984	2100_025yr_Ab1	Design_in-kind	1706	1.22	12.6816		12.69	0.000022	0.91	2409.44	469.53	0.05
1	892.5984	2100_025yr_Ab1	Design_Exist	1706	1.22	12.745		12.76	0.000022	0.9	2439.24	470.68	0.05
1	892.5984	2100_050yr_Ab1	Design_20'	1717	1.22	10.802		10.82	0.00005	1.2	1661.88	339.31	0.07
1	892.5984	2100_050yr_Ab1	Design_12'	1717	1.22	12.0945		12.11	0.000029	1	2136.9	458.88	0.06
1	892.5984	2100_050yr_Ab1	Design_in-kind	1717	1.22	12.7334		12.74	0.000022	0.91	2433.81	470.47	0.05
1	892.5984	2100_050yr_Ab1	Design_Exist	1717	1.22	12.7353		12.75	0.000022	0.91	2434.66	470.5	0.05
1	892.5984	2100_100yr_Ab1	Design_20'	2562	1.22	13.4945		13.51	0.000036	1.21	2797.15	484.53	0.06
1	892.5984	2100_100yr_Ab1	Design_12'	2562	1.22	13.4941		13.51	0.000036	1.21	2796.99	484.52	0.06
1	892.5984	2100_100yr_Ab1	Design_in-kind	2562	1.22	13.4485		13.47	0.000036	1.22	2774.89	483.66	0.06
1	892.5984	2100_100yr_Ab1	Design_Exist	2562	1.22	13.5696		13.59	0.000035	1.2	2833.59	485.94	0.06
1	892.5984	2018_025yr(Surge	Design_20'	1228	1.22	10.0286		10.04	0.000037	0.97	1417.76	291.83	0.06
1	892.5984	2015_025yr(Surge	Design_12'	1228	1.22	11.5055		11.51	0.000019	0.77	1910.14	364.13	0.04
1	892.5984	2015_025yr(Surge	Design_in-kind	1228	1.22	12.2104		12.22	0.000014	0.7	2190.19	460.98	0.04
1	892.5984	2015_025yr(Surge	Design_Exist	1228	1.22	12.2051		12.21	0.000014	0.7	2187.77	460.89	0.04
1	892.5984	2018_050yr(Surge	Design_20'	1565	1.22	11.061		11.08	0.000037	1.05	1751.31	350.44	0.06
1	892.5984	2015_050yr(Surge	Design_12'	1565	1.22	12.1222		12.13	0.000024	0.91	2149.61	459.38	0.05

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	892.5984	2015_050yr(Surge	Design_in-kind	1565	1.22	12.6171		12.63	0.000019	0.84	2379.19	468.36	0.05
1	892.5984	2015_050yr(Surge	Design_Exist	1565	1.22	12.8087		12.82	0.000018	0.82	2469.25	471.83	0.04
1	892.5984	015_100yr(Surge)	Design_20'	2000	1.22	11.9654		11.98	0.000041	1.18	2080.48	376.36	0.07
1	892.5984	015_100yr(Surge)	Design_12'	2000	1.22	12.6497		12.67	0.000031	1.07	2394.46	468.95	0.06
1	892.5984	015_100yr(Surge)	Design_in-kind	2000	1.22	13.0028		13.02	0.000027	1.02	2561.17	475.35	0.05
1	892.5984	015_100yr(Surge)	Design_Exist	2000	1.22	13.1322		13.15	0.000025	1	2622.85	477.73	0.05
1	816.2677	2018_002yr	Design_20'	232	1.23	4.9512		4.95	0.00003	0.44	522.64	185.84	0.05
1	816.2677	2018_002yr	Design_12'	232	1.23	5.0489		5.05	0.000027	0.43	540.81	186.11	0.04
1	816.2677	2018_002yr	Design_in-kind	232	1.23	5.414		5.42	0.000018	0.38	608.94	187.12	0.04
1	816.2677	2018_002yr	Design_Exist	232	1.23	6.472		6.47	0.000007	0.29	808.22	190.56	0.02
1	816.2677	2018_010yr	Design_20'	845	1.23	7.1853		7.2	0.000057	0.89	956.05	225.69	0.07
1	816.2677	2018_010yr	Design_12'	845	1.23	7.4746		7.49	0.000047	0.84	1022.42	233.07	0.07
1	816.2677	2018_010yr	Design_in-kind	845	1.23	11.1272		11.13	0.000007	0.46	2110.23	386.77	0.03
1	816.2677	2018_010yr	Design_Exist	845	1.23	11.4064		11.41	0.000006	0.45	2220.56	403.63	0.03
1	816.2677	2018_025y	Design_20'	1228	1.23	8.9103		8.92	0.000043	0.94	1387.42	278.46	0.06
1	816.2677	2018_025y	Design_12'	1228	1.23	9.8922		9.9	0.000026	0.81	1677.28	313.63	0.05
1	816.2677	2018_025y	Design_in-kind	1228	1.23	12.0031		12.01	0.00001	0.6	2478.17	481.56	0.03
1	816.2677	2018_025y	Design_Exist	1228	1.23	12.1995		12.2	0.00001	0.58	2573.18	485.96	0.03
1	816.2677	2018_050yr	Design_20'	1565	1.23	10.2944		10.31	0.000035	0.97	1808.9	337.93	0.06
1	816.2677	2018_050yr	Design_12'	1565	1.23	11.6206		11.63	0.00002	0.8	2308.59	423.42	0.05
1	816.2677	2018_050yr	Design_in-kind	1565	1.23	12.5046		12.51	0.000014	0.71	2722.46	492.78	0.04
1	816.2677	2018_050yr	Design_Exist	1565	1.23	12.8062		12.81	0.000012	0.68	2872.11	499.53	0.04
1	816.2677	2018_100yr	Design_20'	2000	1.23	11.6728		11.69	0.000032	1.02	2330.84	428.79	0.06
1	816.2677	2018_100yr	Design_12'	2000	1.23	12.3825		12.39	0.000024	0.92	2662.49	490.05	0.05
1	816.2677	2018_100yr	Design_in-kind	2000	1.23	12.9069		12.92	0.000019	0.85	2922.52	501.79	0.05
1	816.2677	2018_100yr	Design_Exist	2000	1.23	13.1354		13.14	0.000017	0.83	3037.8	506.92	0.04
1	816.2677	2018_500yr	Design_20'	2671	1.23	13.6751		13.69	0.000025	1.03	3314.66	519.03	0.05
1	816.2677	2018_500yr	Design_12'	2671	1.23	13.6751		13.69	0.000025	1.03	3314.65	519.03	0.05
1	816.2677	2018_500yr	Design_in-kind	2671	1.23	13.5244		13.54	0.000026	1.05	3236.65	515.65	0.06
1	816.2677	2018_500yr	Design_Exist	2671	1.23	13.6546		13.67	0.000025	1.03	3304	518.57	0.05
1	816.2677	2018_25yr_MHHW_M	Design_20'	1228	1.23	8.9103		8.92	0.000043	0.94	1387.43	278.46	0.06
1	816.2677	2018_25yr_MHHW_M	Design_12'	1228	1.23	10.1485		10.16	0.000023	0.78	1760.07	331.67	0.05
1	816.2677	2018_25yr_MHHW_M	Design_in-kind	1228	1.23	12.0106		12.02	0.00001	0.6	2481.77	481.73	0.03
1	816.2677	2018_25yr_MHHW_M	Design_Exist	1228	1.23	12.2143		12.22	0.00001	0.58	2580.37	486.29	0.03
1	816.2677	2018_25yr_MSL_Ma	Design_20'	1228	1.23	8.9103		8.92	0.000043	0.94	1387.42	278.46	0.06
1	816.2677	2018_25yr_MSL_Ma	Design_12'	1228	1.23	9.9475		9.96	0.000026	0.8	1694.68	315.54	0.05
1	816.2677	2018_25yr_MSL_Ma	Design_in-kind	1228	1.23	12.0149		12.02	0.00001	0.6	2483.84	481.82	0.03
1	816.2677	2018_25yr_MSL_Ma	Design_Exist	1228	1.23	12.1917		12.2	0.00001	0.58	2569.39	485.78	0.03
1	816.2677	2100_025yr_Ab1	Design_20'	1706	1.23	10.759		10.77	0.000034	0.99	1971.89	364.67	0.06
1	816.2677	2100_025yr_Ab1	Design_12'	1706	1.23	12.0811		12.09	0.000019	0.82	2515.8	483.31	0.05
1	816.2677	2100_025yr_Ab1	Design_in-kind	1706	1.23	12.6826		12.69	0.000015	0.75	2810.54	496.77	0.04
1	816.2677	2100_025yr_Ab1	Design_Exist	1706	1.23	12.7459		12.75	0.000015	0.75	2842.06	498.18	0.04
1	816.2677	2100_050yr_Ab1	Design_20'	1717	1.23	10.8035		10.82	0.000034	0.99	1988.18	367.34	0.06
1	816.2677	2100_050yr_Ab1	Design_12'	1717	1.23	12.0956		12.11	0.00002	0.83	2522.83	483.63	0.05
1	816.2677	2100_050yr_Ab1	Design_in-kind	1717	1.23	12.7344		12.74	0.000015	0.75	2836.32	497.93	0.04
1	816.2677	2100_050yr_Ab1	Design_Exist	1717	1.23	12.7362		12.74	0.000015	0.75	2837.22	497.97	0.04
1	816.2677	2100_100yr_Ab1	Design_20'	2562	1.23	13.4961		13.51	0.000025	1.01	3222.11	515.02	0.05
1	816.2677	2100_100yr_Ab1	Design_12'	2562	1.23	13.4958		13.51	0.000025	1.01	3221.95	515.01	0.05
1	816.2677	2100_100yr_Ab1	Design_in-kind	2562	1.23	13.4502		13.46	0.000025	1.02	3198.47	513.99	0.05
1	816.2677	2100_100yr_Ab1	Design_Exist	2562	1.23	13.5712		13.58	0.000024	1	3260.84	516.7	0.05
1	816.2677	2018_025yr(Surge	Design_20'	1228	1.23	10.0294		10.04	0.000025	0.79	1720.89	326.22	0.05
1	816.2677	2015_025yr(Surge	Design_12'	1228	1.23	11.5061		11.51	0.000013	0.64	2261.13	409.99	0.04
1	816.2677	2015_025yr(Surge	Design_in-kind	1228	1.23	12.2109		12.22	0.00001	0.58	2578.73	486.21	0.03
1	816.2677	2015_025yr(Surge	Design_Exist	1228	1.23	12.2057		12.21	0.00001	0.58	2576.18	486.09	0.03
1	816.2677	2018_050yr(Surge	Design_20'	1565	1.23	11.0622		11.07	0.000025	0.87	2085.2	382.87	0.05
1	816.2677	2015_050yr(Surge	Design_12'	1565	1.23	12.1231		12.13	0.000016	0.75	2536.13	484.25	0.04
1	816.2677	2015_050yr(Surge	Design_in-kind	1565	1.23	12.6179		12.62	0.000013	0.7	2778.46	495.32	0.04
1	816.2677	2015_050yr(Surge	Design_Exist	1565	1.23	12.8095		12.82	0.000012	0.68	2873.75	499.61	0.04
1	816.2677	015_100yr(Surge)	Design_20'	2000	1.23	11.9669		11.98	0.000028	0.98	2461.36	458.71	0.06
1	816.2677	015_100yr(Surge)	Design_12'	2000	1.23	12.651		12.66	0.000021	0.89	2794.87	496.06	0.05
1	816.2677	015_100yr(Surge)	Design_in-kind	2000	1.23	13.004		13.01	0.000018	0.84	2971.35	503.96	0.05
1	816.2677	015_100yr(Surge)	Design_Exist	2000	1.23	13.1334		13.14	0.000017	0.83	3036.75	506.87	0.04
1	742.3986	2018_002yr	Design_20'	232	0.93	4.9462		4.95	0.000044	0.58	402.92	128.34	0.06
1	742.3986	2018_002yr	Design_12'	232	0.93	5.0443		5.05	0.00004	0.56	415.51	128.53	0.05
1	742.3986	2018_002yr	Design_in-kind	232	0.93	5.4105		5.41	0.000028	0.5	462.75	129.68	0.05
1	742.3986	2018_002yr	Design_Exist	232	0.93	6.4702		6.47	0.000012	0.38	603.02	135.08	0.03
1	742.3986	2018_010yr	Design_20'	845	0.93	7.1682		7.19	0.000103	1.21	704.04	158.75	0.09
1	742.3986	2018_010yr	Design_12'	845	0.93	7.4598		7.48	0.000086	1.14	751.7	168.19	0.09
1	742.3986	2018_010yr	Design_in-kind	845	0.93	11.1246		11.13	0.000012	0.6	1792.94	467.96	0.03
1	742.3986	2018_010yr	Design_Exist	845	0.93	11.4042		11.41	0.00001	0.57	1927.53	493.8	0.03

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	742.3986	2018_025y	Design_20'	1228	0.93	8.8934		8.92	0.000079	1.28	1029.43	225.22	0.09
1	742.3986	2018_025y	Design_12'	1228	0.93	9.8812		9.9	0.000047	1.08	1285.28	294.8	0.07
1	742.3986	2018_025y	Design_in-kind	1228	0.93	12.0001		12.01	0.000016	0.73	2230.09	521.49	0.04
1	742.3986	2018_025y	Design_Exist	1228	0.93	12.1969		12.2	0.000014	0.71	2333.09	525.29	0.04
1	742.3986	2018_050yr	Design_20'	1565	0.93	10.2794		10.3	0.000063	1.29	1429.69	402.77	0.08
1	742.3986	2018_050yr	Design_12'	1565	0.93	11.6141		11.63	0.000031	1.01	2032.21	503.85	0.06
1	742.3986	2018_050yr	Design_in-kind	1565	0.93	12.5011		12.51	0.00002	0.85	2493.79	531.15	0.05
1	742.3986	2018_050yr	Design_Exist	1565	0.93	12.8034		12.81	0.000017	0.8	2655.24	536.99	0.04
1	742.3986	2018_100yr	Design_20'	2000	0.93	11.6625		11.68	0.000049	1.27	2056.66	506.06	0.07
1	742.3986	2018_100yr	Design_12'	2000	0.93	12.3764		12.39	0.000034	1.11	2427.69	528.74	0.06
1	742.3986	2018_100yr	Design_in-kind	2000	0.93	12.9026		12.92	0.000026	1	2708.62	538.91	0.05
1	742.3986	2018_100yr	Design_Exist	2000	0.93	13.1318		13.14	0.000023	0.96	2832.64	543.33	0.05
1	742.3986	2018_500yr	Design_20'	2671	0.93	13.6708		13.69	0.000032	1.17	3128.48	554.9	0.06
1	742.3986	2018_500yr	Design_12'	2671	0.93	13.6707		13.69	0.000032	1.17	3128.47	554.9	0.06
1	742.3986	2018_500yr	Design_in-kind	2671	0.93	13.5195		13.54	0.000035	1.2	3044.79	551.53	0.06
1	742.3986	2018_500yr	Design_Exist	2671	0.93	13.6501		13.67	0.000033	1.18	3117.04	554.44	0.06
1	742.3986	2018_25yr_MHHW_M	Design_20'	1228	0.93	8.8934		8.92	0.000079	1.28	1029.43	225.22	0.09
1	742.3986	2018_25yr_MHHW_M	Design_12'	1228	0.93	10.1385		10.15	0.000042	1.04	1373.51	395.04	0.06
1	742.3986	2018_25yr_MHHW_M	Design_in-kind	1228	0.93	12.0076		12.01	0.000016	0.73	2233.99	521.64	0.04
1	742.3986	2018_25yr_MHHW_M	Design_Exist	1228	0.93	12.2117		12.22	0.000014	0.7	2340.88	525.57	0.04
1	742.3986	2018_25yr_MSL_Ma	Design_20'	1228	0.93	8.8934		8.92	0.000079	1.28	1029.43	225.22	0.09
1	742.3986	2018_25yr_MSL_Ma	Design_12'	1228	0.93	9.9368		9.95	0.000046	1.07	1301.76	298.53	0.07
1	742.3986	2018_25yr_MSL_Ma	Design_in-kind	1228	0.93	12.0119		12.02	0.000015	0.73	2236.24	521.72	0.04
1	742.3986	2018_25yr_MSL_Ma	Design_Exist	1228	0.93	12.1891		12.2	0.000014	0.71	2328.98	525.13	0.04
1	742.3986	2100_025yr_Ab1	Design_20'	1706	0.93	10.7455		10.77	0.000058	1.29	1623.56	429.29	0.08
1	742.3986	2100_025yr_Ab1	Design_12'	1706	0.93	12.0756		12.09	0.000029	1	2269.51	522.95	0.06
1	742.3986	2100_025yr_Ab1	Design_in-kind	1706	0.93	12.679		12.69	0.000021	0.89	2588.57	534.58	0.05
1	742.3986	2100_025yr_Ab1	Design_Exist	1706	0.93	12.7425		12.75	0.000021	0.88	2622.56	535.81	0.05
1	742.3986	2100_050yr_Ab1	Design_20'	1717	0.93	10.7902		10.81	0.000057	1.29	1642.81	431.86	0.08
1	742.3986	2100_050yr_Ab1	Design_12'	1717	0.93	12.0901		12.1	0.000029	1.01	2277.1	523.23	0.06
1	742.3986	2100_050yr_Ab1	Design_in-kind	1717	0.93	12.7309		12.74	0.000021	0.89	2616.35	535.59	0.05
1	742.3986	2100_050yr_Ab1	Design_Exist	1717	0.93	12.7327		12.74	0.000021	0.89	2617.32	535.62	0.05
1	742.3986	2100_100yr_Ab1	Design_20'	2562	0.93	13.4916		13.51	0.000032	1.16	3029.4	550.91	0.06
1	742.3986	2100_100yr_Ab1	Design_12'	2562	0.93	13.4912		13.51	0.000032	1.16	3029.23	550.9	0.06
1	742.3986	2100_100yr_Ab1	Design_in-kind	2562	0.93	13.4455		13.46	0.000033	1.17	3004.03	549.88	0.06
1	742.3986	2100_100yr_Ab1	Design_Exist	2562	0.93	13.5669		13.58	0.000031	1.14	3070.96	552.59	0.06
1	742.3986	2018_025yr(Surge	Design_20'	1228	0.93	10.0191		10.04	0.000044	1.06	1327.32	353.23	0.07
1	742.3986	2015_025yr(Surge	Design_12'	1228	0.93	11.5018		11.51	0.00002	0.81	1975.94	498.47	0.05
1	742.3986	2015_025yr(Surge	Design_in-kind	1228	0.93	12.2083		12.21	0.000014	0.7	2339.11	525.51	0.04
1	742.3986	2015_025yr(Surge	Design_Exist	1228	0.93	12.2031		12.21	0.000014	0.7	2336.34	525.4	0.04
1	742.3986	2018_050yr(Surge	Design_20'	1565	0.93	11.0527		11.07	0.000042	1.12	1759.56	460.88	0.07
1	742.3986	2015_050yr(Surge	Design_12'	1565	0.93	12.1186		12.13	0.000024	0.91	2292.04	523.78	0.05
1	742.3986	2015_050yr(Surge	Design_in-kind	1565	0.93	12.6148		12.62	0.000018	0.83	2554.27	533.34	0.05
1	742.3986	2015_050yr(Surge	Design_Exist	1565	0.93	12.8067		12.81	0.000017	0.8	2657	537.05	0.04
1	742.3986	015_100yr(Surge)	Design_20'	2000	0.93	11.9585		11.98	0.000042	1.2	2208.45	519.7	0.07
1	742.3986	015_100yr(Surge)	Design_12'	2000	0.93	12.6459		12.66	0.00003	1.05	2570.92	533.94	0.06
1	742.3986	015_100yr(Surge)	Design_in-kind	2000	0.93	13		13.01	0.000025	0.99	2761.19	540.8	0.05
1	742.3986	015_100yr(Surge)	Design_Exist	2000	0.93	13.1298		13.14	0.000023	0.96	2831.51	543.29	0.05
1	607.5615	2018_002yr	Design_20'	232	0.79	4.917	2.16	4.94	0.000176	1.19	195.67	57.77	0.11
1	607.5615	2018_002yr	Design_12'	232	0.79	5.0171	2.16	5.04	0.000161	1.15	201.46	57.96	0.11
1	607.5615	2018_002yr	Design_in-kind	232	0.79	5.3893	2.16	5.41	0.000117	1.04	223.16	58.66	0.09
1	607.5615	2018_002yr	Design_Exist	232	0.79	6.4584	2.16	6.47	0.000053	0.81	287.36	63	0.07
1	607.5615	2018_010yr	Design_20'	845	0.79	7.0496	3.34	7.16	0.000486	2.61	327.87	84.18	0.2
1	607.5615	2018_010yr	Design_12'	845	0.79	7.3569	3.34	7.45	0.000399	2.46	355.85	95.16	0.18
1	607.5615	2018_010yr	Design_in-kind	845	0.79	11.1034	3.34	11.12	0.000053	1.26	884.97	400.59	0.07
1	607.5615	2018_010yr	Design_Exist	845	0.79	11.3851	3.34	11.4	0.000047	1.21	935.47	429.37	0.07
1	607.5615	2018_025y	Design_20'	1228	0.79	8.7781	3.89	8.89	0.000366	2.74	515.4	129.62	0.18
1	607.5615	2018_025y	Design_12'	1228	0.79	9.8061	3.89	9.88	0.000213	2.29	664.15	159.74	0.14
1	607.5615	2018_025y	Design_in-kind	1228	0.79	11.9669	3.89	12	0.000077	1.6	1042.9	514.83	0.09
1	607.5615	2018_025y	Design_Exist	1228	0.79	12.1658	3.89	12.2	0.00007	1.56	1080.7	554.6	0.08
1	607.5615	2018_050yr	Design_20'	1565	0.79	10.1745	4.34	10.28	0.000287	2.73	724.72	303.89	0.17
1	607.5615	2018_050yr	Design_12'	1565	0.79	11.552	4.34	11.61	0.000149	2.18	965.85	446.91	0.12
1	607.5615	2018_050yr	Design_in-kind	1565	0.79	12.4789	4.34	12.5	0.000066	1.54	1745.35	565.89	0.08
1	607.5615	2018_050yr	Design_Exist	1565	0.79	12.7861	4.34	12.81	0.000053	1.41	1920.86	576.69	0.07
1	607.5615	2018_100yr	Design_20'	2000	0.79	11.5613	4.87	11.66	0.000242	2.78	967.54	447.89	0.16
1	607.5615	2018_100yr	Design_12'	2000	0.79	12.3354	4.87	12.38	0.00012	2.05	1664.53	560.85	0.11
1	607.5615	2018_100yr	Design_in-kind	2000	0.79	12.8763	4.87	12.91	0.000082	1.76	1973.01	579.87	0.09
1	607.5615	2018_100yr	Design_Exist	2000	0.79	13.1099	4.87	13.14	0.00007	1.65	2109.44	588.11	0.09
1	607.5615	2018_500yr	Design_20'	2671	0.79	13.6445	5.6	13.68	0.000089	1.91	2428.36	604.9	0.1
1	607.5615	2018_500yr	Design_12'	2671	0.79	13.6445	5.6	13.68	0.000089	1.91	2428.35	604.9	0.1
1	607.5615	2018_500yr	Design_in-kind	2671	0.79	13.4901	5.6	13.53	0.000098	1.99	2335.31	600.05	0.1

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	607.5615	2018_500yr	Design_Exist	2671	0.79	13.6235	5.6	13.66	0.00009	1.92	2415.65	604.24	0.1
1	607.5615	2018_25yr_MHHW_M	Design_20'	1228	0.79	8.7781	3.89	8.89	0.000366	2.74	515.4	129.62	0.18
1	607.5615	2018_25yr_MHHW_M	Design_12'	1228	0.79	10.0713	3.89	10.14	0.000187	2.18	707.5	293.82	0.13
1	607.5615	2018_25yr_MHHW_M	Design_in-kind	1228	0.79	11.9745	3.89	12.01	0.000076	1.6	1044.33	518.35	0.09
1	607.5615	2018_25yr_MHHW_M	Design_Exist	1228	0.79	12.1808	3.89	12.21	0.00007	1.55	1083.58	555.53	0.08
1	607.5615	2018_25yr_MSL_Ma	Design_20'	1228	0.79	8.7781	3.89	8.89	0.000366	2.74	515.4	129.62	0.18
1	607.5615	2018_25yr_MSL_Ma	Design_12'	1228	0.79	9.8633	3.89	9.94	0.000207	2.26	673.35	161.41	0.14
1	607.5615	2018_25yr_MSL_Ma	Design_in-kind	1228	0.79	11.9789	3.89	12.01	0.000076	1.6	1045.15	519.31	0.09
1	607.5615	2018_25yr_MSL_Ma	Design_Exist	1228	0.79	12.1579	3.89	12.19	0.000071	1.56	1079.18	553.56	0.09
1	607.5615	2100_025yr_Ab1	Design_20'	1706	0.79	10.6421	4.52	10.75	0.000271	2.75	804.19	352.51	0.16
1	607.5615	2100_025yr_Ab1	Design_12'	1706	0.79	12.0125	4.52	12.08	0.000145	2.21	1051.5	535.14	0.12
1	607.5615	2100_025yr_Ab1	Design_in-kind	1706	0.79	12.6561	4.52	12.68	0.000069	1.6	1846.19	572.12	0.08
1	607.5615	2100_025yr_Ab1	Design_Exist	1706	0.79	12.7208	4.52	12.75	0.000066	1.57	1883.27	574.4	0.08
1	607.5615	2100_050yr_Ab1	Design_20'	1717	0.79	10.6873	4.53	10.79	0.000268	2.75	812	357.25	0.16
1	607.5615	2100_050yr_Ab1	Design_12'	1717	0.79	12.0265	4.53	12.09	0.000146	2.22	1054.15	537.14	0.12
1	607.5615	2100_050yr_Ab1	Design_in-kind	1717	0.79	12.7087	4.53	12.73	0.000068	1.58	1876.33	573.97	0.08
1	607.5615	2100_050yr_Ab1	Design_Exist	1717	0.79	12.7105	4.53	12.74	0.000068	1.58	1877.39	574.03	0.08
1	607.5615	2100_100yr_Ab1	Design_20'	2562	0.79	13.464	5.49	13.5	0.000091	1.92	2319.67	599.23	0.1
1	607.5615	2100_100yr_Ab1	Design_12'	2562	0.79	13.4637	5.49	13.5	0.000091	1.92	2319.47	599.22	0.1
1	607.5615	2100_100yr_Ab1	Design_in-kind	2562	0.79	13.4169	5.49	13.45	0.000094	1.94	2291.49	597.75	0.1
1	607.5615	2100_100yr_Ab1	Design_Exist	2562	0.79	13.5408	5.49	13.57	0.000087	1.88	2365.81	601.65	0.1
1	607.5615	2018_025yr(Surge	Design_20'	1228	0.79	9.9482	3.89	10.02	0.000199	2.23	687.15	163.88	0.14
1	607.5615	2015_025yr(Surge	Design_12'	1228	0.79	11.4624	3.89	11.5	0.000095	1.73	949.5	437.5	0.1
1	607.5615	2015_025yr(Surge	Design_in-kind	1228	0.79	12.1774	3.89	12.21	0.00007	1.56	1082.92	555.41	0.08
1	607.5615	2015_025yr(Surge	Design_Exist	1228	0.79	12.172	3.89	12.2	0.00007	1.56	1081.9	555.22	0.08
1	607.5615	2018_050yr(Surge	Design_20'	1565	0.79	10.9763	4.34	11.05	0.000194	2.39	862.48	387.4	0.14
1	607.5615	2015_050yr(Surge	Design_12'	1565	0.79	12.0665	4.34	12.12	0.000119	2.01	1061.74	541.94	0.11
1	607.5615	2015_050yr(Surge	Design_in-kind	1565	0.79	12.5945	4.34	12.62	0.000061	1.49	1811.03	569.96	0.08
1	607.5615	2015_050yr(Surge	Design_Exist	1565	0.79	12.7894	4.34	12.81	0.000053	1.41	1922.78	576.81	0.07
1	607.5615	015_100yr(Surge)	Design_20'	2000	0.79	11.8674	4.87	11.96	0.000212	2.65	1024.2	490.94	0.15
1	607.5615	015_100yr(Surge)	Design_12'	2000	0.79	12.6134	4.87	12.65	0.000098	1.89	1821.77	570.62	0.1
1	607.5615	015_100yr(Surge)	Design_in-kind	2000	0.79	12.9757	4.87	13	0.000077	1.71	2030.81	583.39	0.09
1	607.5615	015_100yr(Surge)	Design_Exist	2000	0.79	13.1078	4.87	13.13	0.00007	1.65	2108.2	588.04	0.09
1	550.7734	2018_002yr	Design_20'	232	0.88	4.9164	2.06	4.93	0.000099	0.87	266.23	82.51	0.09
1	550.7734	2018_002yr	Design_12'	232	0.88	5.0168	2.06	5.03	0.000089	0.85	274.52	82.73	0.08
1	550.7734	2018_002yr	Design_in-kind	232	0.88	5.3898	2.06	5.4	0.000064	0.76	305.53	83.55	0.07
1	550.7734	2018_002yr	Design_Exist	232	0.88	6.4595	2.06	6.46	0.000028	0.59	399.36	98.47	0.05
1	550.7734	2018_010yr	Design_20'	845	0.88	7.0661	3.1	7.12	0.000251	1.87	463.37	117.91	0.15
1	550.7734	2018_010yr	Design_12'	845	0.88	7.373	3.1	7.42	0.000204	1.75	503.44	140.19	0.13
1	550.7734	2018_010yr	Design_in-kind	845	0.88	11.1111	3.1	11.12	0.000021	0.79	1498.46	482.66	0.05
1	550.7734	2018_010yr	Design_Exist	845	0.88	11.3925	3.1	11.4	0.000017	0.74	1635.91	493.52	0.04
1	550.7734	2018_025y	Design_20'	1228	0.88	8.8059	3.55	8.86	0.000172	1.88	741.68	190.46	0.13
1	550.7734	2018_025y	Design_12'	1228	0.88	9.8275	3.55	9.86	0.000095	1.53	953.75	290.34	0.1
1	550.7734	2018_025y	Design_in-kind	1228	0.88	11.9811	3.55	11.99	0.000025	0.92	1932.07	512.82	0.05
1	550.7734	2018_025y	Design_Exist	1228	0.88	12.1795	3.55	12.19	0.000022	0.88	2034.5	520.23	0.05
1	550.7734	2018_050yr	Design_20'	1565	0.88	10.2062	3.89	10.25	0.000125	1.81	1040.92	386.78	0.11
1	550.7734	2018_050yr	Design_12'	1565	0.88	11.5769	3.89	11.6	0.000053	1.3	1727.45	499.48	0.07
1	550.7734	2018_050yr	Design_in-kind	1565	0.88	12.4856	3.89	12.5	0.00003	1.05	2195.68	533.11	0.06
1	550.7734	2018_050yr	Design_Exist	1565	0.88	12.791	3.89	12.8	0.000025	0.98	2360.76	548.28	0.05
1	550.7734	2018_100yr	Design_20'	2000	0.88	11.6022	4.3	11.63	0.000085	1.65	1740.13	500.3	0.09
1	550.7734	2018_100yr	Design_12'	2000	0.88	12.3481	4.3	12.37	0.000053	1.38	2122.78	527.09	0.08
1	550.7734	2018_100yr	Design_in-kind	2000	0.88	12.8836	4.3	12.9	0.000039	1.22	2411.77	553.37	0.07
1	550.7734	2018_100yr	Design_Exist	2000	0.88	13.1157	4.3	13.13	0.000035	1.17	2542.17	571.42	0.06
1	550.7734	2018_500yr	Design_20'	2671	0.88	13.6507	4.89	13.67	0.000046	1.39	2865.59	627.43	0.07
1	550.7734	2018_500yr	Design_12'	2671	0.88	13.6507	4.89	13.67	0.000046	1.39	2865.59	627.42	0.07
1	550.7734	2018_500yr	Design_in-kind	2671	0.88	13.4972	4.89	13.52	0.00005	1.44	2769.99	617.69	0.07
1	550.7734	2018_500yr	Design_Exist	2671	0.88	13.6298	4.89	13.65	0.000047	1.4	2852.49	626.13	0.07
1	550.7734	2018_25yr_MHHW_M	Design_20'	1228	0.88	8.8059	3.55	8.86	0.000172	1.88	741.68	190.46	0.13
1	550.7734	2018_25yr_MHHW_M	Design_12'	1228	0.88	10.0912	3.55	10.12	0.000082	1.46	1014.04	372.4	0.09
1	550.7734	2018_25yr_MHHW_M	Design_in-kind	1228	0.88	11.9887	3.55	12	0.000025	0.92	1935.95	513.05	0.05
1	550.7734	2018_25yr_MHHW_M	Design_Exist	1228	0.88	12.1944	3.55	12.2	0.000022	0.88	2042.27	520.8	0.05
1	550.7734	2018_25yr_MSL_Ma	Design_20'	1228	0.88	8.8059	3.55	8.86	0.000172	1.88	741.68	190.46	0.13
1	550.7734	2018_25yr_MSL_Ma	Design_12'	1228	0.88	9.8845	3.55	9.92	0.000092	1.52	966.58	300.02	0.09
1	550.7734	2018_25yr_MSL_Ma	Design_in-kind	1228	0.88	11.993	3.55	12	0.000025	0.92	1938.18	513.18	0.05
1	550.7734	2018_25yr_MSL_Ma	Design_Exist	1228	0.88	12.1716	3.55	12.18	0.000022	0.88	2030.4	519.93	0.05
1	550.7734	2100_025yr_Ab1	Design_20'	1706	0.88	10.6747	4.03	10.72	0.000115	1.81	1153.33	443.61	0.11
1	550.7734	2100_025yr_Ab1	Design_12'	1706	0.88	12.0396	4.03	12.06	0.000047	1.27	1962.14	514.9	0.07
1	550.7734	2100_025yr_Ab1	Design_in-kind	1706	0.88	12.6628	4.03	12.68	0.000032	1.1	2290.88	541.71	0.06
1	550.7734	2100_025yr_Ab1	Design_Exist	1706	0.88	12.727	4.03	12.74	0.000031	1.08	2325.79	544.91	0.06
1	550.7734	2100_050yr_Ab1	Design_20'	1717	0.88	10.7198	4.04	10.76	0.000114	1.8	1164.41	448.63	0.11
1	550.7734	2100_050yr_Ab1	Design_12'	1717	0.88	12.0539	4.04	12.07	0.000047	1.27	1969.49	515.44	0.07

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	550.7734	2100_050yr_Ab1	Design_in-kind	1717	0.88	12.7151	4.04	12.73	0.000032	1.09	2319.29	544.28	0.06
1	550.7734	2100_050yr_Ab1	Design_Exist	1717	0.88	12.7169	4.04	12.73	0.000032	1.09	2320.29	544.37	0.06
1	550.7734	2100_100yr_Ab1	Design_20'	2562	0.88	13.4707	4.79	13.49	0.000047	1.39	2753.65	615.78	0.07
1	550.7734	2100_100yr_Ab1	Design_12'	2562	0.88	13.4704	4.79	13.49	0.000047	1.39	2753.45	615.76	0.07
1	550.7734	2100_100yr_Ab1	Design_in-kind	2562	0.88	13.4239	4.79	13.44	0.000048	1.4	2724.92	612.41	0.07
1	550.7734	2100_100yr_Ab1	Design_Exist	2562	0.88	13.5471	4.79	13.57	0.000045	1.37	2800.9	621.01	0.07
1	550.7734	2018_025yr(Surge	Design_20'	1228	0.88	9.9688	3.55	10	0.000088	1.49	985.78	323.15	0.09
1	550.7734	2015_025yr(Surge	Design_12'	1228	0.88	11.4779	3.55	11.49	0.000035	1.05	1678.19	496.28	0.06
1	550.7734	2015_025yr(Surge	Design_in-kind	1228	0.88	12.191	3.55	12.2	0.000022	0.88	2040.5	520.67	0.05
1	550.7734	2015_025yr(Surge	Design_Exist	1228	0.88	12.1857	3.55	12.19	0.000022	0.88	2037.74	520.46	0.05
1	550.7734	2018_050yr(Surge	Design_20'	1565	0.88	11.0032	3.89	11.03	0.000077	1.51	1446.64	478.04	0.09
1	550.7734	2015_050yr(Surge	Design_12'	1565	0.88	12.0891	3.89	12.1	0.000038	1.15	1987.65	516.78	0.06
1	550.7734	2015_050yr(Surge	Design_in-kind	1565	0.88	12.6005	3.89	12.61	0.000028	1.02	2257.23	538.52	0.06
1	550.7734	2015_050yr(Surge	Design_Exist	1565	0.88	12.7943	3.89	12.8	0.000025	0.98	2362.57	548.46	0.05
1	550.7734	015_100yr(Surge)	Design_20'	2000	0.88	11.9061	4.3	11.93	0.00007	1.53	1893.69	510.53	0.09
1	550.7734	015_100yr(Surge)	Design_12'	2000	0.88	12.6229	4.3	12.64	0.000045	1.3	2269.33	539.89	0.07
1	550.7734	015_100yr(Surge)	Design_in-kind	2000	0.88	12.9823	4.3	13	0.000037	1.2	2466.67	559.41	0.06
1	550.7734	015_100yr(Surge)	Design_Exist	2000	0.88	13.1136	4.3	13.13	0.000035	1.17	2540.97	571.25	0.06
1	487.0596	2018_002yr	Design_20'	232	0.59	4.9109		4.92	0.000089	0.84	276.14	83.58	0.08
1	487.0596	2018_002yr	Design_12'	232	0.59	5.0118		5.02	0.000081	0.82	284.58	83.69	0.08
1	487.0596	2018_002yr	Design_in-kind	232	0.59	5.3862		5.39	0.000058	0.73	315.98	84.08	0.07
1	487.0596	2018_002yr	Design_Exist	232	0.59	6.458		6.46	0.000026	0.57	406.76	85.78	0.05
1	487.0596	2018_010yr	Design_20'	845	0.59	7.0506		7.1	0.000239	1.84	459.9	106.05	0.14
1	487.0596	2018_010yr	Design_12'	845	0.59	7.3601		7.41	0.000196	1.73	499.33	151.06	0.13
1	487.0596	2018_010yr	Design_in-kind	845	0.59	11.1115		11.12	0.000016	0.69	1747.88	517.24	0.04
1	487.0596	2018_010yr	Design_Exist	845	0.59	11.3929		11.4	0.000013	0.64	1895.04	528.38	0.04
1	487.0596	2018_025y	Design_20'	1228	0.59	8.7969		8.85	0.000161	1.84	795.93	291.05	0.12
1	487.0596	2018_025y	Design_12'	1228	0.59	9.8257		9.85	0.000081	1.43	1142.13	374.42	0.09
1	487.0596	2018_025y	Design_in-kind	1228	0.59	11.9816		11.99	0.000019	0.81	2211.69	549.31	0.04
1	487.0596	2018_025y	Design_Exist	1228	0.59	12.1799		12.19	0.000017	0.77	2321.24	555.04	0.04
1	487.0596	2018_050yr	Design_20'	1565	0.59	10.2058		10.24	0.000103	1.65	1302.14	463.93	0.1
1	487.0596	2018_050yr	Design_12'	1565	0.59	11.578		11.59	0.00004	1.14	1993.39	534.26	0.06
1	487.0596	2018_050yr	Design_in-kind	1565	0.59	12.4862		12.49	0.000023	0.92	2492.39	562.46	0.05
1	487.0596	2018_050yr	Design_Exist	1565	0.59	12.7915		12.8	0.000019	0.86	2665.25	569.86	0.05
1	487.0596	2018_100yr	Design_20'	2000	0.59	11.604		11.63	0.000064	1.45	2007.3	535.09	0.08
1	487.0596	2018_100yr	Design_12'	2000	0.59	12.3491		12.36	0.00004	1.21	2415.53	559.14	0.07
1	487.0596	2018_100yr	Design_in-kind	2000	0.59	12.8844		12.9	0.00003	1.07	2718.29	572.12	0.06
1	487.0596	2018_100yr	Design_Exist	2000	0.59	13.1164		13.13	0.000026	1.02	2851.67	577.75	0.05
1	487.0596	2018_500yr	Design_20'	2671	0.59	13.6516		13.67	0.000035	1.22	3164.39	590.85	0.06
1	487.0596	2018_500yr	Design_12'	2671	0.59	13.6515		13.67	0.000035	1.22	3164.39	590.85	0.06
1	487.0596	2018_500yr	Design_in-kind	2671	0.59	13.4982		13.51	0.000038	1.26	3074.05	587.16	0.06
1	487.0596	2018_500yr	Design_Exist	2671	0.59	13.6307		13.65	0.000036	1.23	3152.06	590.35	0.06
1	487.0596	2018_25yr_MHHW_M	Design_20'	1228	0.59	8.7969		8.85	0.000161	1.84	795.93	291.05	0.12
1	487.0596	2018_25yr_MHHW_M	Design_12'	1228	0.59	10.0904		10.11	0.000069	1.34	1248.96	457.2	0.08
1	487.0596	2018_25yr_MHHW_M	Design_in-kind	1228	0.59	11.9892		12	0.000019	0.81	2215.84	549.55	0.04
1	487.0596	2018_25yr_MHHW_M	Design_Exist	1228	0.59	12.1948		12.2	0.000017	0.77	2329.53	555.4	0.04
1	487.0596	2018_25yr_MSL_Ma	Design_20'	1228	0.59	8.7969		8.85	0.000161	1.84	795.93	291.05	0.12
1	487.0596	2018_25yr_MSL_Ma	Design_12'	1228	0.59	9.883		9.91	0.000078	1.41	1163.68	378.81	0.09
1	487.0596	2018_25yr_MSL_Ma	Design_in-kind	1228	0.59	11.9935		12	0.000019	0.81	2218.22	549.96	0.04
1	487.0596	2018_25yr_MSL_Ma	Design_Exist	1228	0.59	12.172		12.18	0.000017	0.77	2316.87	554.85	0.04
1	487.0596	2100_025yr_Ab1	Design_20'	1706	0.59	10.6776		10.71	0.000087	1.58	1528.22	494.16	0.09
1	487.0596	2100_025yr_Ab1	Design_12'	1706	0.59	12.0406		12.05	0.000035	1.11	2244.15	551.66	0.06
1	487.0596	2100_025yr_Ab1	Design_in-kind	1706	0.59	12.6634		12.67	0.000024	0.96	2592.45	566.76	0.05
1	487.0596	2100_025yr_Ab1	Design_Exist	1706	0.59	12.7277		12.74	0.000024	0.95	2628.91	568.32	0.05
1	487.0596	2100_050yr_Ab1	Design_20'	1717	0.59	10.723		10.75	0.000085	1.57	1550.71	496.3	0.09
1	487.0596	2100_050yr_Ab1	Design_12'	1717	0.59	12.0548		12.07	0.000035	1.11	2252.03	552.01	0.06
1	487.0596	2100_050yr_Ab1	Design_in-kind	1717	0.59	12.7157		12.72	0.000024	0.95	2622.14	568.03	0.05
1	487.0596	2100_050yr_Ab1	Design_Exist	1717	0.59	12.7176		12.73	0.000024	0.95	2623.18	568.07	0.05
1	487.0596	2100_100yr_Ab1	Design_20'	2562	0.59	13.4716		13.49	0.000036	1.21	3058.47	586.52	0.06
1	487.0596	2100_100yr_Ab1	Design_12'	2562	0.59	13.4713		13.49	0.000036	1.21	3058.28	586.51	0.06
1	487.0596	2100_100yr_Ab1	Design_in-kind	2562	0.59	13.4249		13.44	0.000036	1.23	3031.08	585.4	0.06
1	487.0596	2100_100yr_Ab1	Design_Exist	2562	0.59	13.5479		13.56	0.000034	1.2	3103.31	588.36	0.06
1	487.0596	2018_025yr(Surge	Design_20'	1228	0.59	9.9677		9.99	0.000074	1.38	1196.05	385.32	0.09
1	487.0596	2015_025yr(Surge	Design_12'	1228	0.59	11.4786		11.49	0.000026	0.92	1940.48	531.1	0.05
1	487.0596	2015_025yr(Surge	Design_in-kind	1228	0.59	12.1914		12.2	0.000017	0.77	2327.64	555.32	0.04
1	487.0596	2015_025yr(Surge	Design_Exist	1228	0.59	12.1861		12.19	0.000017	0.77	2324.7	555.19	0.04
1	487.0596	2018_050yr(Surge	Design_20'	1565	0.59	11.0048		11.02	0.000058	1.32	1692.91	512.77	0.08
1	487.0596	2015_050yr(Surge	Design_12'	1565	0.59	12.0899		12.1	0.000029	1	2271.37	552.86	0.06
1	487.0596	2015_050yr(Surge	Design_in-kind	1565	0.59	12.6011		12.61	0.000021	0.89	2557.16	565.25	0.05
1	487.0596	2015_050yr(Surge	Design_Exist	1565	0.59	12.7948		12.8	0.000019	0.85	2667.14	569.94	0.05
1	487.0596	015_100yr(Surge)	Design_20'	2000	0.59	11.9075		11.93	0.000053	1.34	2171.19	544.74	0.07

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	487.0596	015_100yr(Surge)	Design_12'	2000	0.59	12.6238		12.64	0.000034	1.13	2570.04	565.8	0.06
1	487.0596	015_100yr(Surge)	Design_in-kind	2000	0.59	12.983		12.99	0.000028	1.05	2774.84	574.51	0.06
1	487.0596	015_100yr(Surge)	Design_Exist	2000	0.59	13.1143		13.12	0.000026	1.02	2850.45	577.7	0.05
1	441.3088	2018_002yr	Design_20'	232	0.55	4.8933		4.92	0.000158	1.19	195.07	55.14	0.11
1	441.3088	2018_002yr	Design_12'	232	0.55	4.9953		5.02	0.000145	1.16	200.71	55.42	0.11
1	441.3088	2018_002yr	Design_in-kind	232	0.55	5.3731		5.39	0.000106	1.05	221.78	55.89	0.09
1	441.3088	2018_002yr	Design_Exist	232	0.55	6.4503		6.46	0.00005	0.82	282.04	55.99	0.06
1	441.3088	2018_010yr	Design_20'	845	0.55	6.9668		7.08	0.000492	2.72	311.03	57.28	0.2
1	441.3088	2018_010yr	Design_12'	845	0.55	7.2856		7.39	0.000422	2.57	330.1	65.88	0.19
1	441.3088	2018_010yr	Design_in-kind	845	0.55	11.1066		11.12	0.000028	0.94	1490.7	553.99	0.05
1	441.3088	2018_010yr	Design_Exist	845	0.55	11.3892		11.4	0.000022	0.85	1648.22	560.49	0.05
1	441.3088	2018_025y	Design_20'	1228	0.55	8.7139		8.83	0.00037	2.79	532.39	225.05	0.18
1	441.3088	2018_025y	Design_12'	1228	0.55	9.7887		9.84	0.00017	2.08	826.35	312.5	0.13
1	441.3088	2018_025y	Design_in-kind	1228	0.55	11.9775		11.99	0.00003	1.02	1981.59	572.92	0.06
1	441.3088	2018_025y	Design_Exist	1228	0.55	12.1765		12.18	0.000026	0.96	2096.16	578.68	0.05
1	441.3088	2018_050yr	Design_20'	1565	0.55	10.1533		10.23	0.000227	2.47	973.72	529.87	0.15
1	441.3088	2018_050yr	Design_12'	1565	0.55	11.5677		11.59	0.000066	1.48	1748.56	564.3	0.08
1	441.3088	2018_050yr	Design_in-kind	1565	0.55	12.482		12.49	0.000034	1.12	2274.29	587.45	0.06
1	441.3088	2018_050yr	Design_Exist	1565	0.55	12.7883		12.8	0.000028	1.03	2455.59	596.25	0.05
1	441.3088	2018_100yr	Design_20'	2000	0.55	11.5874		11.62	0.000107	1.88	1759.72	564.71	0.1
1	441.3088	2018_100yr	Design_12'	2000	0.55	12.3413		12.36	0.000061	1.49	2191.93	583.41	0.08
1	441.3088	2018_100yr	Design_in-kind	2000	0.55	12.8795		12.89	0.000042	1.28	2510.1	598.87	0.07
1	441.3088	2018_100yr	Design_Exist	2000	0.55	13.1123		13.13	0.000037	1.21	2650.23	605	0.06
1	441.3088	2018_500yr	Design_20'	2671	0.55	13.6467		13.66	0.000047	1.42	2977.45	619.64	0.07
1	441.3088	2018_500yr	Design_12'	2671	0.55	13.6467		13.66	0.000047	1.42	2977.45	619.64	0.07
1	441.3088	2018_500yr	Design_in-kind	2671	0.55	13.4928		13.51	0.000052	1.47	2882.38	615.42	0.08
1	441.3088	2018_500yr	Design_Exist	2671	0.55	13.6258		13.64	0.000048	1.43	2964.47	619.07	0.07
1	441.3088	2018_25yr_MHHW_M	Design_20'	1228	0.55	8.7139		8.83	0.00037	2.79	532.39	225.05	0.18
1	441.3088	2018_25yr_MHHW_M	Design_12'	1228	0.55	10.0544		10.11	0.000153	2.01	921.41	527.22	0.12
1	441.3088	2018_25yr_MHHW_M	Design_in-kind	1228	0.55	11.9851		11.99	0.00003	1.02	1985.94	573.08	0.06
1	441.3088	2018_25yr_MHHW_M	Design_Exist	1228	0.55	12.1914		12.2	0.000025	0.96	2104.83	579.11	0.05
1	441.3088	2018_25yr_MSL_Ma	Design_20'	1228	0.55	8.7139		8.83	0.00037	2.79	532.39	225.05	0.18
1	441.3088	2018_25yr_MSL_Ma	Design_12'	1228	0.55	9.8476		9.9	0.000163	2.04	844.88	316.43	0.13
1	441.3088	2018_25yr_MSL_Ma	Design_in-kind	1228	0.55	11.9894		12	0.00003	1.01	1988.43	573.17	0.06
1	441.3088	2018_25yr_MSL_Ma	Design_Exist	1228	0.55	12.1686		12.18	0.000026	0.96	2091.59	578.45	0.05
1	441.3088	2100_025yr_Ab1	Design_20'	1706	0.55	10.6425		10.7	0.000173	2.24	1236.11	543.01	0.13
1	441.3088	2100_025yr_Ab1	Design_12'	1706	0.55	12.033		12.05	0.000055	1.39	2013.42	574.49	0.08
1	441.3088	2100_025yr_Ab1	Design_in-kind	1706	0.55	12.6591		12.67	0.000036	1.16	2378.81	592.54	0.06
1	441.3088	2100_025yr_Ab1	Design_Exist	1706	0.55	12.7236		12.74	0.000034	1.14	2417.07	594.39	0.06
1	441.3088	2100_050yr_Ab1	Design_20'	1717	0.55	10.6894		10.74	0.000168	2.21	1261.58	544.28	0.13
1	441.3088	2100_050yr_Ab1	Design_12'	1717	0.55	12.0472		12.07	0.000055	1.39	2021.62	574.96	0.08
1	441.3088	2100_050yr_Ab1	Design_in-kind	1717	0.55	12.7116		12.72	0.000035	1.15	2409.93	594.05	0.06
1	441.3088	2100_050yr_Ab1	Design_Exist	1717	0.55	12.7134		12.73	0.000035	1.15	2411.03	594.1	0.06
1	441.3088	2100_100yr_Ab1	Design_20'	2562	0.55	13.4666		13.48	0.000048	1.42	2866.25	614.7	0.07
1	441.3088	2100_100yr_Ab1	Design_12'	2562	0.55	13.4662		13.48	0.000048	1.42	2866.06	614.69	0.07
1	441.3088	2100_100yr_Ab1	Design_in-kind	2562	0.55	13.4196		13.44	0.00005	1.44	2837.44	613.42	0.07
1	441.3088	2100_100yr_Ab1	Design_Exist	2562	0.55	13.5432		13.56	0.000046	1.4	2913.42	616.8	0.07
1	441.3088	2018_025yr(Surge	Design_20'	1228	0.55	9.9346		9.98	0.000153	1.99	872.67	322.22	0.12
1	441.3088	2015_025yr(Surge	Design_12'	1228	0.55	11.4716		11.49	0.000044	1.2	1694.47	562.28	0.07
1	441.3088	2015_025yr(Surge	Design_in-kind	1228	0.55	12.188		12.2	0.000026	0.96	2102.86	579.01	0.05
1	441.3088	2015_025yr(Surge	Design_Exist	1228	0.55	12.1827		12.19	0.000026	0.96	2099.77	578.86	0.05
1	441.3088	2018_050yr(Surge	Design_20'	1565	0.55	10.9851		11.02	0.000107	1.81	1423.6	551.18	0.1
1	441.3088	2015_050yr(Surge	Design_12'	1565	0.55	12.0838		12.1	0.000045	1.26	2042.64	576.05	0.07
1	441.3088	2015_050yr(Surge	Design_in-kind	1565	0.55	12.5972		12.61	0.000031	1.08	2342.2	590.77	0.06
1	441.3088	2015_050yr(Surge	Design_Exist	1565	0.55	12.7916		12.8	0.000027	1.03	2457.57	596.35	0.05
1	441.3088	015_100yr(Surge)	Design_20'	2000	0.55	11.8955		11.92	0.000084	1.7	1934.69	571.19	0.09
1	441.3088	015_100yr(Surge)	Design_12'	2000	0.55	12.6177		12.63	0.00005	1.38	2354.29	591.35	0.07
1	441.3088	015_100yr(Surge)	Design_in-kind	2000	0.55	12.9785		12.99	0.00004	1.25	2569.52	601.38	0.07
1	441.3088	015_100yr(Surge)	Design_Exist	2000	0.55	13.1102		13.12	0.000037	1.21	2648.96	604.94	0.06
1	328.7169	2018_002yr	Design_20'	254	0.01	4.8034		4.88	0.000506	2.2	115.25	25.85	0.18
1	328.7169	2018_002yr	Design_12'	254	0.01	4.9103		4.98	0.000472	2.15	118.02	25.86	0.18
1	328.7169	2018_002yr	Design_in-kind	254	0.01	5.3031		5.36	0.000369	1.98	128.18	25.88	0.16
1	328.7169	2018_002yr	Design_Exist	254	0.01	6.4051		6.45	0.000211	1.64	155.1	25.96	0.12
1	328.7169	2018_010yr	Design_20'	924	0.01	6.376		6.92	0.002746	5.92	155.99	25.95	0.43
1	328.7169	2018_010yr	Design_12'	924	0.01	6.7706		7.25	0.002283	5.56	166.23	25.98	0.39
1	328.7169	2018_010yr	Design_in-kind	924	0.01	11.0405		11.1	0.000223	2.33	637.95	266.64	0.13
1	328.7169	2018_010yr	Design_Exist	924	0.01	11.3377		11.39	0.000178	2.11	717.43	279.22	0.11
1	328.7169	2018_025y	Design_20'	1363	0.01	7.9416		8.67	0.002951	6.86	204.32	38.09	0.44
1	328.7169	2018_025y	Design_12'	1363	0.01	9.2922		9.76	0.001627	5.58	272.34	109.25	0.33
1	328.7169	2018_025y	Design_in-kind	1363	0.01	11.9072		11.97	0.000246	2.58	884.87	303.06	0.14

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	328.7169	2018_025y	Design_Exist	1363	0.01	12.1155		12.17	0.000217	2.45	956.24	407.58	0.13
1	328.7169	2018_050yr	Design_20'	1772	0.01	9.3149		10.09	0.00272	7.22	274.93	117.46	0.43
1	328.7169	2018_050yr	Design_12'	1772	0.01	11.3838		11.56	0.000624	3.98	731.99	281.15	0.21
1	328.7169	2018_050yr	Design_in-kind	1772	0.01	12.4017		12.48	0.000289	2.88	1079.19	445.26	0.15
1	328.7169	2018_050yr	Design_Exist	1772	0.01	12.7283		12.79	0.000223	2.57	1230.15	481.42	0.13
1	328.7169	2018_100yr	Design_20'	2267	0.01	11.248		11.56	0.001137	5.33	694.19	275.45	0.29
1	328.7169	2018_100yr	Design_12'	2267	0.01	12.1812		12.33	0.000565	3.97	984.89	414.4	0.21
1	328.7169	2018_100yr	Design_in-kind	2267	0.01	12.786		12.87	0.000346	3.21	1259.67	483.85	0.16
1	328.7169	2018_100yr	Design_Exist	2267	0.01	13.0371		13.11	0.000284	2.95	1380.83	496.47	0.15
1	328.7169	2018_500yr	Design_20'	3078	0.01	13.5558		13.64	0.000348	3.36	1649.4	530.17	0.16
1	328.7169	2018_500yr	Design_12'	3078	0.01	13.5558		13.64	0.000348	3.36	1649.39	530.17	0.16
1	328.7169	2018_500yr	Design_in-kind	3078	0.01	13.3886		13.49	0.000396	3.55	1561.52	521.25	0.17
1	328.7169	2018_500yr	Design_Exist	3078	0.01	13.5332		13.62	0.000356	3.39	1635.8	528.94	0.17
1	328.7169	2018_25yr_MHHW_M	Design_20'	1363.01	0.01	7.9416		8.67	0.002951	6.86	204.32	38.09	0.44
1	328.7169	2018_25yr_MHHW_M	Design_12'	1363.01	0.01	9.6365		10.03	0.001347	5.21	319.38	155.04	0.3
1	328.7169	2018_25yr_MHHW_M	Design_in-kind	1363.01	0.01	11.9153		11.98	0.000245	2.58	887.31	303.4	0.13
1	328.7169	2018_25yr_MHHW_M	Design_Exist	1363.01	0.01	12.1313		12.19	0.000214	2.43	962.71	409.23	0.13
1	328.7169	2018_25yr_MSL_Ma	Design_20'	1363	0.01	7.9416		8.67	0.002951	6.86	204.32	38.09	0.44
1	328.7169	2018_25yr_MSL_Ma	Design_12'	1363	0.01	9.3661		9.82	0.001567	5.5	281.14	124.87	0.33
1	328.7169	2018_25yr_MSL_Ma	Design_in-kind	1363	0.01	11.9199		11.99	0.000244	2.57	888.71	303.6	0.13
1	328.7169	2018_25yr_MSL_Ma	Design_Exist	1363	0.01	12.1071		12.17	0.000219	2.46	952.84	406.72	0.13
1	328.7169	2100_025yr_Ab1	Design_20'	1930	0.01	9.914		10.58	0.002277	6.9	367.05	187.14	0.4
1	328.7169	2100_025yr_Ab1	Design_12'	1930	0.01	11.889		12.02	0.000501	3.68	879.37	302.27	0.19
1	328.7169	2100_025yr_Ab1	Design_in-kind	1930	0.01	12.5778		12.65	0.000297	2.94	1159.85	474.17	0.15
1	328.7169	2100_025yr_Ab1	Design_Exist	1930	0.01	12.6471		12.72	0.000282	2.88	1191.19	477.66	0.15
1	328.7169	2100_050yr_Ab1	Design_20'	1946	0.01	9.9802		10.63	0.002216	6.84	379.55	190.64	0.39
1	328.7169	2100_050yr_Ab1	Design_12'	1946	0.01	11.9025		12.04	0.000504	3.69	883.43	302.85	0.19
1	328.7169	2100_050yr_Ab1	Design_in-kind	1946	0.01	12.6328		12.71	0.000288	2.91	1186.02	476.94	0.15
1	328.7169	2100_050yr_Ab1	Design_Exist	1946	0.01	12.6347		12.71	0.00029	2.91	1185.3	477.04	0.15
1	328.7169	2100_100yr_Ab1	Design_20'	2943	0.01	13.37	8.11	13.46	0.000367	3.42	1551.82	520.36	0.17
1	328.7169	2100_100yr_Ab1	Design_12'	2943	0.01	13.3696	8.11	13.46	0.000367	3.42	1551.64	520.33	0.17
1	328.7169	2100_100yr_Ab1	Design_in-kind	2943	0.01	13.3189		13.42	0.000382	3.48	1525.34	516.33	0.17
1	328.7169	2100_100yr_Ab1	Design_Exist	2943	0.01	13.453		13.54	0.000346	3.33	1593.53	524.59	0.16
1	328.7169	2018_025yr(Surge	Design_20'	1363	0.01	9.4772		9.9	0.001476	5.38	295.91	139.47	0.32
1	328.7169	2015_025yr(Surge	Design_12'	1363	0.01	11.3615		11.46	0.000376	3.09	725.74	280.22	0.17
1	328.7169	2015_025yr(Surge	Design_in-kind	1363	0.01	12.1278		12.18	0.000213	2.43	962.92	408.86	0.13
1	328.7169	2015_025yr(Surge	Design_Exist	1363	0.01	12.1221		12.18	0.000216	2.44	958.93	408.27	0.13
1	328.7169	2018_050yr(Surge	Design_20'	1772	0.01	10.6347		10.96	0.001131	5.11	533.28	249.29	0.28
1	328.7169	2015_050yr(Surge	Design_12'	1772	0.01	11.9703		12.08	0.000397	3.29	904.08	305.77	0.17
1	328.7169	2015_050yr(Surge	Design_in-kind	1772	0.01	12.5254		12.59	0.000261	2.75	1135.33	462.37	0.14
1	328.7169	2015_050yr(Surge	Design_Exist	1772	0.01	12.7318		12.79	0.000222	2.56	1231.83	481.57	0.13
1	328.7169	015_100yr(Surge)	Design_20'	2267	0.01	11.6546	6.54	11.88	0.000827	4.66	809.65	292.47	0.25
1	328.7169	015_100yr(Surge)	Design_12'	2267	0.01	12.4969		12.61	0.000437	3.56	1122.15	460.14	0.18
1	328.7169	015_100yr(Surge)	Design_in-kind	2267	0.01	12.8934		12.97	0.000317	3.1	1311.87	488.35	0.16
1	328.7169	015_100yr(Surge)	Design_Exist	2267	0.01	13.0349		13.11	0.000285	2.95	1379.71	496.17	0.15
1	260.5812	2018_002yr	Design_20'	254	-0.2	4.6954	2.24	4.83	0.000934	2.9	87.59	21.8	0.26
1	260.5812	2018_002yr	Design_12'	254	-0.2	4.8098	2.24	4.93	0.000859	2.82	90.08	21.83	0.24
1	260.5812	2018_002yr	Design_in-kind	254	-0.2	5.255	1.64	5.33	0.00043	2.26	112.43	21.95	0.18
1	260.5812	2018_002yr	Design_Exist	254	-0.91	6.3728	1.63	6.43	0.000231	1.91	132.69	22.26	0.13
1	260.5812	2018_010yr	Design_20'	924	-0.2	4.496	4.5	6.41	0.014363	11.1	83.25	21.74	1
1	260.5812	2018_010yr	Design_12'	924	-0.2	5.9672	4.49	6.96	0.005506	8	115.53	22.15	0.62
1	260.5812	2018_010yr	Design_in-kind	924	-0.2	10.8603	3.9	11.06	0.00064	3.69	291.78	81.9	0.2
1	260.5812	2018_010yr	Design_Exist	924	-0.91	11.1727	3.93	11.35	0.00059	3.51	319.69	105.64	0.19
1	260.5812	2018_025y	Design_20'	1363	-0.2	5.6405	5.64	8.1	0.014438	12.58	108.31	22.06	1
1	260.5812	2018_025y	Design_12'	1363	-0.2	8.5928	5.64	9.54	0.003737	7.81	174.46	22.62	0.5
1	260.5812	2018_025y	Design_in-kind	1363	-0.2	11.5917	5.06	11.92	0.000992	4.8	375.57	156.86	0.25
1	260.5812	2018_025y	Design_Exist	1363	-0.91	11.8407	5.1	12.12	0.00091	4.54	416.7	178.02	0.24
1	260.5812	2018_050yr	Design_20'	1772	-0.2	6.5976	6.6	9.51	0.014584	13.68	129.55	22.32	1
1	260.5812	2018_050yr	Design_12'	1772	-0.2	10.4006	6.61	11.39	0.003416	8.05	243.61	73.16	0.46
1	260.5812	2018_050yr	Design_in-kind	1772	-0.2	11.9504	6.02	12.4	0.001376	5.77	436.99	197.04	0.3
1	260.5812	2018_050yr	Design_Exist	1772	-0.91	12.3794	6.08	12.72	0.001128	5.21	544.48	287.98	0.27
1	260.5812	2018_100yr	Design_20'	2267	-0.2	7.6504	7.65	11.05	0.014856	14.8	153.18	22.53	1
1	260.5812	2018_100yr	Design_12'	2267	-0.2	10.6315	7.65	12.11	0.005052	9.91	260.98	77.35	0.57
1	260.5812	2018_100yr	Design_in-kind	2267	-0.2	12.0725	7.09	12.76	0.00211	7.2	463.78	242.04	0.37
1	260.5812	2018_100yr	Design_Exist	2267	-0.91	12.5024	7.17	13.02	0.001708	6.45	581.56	310.3	0.33
1	260.5812	2018_500yr	Design_20'	3078	-0.2	10.884	10.88	13.34	0.008315	12.88	281.13	82.54	0.73
1	260.5812	2018_500yr	Design_12'	3078	-0.2	10.884	10.88	13.34	0.008315	12.88	281.13	82.54	0.73
1	260.5812	2018_500yr	Design_in-kind	3078	-0.2	11.8859	8.64	13.29	0.004297	10.16	424.82	181.27	0.53
1	260.5812	2018_500yr	Design_Exist	3078	-0.91	12.6126	8.79	13.49	0.002903	8.47	616.5	323.41	0.43
1	260.5812	2018_25yr_MHHW_M	Design_20'	1363.01	-0.2	5.6408	5.64	8.1	0.014436	12.58	108.32	22.06	1
1	260.5812	2018_25yr_MHHW_M	Design_12'	1363.01	-0.2	8.9845	5.64	9.84	0.003258	7.43	183.33	22.66	0.46

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	260.5812	2018_25yr_MHHW_M	Design_in-kind	1363.01	-0.2	11.6013	5.06	11.92	0.000987	4.79	377.07	157.48	0.25
1	260.5812	2018_25yr_MHHW_M	Design_Exist	1363.01	-0.91	11.8593	5.1	12.14	0.0009	4.52	420.03	179.36	0.24
1	260.5812	2018_25yr_MSL_Ma	Design_20'	1363	-0.2	5.6405	5.64	8.1	0.014438	12.58	108.31	22.06	1
1	260.5812	2018_25yr_MSL_Ma	Design_12'	1363	-0.2	8.6803	5.64	9.61	0.003622	7.72	176.44	22.63	0.49
1	260.5812	2018_25yr_MSL_Ma	Design_in-kind	1363	-0.2	11.6068	5.06	11.93	0.000984	4.78	377.94	157.83	0.25
1	260.5812	2018_25yr_MSL_Ma	Design_Exist	1363	-0.91	11.8317	5.1	12.11	0.000913	4.54	415.11	176.78	0.24
1	260.5812	2100_025yr_Ab1	Design_20'	1930	-0.2	6.9498	6.95	10.01	0.014627	14.04	137.43	22.42	1
1	260.5812	2100_025yr_Ab1	Design_12'	1930	-0.2	10.9144	6.95	11.87	0.003225	8.04	283.65	83.38	0.45
1	260.5812	2100_025yr_Ab1	Design_in-kind	1930	-0.2	12.0684	6.37	12.57	0.001533	6.13	462.8	241.51	0.32
1	260.5812	2100_025yr_Ab1	Design_Exist	1930	-0.91	12.1724	6.45	12.64	0.001515	5.97	488.61	255.06	0.31
1	260.5812	2100_050yr_Ab1	Design_20'	1946	-0.2	6.9836	6.98	10.07	0.01464	14.08	138.19	22.42	1
1	260.5812	2100_050yr_Ab1	Design_12'	1946	-0.2	10.9074	6.98	11.88	0.003289	8.11	283.07	83.18	0.46
1	260.5812	2100_050yr_Ab1	Design_in-kind	1946	-0.2	12.1367	6.4	12.63	0.001495	6.08	479.59	250.41	0.32
1	260.5812	2100_050yr_Ab1	Design_Exist	1946	-0.91	12.1422	6.48	12.63	0.001569	6.06	480.97	251.13	0.31
1	260.5812	2100_100yr_Ab1	Design_20'	2943	-0.2	8.9563	8.96	12.99	0.015337	16.11	182.69	22.66	1
1	260.5812	2100_100yr_Ab1	Design_12'	2943	-0.2	8.9594	8.96	12.99	0.01532	16.1	182.76	22.66	1
1	260.5812	2100_100yr_Ab1	Design_in-kind	2943	-0.2	12.121	8.4	13.25	0.003453	9.23	475.66	248.36	0.48
1	260.5812	2100_100yr_Ab1	Design_Exist	2943	-0.91	12.6217	8.53	13.41	0.002635	8.07	619.47	324.3	0.41
1	260.5812	2018_025yr(Surge	Design_20'	1363	-0.2	8.8079	5.64	9.71	0.003463	7.6	179.33	22.65	0.48
1	260.5812	2015_025yr(Surge	Design_12'	1363	-0.2	10.9	5.64	11.38	0.001619	5.69	282.45	82.98	0.32
1	260.5812	2015_025yr(Surge	Design_in-kind	1363	-0.2	11.8538	5.06	12.13	0.000858	4.53	419.04	178.96	0.24
1	260.5812	2015_025yr(Surge	Design_Exist	1363	-0.91	11.8484	5.1	12.13	0.000906	4.53	418.09	178.57	0.24
1	260.5812	2018_050yr(Surge	Design_20'	1772	-0.2	9.403	6.6	10.72	0.004794	9.19	192.82	22.7	0.56
1	260.5812	2015_050yr(Surge	Design_12'	1772	-0.2	11.2628	6.61	11.96	0.002316	6.95	317.04	117.62	0.38
1	260.5812	2015_050yr(Surge	Design_in-kind	1772	-0.2	12.111	6.02	12.52	0.00126	5.57	473.19	247.06	0.29
1	260.5812	2015_050yr(Surge	Design_Exist	1772	-0.91	12.3835	6.08	12.73	0.001126	5.21	545.67	289.14	0.27
1	260.5812	015_100yr(Surge)	Design_20'	2267	-0.2	9.4031	7.65	11.55	0.007846	11.76	192.83	22.7	0.71
1	260.5812	015_100yr(Surge)	Design_12'	2267	-0.2	11.3383	7.65	12.44	0.003651	8.77	326.33	128.69	0.48
1	260.5812	015_100yr(Surge)	Design_in-kind	2267	-0.2	12.2671	7.09	12.88	0.001871	6.85	513.37	268.13	0.35
1	260.5812	015_100yr(Surge)	Design_Exist	2267	-0.91	12.4982	7.17	13.02	0.001713	6.46	580.23	309.87	0.33
1	239.34			Culvert									
1	212.9068	2018_002yr	Design_20'	254	-5.32	4.7664	-3.84	4.77	0.00002	0.7	361.07	47.07	0.04
1	212.9068	2018_002yr	Design_12'	254	-5.32	4.7664	-3.84	4.77	0.00002	0.7	361.07	47.07	0.04
1	212.9068	2018_002yr	Design_in-kind	254	-5.32	4.7664	-3.84	4.77	0.00002	0.7	361.07	47.07	0.04
1	212.9068	2018_002yr	Design_Exist	254	-5.32	6.0515	-0.9	6.12	0.000298	2.14	118.55	48.92	0.12
1	212.9068	2018_010yr	Design_20'	924	-5.32	4.7217	-2.17	4.82	0.000264	2.57	358.97	47.01	0.16
1	212.9068	2018_010yr	Design_12'	924	-5.32	4.7217	-2.17	4.82	0.000264	2.57	358.97	47.01	0.16
1	212.9068	2018_010yr	Design_in-kind	924	-5.32	4.7217	-2.17	4.82	0.000264	2.57	358.97	47.01	0.16
1	212.9068	2018_010yr	Design_Exist	924	-5.32	7.8034	2.24	8.47	0.002385	6.55	141	51.44	0.35
1	212.9068	2018_025y	Design_20'	1363	-5.32	4.6627	-1.35	4.89	0.000588	3.83	356.2	46.92	0.24
1	212.9068	2018_025y	Design_12'	1363	-5.32	4.6627	-1.35	4.89	0.000588	3.83	356.2	46.92	0.24
1	212.9068	2018_025y	Design_in-kind	1363	-5.32	4.6627	-1.35	4.89	0.000588	3.83	356.2	46.92	0.24
1	212.9068	2018_025y	Design_Exist	1363	-5.32	8.4896	3.86	9.78	0.004365	9.1	149.79	52.43	0.47
1	212.9068	2018_050yr	Design_20'	1772	-5.32	4.5834	-0.67	4.98	0.001024	5.03	352.48	46.81	0.32
1	212.9068	2018_050yr	Design_12'	1772	-5.32	4.5834	-0.67	4.98	0.001024	5.03	352.48	46.81	0.32
1	212.9068	2018_050yr	Design_in-kind	1772	-5.32	4.5834	-0.67	4.98	0.001024	5.03	352.48	46.81	0.32
1	212.9068	2018_050yr	Design_Exist	1772	-5.32	10.979	5.2	11.08	0.000214	2.62	758.43	205.62	0.13
1	212.9068	2018_100yr	Design_20'	2267	-5.32	4.4494	0.09	5.12	0.001754	6.55	346.22	46.62	0.42
1	212.9068	2018_100yr	Design_12'	2267	-5.32	4.4494	0.09	5.12	0.001754	6.55	346.22	46.62	0.42
1	212.9068	2018_100yr	Design_in-kind	2267	-5.32	4.4494	0.09	5.12	0.001754	6.55	346.22	46.62	0.42
1	212.9068	2018_100yr	Design_Exist	2267	-5.32	10.6487	6.71	10.84	0.000391	3.49	699.08	150.47	0.18
1	212.9068	2018_500yr	Design_20'	3078	-5.32	4.0975	1.22	5.45	0.003743	9.33	329.9	46.12	0.61
1	212.9068	2018_500yr	Design_12'	3078	-5.32	4.0975	1.22	5.45	0.003743	9.33	329.9	46.12	0.61
1	212.9068	2018_500yr	Design_in-kind	3078	-5.32	4.0975	1.22	5.45	0.003743	9.33	329.9	46.12	0.61
1	212.9068	2018_500yr	Design_Exist	3078	-5.32	11.3172	9.04	11.6	0.000574	4.37	832.81	232.41	0.22
1	212.9068	2018_25yr_MHHW_M	Design_20'	1363.01	-5.32	5.6671	-1.35	5.84	0.000409	3.37	404.05	48.37	0.21
1	212.9068	2018_25yr_MHHW_M	Design_12'	1363.01	-5.32	5.6671	-1.35	5.84	0.000409	3.37	404.05	48.37	0.21
1	212.9068	2018_25yr_MHHW_M	Design_in-kind	1363.01	-5.32	5.6671	-1.35	5.84	0.000409	3.37	404.05	48.37	0.21
1	212.9068	2018_25yr_MHHW_M	Design_Exist	1363.01	-5.32	8.4889	3.86	9.78	0.004366	9.1	149.78	52.43	0.47
1	212.9068	2018_25yr_MSL_Ma	Design_20'	1363	-5.32	0.297	-1.35	1.13	0.003222	7.3	186.69	36.03	0.57
1	212.9068	2018_25yr_MSL_Ma	Design_12'	1363	-5.32	0.297	-1.35	1.13	0.003222	7.3	186.69	36.03	0.57
1	212.9068	2018_25yr_MSL_Ma	Design_in-kind	1363	-5.32	0.297	-1.35	1.13	0.003222	7.3	186.69	36.03	0.57
1	212.9068	2018_25yr_MSL_Ma	Design_Exist	1363	-5.32	8.4845	3.86	9.77	0.00437	9.1	149.72	52.42	0.47
1	212.9068	2100_025yr_Ab1	Design_20'	1930	-5.32	6.6364	-0.42	6.92	0.000594	4.27	451.6	49.76	0.25
1	212.9068	2100_025yr_Ab1	Design_12'	1930	-5.32	6.6364	-0.42	6.92	0.000594	4.27	451.6	49.76	0.25
1	212.9068	2100_025yr_Ab1	Design_in-kind	1930	-5.32	6.6364	-0.42	6.92	0.000594	4.27	451.6	49.76	0.25
1	212.9068	2100_025yr_Ab1	Design_Exist	1930	-5.32	8.5991	5.7	11.13	0.008522	12.77	151.19	52.58	0.66
1	212.9068	2100_050yr_Ab1	Design_20'	1946	-5.32	6.634	-0.4	6.92	0.000604	4.31	451.49	49.76	0.25
1	212.9068	2100_050yr_Ab1	Design_12'	1946	-5.32	6.634	-0.4	6.92	0.000604	4.31	451.49	49.76	0.25
1	212.9068	2100_050yr_Ab1	Design_in-kind	1946	-5.32	6.634	-0.4	6.92	0.000604	4.31	451.49	49.76	0.25

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	212.9068	2100_050yr_Ab1	Design_Exist	1946	-5.32	8.5817	5.74	11.16	0.008701	12.89	150.97	52.56	0.66
1	212.9068	2100_100yr_Ab1	Design_20'	2943	-5.32	6.4399	1.04	7.13	0.001475	6.66	441.86	49.48	0.39
1	212.9068	2100_100yr_Ab1	Design_12'	2943	-5.32	6.4399	1.04	7.13	0.001475	6.66	441.86	49.48	0.39
1	212.9068	2100_100yr_Ab1	Design_in-kind	2943	-5.32	6.4399	1.04	7.13	0.001475	6.66	441.86	49.48	0.39
1	212.9068	2100_100yr_Ab1	Design_Exist	2943	-5.32	11.2239	8.69	11.49	0.000543	4.23	811.38	227.36	0.21
1	212.9068	2018_025yr(Surge	Design_20'	1363	-5.32	8.1518	-1.35	8.26	0.00019	2.58	528.66	51.94	0.14
1	212.9068	2015_025yr(Surge	Design_12'	1363	-5.32	8.1518	-1.35	8.26	0.00019	2.58	528.66	51.94	0.14
1	212.9068	2015_025yr(Surge	Design_in-kind	1363	-5.32	8.1518	-1.35	8.26	0.00019	2.58	528.66	51.94	0.14
1	212.9068	2015_025yr(Surge	Design_Exist	1363	-5.32	8.5017	3.86	9.79	0.004352	9.09	149.94	52.44	0.47
1	212.9068	2018_050yr(Surge	Design_20'	1772	-5.32	8.1177	-0.67	8.29	0.000324	3.36	526.89	51.89	0.19
1	212.9068	2015_050yr(Surge	Design_12'	1772	-5.32	8.1177	-0.67	8.29	0.000324	3.36	526.89	51.89	0.19
1	212.9068	2015_050yr(Surge	Design_in-kind	1772	-5.32	8.1177	-0.67	8.29	0.000324	3.36	526.89	51.89	0.19
1	212.9068	2015_050yr(Surge	Design_Exist	1772	-5.32	10.9854	5.2	11.09	0.000214	2.62	759.75	206.15	0.13
1	212.9068	015_100yr(Surge)	Design_20'	2267	-5.32	8.0632	0.09	8.35	0.000538	4.33	524.07	51.81	0.24
1	212.9068	015_100yr(Surge)	Design_12'	2267	-5.32	8.0632	0.09	8.35	0.000538	4.33	524.07	51.81	0.24
1	212.9068	015_100yr(Surge)	Design_in-kind	2267	-5.32	8.0632	0.09	8.35	0.000538	4.33	524.07	51.81	0.24
1	212.9068	015_100yr(Surge)	Design_Exist	2267	-5.32	10.6528	6.71	10.84	0.000391	3.49	699.71	150.79	0.18
1	208.0453	2018_002yr	Design_Exist	254	-5.32	6.0415	-0.81	6.12	0.00034	2.25	112.66	49.15	0.13
1	208.0453	2018_010yr	Design_Exist	924	-5.32	7.7022	2.47	8.45	0.002773	6.94	133.21	51.59	0.37
1	208.0453	2018_025y	Design_Exist	1363	-5.32	8.2652	4.14	9.73	0.005214	9.72	140.19	52.41	0.51
1	208.0453	2018_050yr	Design_Exist	1772	-5.32	8.4445	5.54	10.85	0.008426	12.44	142.42	52.68	0.65
1	208.0453	2018_100yr	Design_Exist	2267	-5.32	10.6431	7.07	10.83	0.0004	3.52	691.88	154.61	0.18
1	208.0453	2018_500yr	Design_Exist	3078	-5.32	11.3072	9.39	11.6	0.000589	4.41	814.53	219.19	0.22
1	208.0453	2018_25yr_MHHW_M	Design_Exist	1363.01	-5.32	8.2644	4.14	9.73	0.005216	9.72	140.18	52.41	0.51
1	208.0453	2018_25yr_MSL_Ma	Design_Exist	1363	-5.32	8.2597	4.14	9.73	0.005222	9.73	140.13	52.41	0.51
1	208.0453	2100_025yr_Ab1	Design_Exist	1930	-5.32	10.2611	6.04	10.41	0.000328	3.12	638.1	129.12	0.16
1	208.0453	2100_050yr_Ab1	Design_Exist	1946	-5.32	10.277	6.1	10.43	0.000331	3.14	640.17	129.48	0.17
1	208.0453	2100_100yr_Ab1	Design_Exist	2943	-5.32	11.2148	9.01	11.49	0.000556	4.27	794.57	212.82	0.22
1	208.0453	2015_025yr(Surge	Design_Exist	1363	-5.32	8.2781	4.14	9.74	0.005197	9.71	140.35	52.43	0.51
1	208.0453	2015_050yr(Surge	Design_Exist	1772	-5.32	8.4561	5.54	10.86	0.008402	12.43	142.56	52.69	0.65
1	208.0453	015_100yr(Surge)	Design_Exist	2267	-5.32	10.6473	7.07	10.84	0.000399	3.52	692.52	154.88	0.18
1	203.1735	2018_002yr	Design_Exist	254	-5.32	6.0921	-0.8	6.1	0.000021	0.64	398.09	49.23	0.04
1	203.1735	2018_010yr	Design_Exist	924	-5.32	8.1871	2.47	8.24	0.000137	1.83	504.44	52.3	0.1
1	203.1735	2018_025y	Design_Exist	1363	-5.32	9.2244	4.14	9.32	0.00022	2.44	559.48	53.81	0.13
1	203.1735	2018_050yr	Design_Exist	1772	-5.32	10.0302	4.6	10.16	0.000296	2.94	606.8	125.18	0.16
1	203.1735	2018_100yr	Design_Exist	2267	-5.32	10.6405	4.6	10.83	0.0004	3.52	692.46	159.73	0.18
1	203.1735	2018_500yr	Design_Exist	3078	-5.32	11.3039	4.6	11.6	0.000588	4.41	818.44	222.15	0.22
1	203.1735	2018_25yr_MHHW_M	Design_Exist	1363.01	-5.32	9.2238	4.14	9.32	0.00022	2.44	559.44	53.81	0.13
1	203.1735	2018_25yr_MSL_Ma	Design_Exist	1363	-5.32	9.2199	4.14	9.31	0.00022	2.44	559.23	53.81	0.13
1	203.1735	2100_025yr_Ab1	Design_Exist	1930	-5.32	10.2589	4.6	10.41	0.000328	3.13	636.02	134.49	0.16
1	203.1735	2100_050yr_Ab1	Design_Exist	1946	-5.32	10.2748	4.6	10.43	0.000332	3.15	638.18	136.18	0.17
1	203.1735	2100_100yr_Ab1	Design_Exist	2943	-5.32	11.2116	4.6	11.49	0.000556	4.27	798.16	217.13	0.22
1	203.1735	2015_025yr(Surge	Design_Exist	1363	-5.32	9.2352	4.14	9.33	0.000219	2.43	560.05	53.83	0.13
1	203.1735	2015_050yr(Surge	Design_Exist	1772	-5.32	10.0385	4.6	10.17	0.000296	2.93	607.84	125.36	0.16
1	203.1735	015_100yr(Surge)	Design_Exist	2267	-5.32	10.6446	4.6	10.84	0.000399	3.52	693.13	159.99	0.18
1	170.7372	2018_002yr	Design_20'	254	-5.32	4.769		4.77	0.000006	0.47	545.48	69.44	0.03
1	170.7372	2018_002yr	Design_12'	254	-5.32	4.769		4.77	0.000006	0.47	545.48	69.44	0.03
1	170.7372	2018_002yr	Design_in-kind	254	-5.32	4.769		4.77	0.000006	0.47	545.48	69.44	0.03
1	170.7372	2018_002yr	Design_Exist	254	-5.32	4.769		4.77	0.000006	0.47	545.48	69.44	0.03
1	170.7372	2018_010yr	Design_20'	924	-5.32	4.7565		4.8	0.000085	1.7	544.61	69.4	0.11
1	170.7372	2018_010yr	Design_12'	924	-5.32	4.7565		4.8	0.000085	1.7	544.61	69.4	0.11
1	170.7372	2018_010yr	Design_in-kind	924	-5.32	4.7565		4.8	0.000085	1.7	544.61	69.4	0.11
1	170.7372	2018_010yr	Design_Exist	924	-5.32	4.7565		4.8	0.000085	1.7	544.61	69.4	0.11
1	170.7372	2018_025y	Design_20'	1363	-5.32	4.7403		4.84	0.000186	2.51	543.49	69.36	0.16
1	170.7372	2018_025y	Design_12'	1363	-5.32	4.7403		4.84	0.000186	2.51	543.49	69.36	0.16
1	170.7372	2018_025y	Design_in-kind	1363	-5.32	4.7403		4.84	0.000186	2.51	543.49	69.36	0.16
1	170.7372	2018_025y	Design_Exist	1363	-5.32	4.7403		4.84	0.000186	2.51	543.49	69.36	0.16
1	170.7372	2018_050yr	Design_20'	1772	-5.32	4.7193		4.89	0.000317	3.27	542.03	69.29	0.21
1	170.7372	2018_050yr	Design_12'	1772	-5.32	4.7193		4.89	0.000317	3.27	542.03	69.29	0.21
1	170.7372	2018_050yr	Design_in-kind	1772	-5.32	4.7193		4.89	0.000317	3.27	542.03	69.29	0.21
1	170.7372	2018_050yr	Design_Exist	1772	-5.32	4.7193		4.89	0.000317	3.27	542.03	69.29	0.21
1	170.7372	2018_100yr	Design_20'	2267	-5.32	4.6856		4.96	0.000525	4.2	539.7	69.19	0.27
1	170.7372	2018_100yr	Design_12'	2267	-5.32	4.6856		4.96	0.000525	4.2	539.7	69.19	0.27
1	170.7372	2018_100yr	Design_in-kind	2267	-5.32	4.6856		4.96	0.000525	4.2	539.7	69.19	0.27
1	170.7372	2018_100yr	Design_Exist	2267	-5.32	4.6856		4.96	0.000525	4.2	539.7	69.19	0.27
1	170.7372	2018_500yr	Design_20'	3078	-5.32	4.6065		5.12	0.000996	5.76	534.23	68.95	0.36
1	170.7372	2018_500yr	Design_12'	3078	-5.32	4.6065		5.12	0.000996	5.76	534.23	68.95	0.36
1	170.7372	2018_500yr	Design_in-kind	3078	-5.32	4.6065		5.12	0.000996	5.76	534.23	68.95	0.36
1	170.7372	2018_500yr	Design_Exist	3078	-5.32	4.6065		5.12	0.000996	5.76	534.23	68.95	0.36

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	170.7372	2018_25yr_MHHW_M	Design_20'	1363.01	-5.32	5.7279		5.8	0.00013	2.22	613.47	72.37	0.13
1	170.7372	2018_25yr_MHHW_M	Design_12'	1363.01	-5.32	5.7279		5.8	0.00013	2.22	613.47	72.37	0.13
1	170.7372	2018_25yr_MHHW_M	Design_in-kind	1363.01	-5.32	5.7279		5.8	0.00013	2.22	613.47	72.37	0.13
1	170.7372	2018_25yr_MHHW_M	Design_Exist	1363.01	-5.32	5.7279		5.8	0.00013	2.22	613.47	72.37	0.13
1	170.7372	2018_25yr_MSL_Ma	Design_20'	1363	-5.32	0.5328		0.9	0.001269	4.89	278.65	56.53	0.39
1	170.7372	2018_25yr_MSL_Ma	Design_12'	1363	-5.32	0.5328		0.9	0.001269	4.89	278.65	56.53	0.39
1	170.7372	2018_25yr_MSL_Ma	Design_in-kind	1363	-5.32	0.5328		0.9	0.001269	4.89	278.65	56.53	0.39
1	170.7372	2018_25yr_MSL_Ma	Design_Exist	1363	-5.32	0.5328		0.9	0.001269	4.89	278.65	56.53	0.39
1	170.7372	2100_025yr_Ab1	Design_20'	1930	-5.32	6.736		6.86	0.00018	2.81	693.42	88.16	0.16
1	170.7372	2100_025yr_Ab1	Design_12'	1930	-5.32	6.736		6.86	0.00018	2.81	693.42	88.16	0.16
1	170.7372	2100_025yr_Ab1	Design_in-kind	1930	-5.32	6.736		6.86	0.00018	2.81	693.42	88.16	0.16
1	170.7372	2100_025yr_Ab1	Design_Exist	1930	-5.32	6.736		6.86	0.00018	2.81	693.42	88.16	0.16
1	170.7372	2100_050yr_Ab1	Design_20'	1946	-5.32	6.7354		6.86	0.000183	2.84	693.37	88.15	0.16
1	170.7372	2100_050yr_Ab1	Design_12'	1946	-5.32	6.7354		6.86	0.000183	2.84	693.37	88.15	0.16
1	170.7372	2100_050yr_Ab1	Design_in-kind	1946	-5.32	6.7354		6.86	0.000183	2.84	693.37	88.15	0.16
1	170.7372	2100_050yr_Ab1	Design_Exist	1946	-5.32	6.7354		6.86	0.000183	2.84	693.37	88.15	0.16
1	170.7372	2100_100yr_Ab1	Design_20'	2943	-5.32	6.6891		6.98	0.000425	4.31	689.3	87.47	0.25
1	170.7372	2100_100yr_Ab1	Design_12'	2943	-5.32	6.6891		6.98	0.000425	4.31	689.3	87.47	0.25
1	170.7372	2100_100yr_Ab1	Design_in-kind	2943	-5.32	6.6891		6.98	0.000425	4.31	689.3	87.47	0.25
1	170.7372	2100_100yr_Ab1	Design_Exist	2943	-5.32	6.6891		6.98	0.000425	4.31	689.3	87.47	0.25
1	170.7372	2018_025yr(Surge	Design_20'	1363	-5.32	8.1886		8.23	0.000055	1.71	840.3	120.18	0.09
1	170.7372	2015_025yr(Surge	Design_12'	1363	-5.32	8.1886		8.23	0.000055	1.71	840.3	120.18	0.09
1	170.7372	2015_025yr(Surge	Design_in-kind	1363	-5.32	8.1886		8.23	0.000055	1.71	840.3	120.18	0.09
1	170.7372	2015_025yr(Surge	Design_Exist	1363	-5.32	8.1886		8.23	0.000055	1.71	840.3	120.18	0.09
1	170.7372	2018_050yr(Surge	Design_20'	1772	-5.32	8.1806		8.26	0.000093	2.22	839.35	120	0.12
1	170.7372	2015_050yr(Surge	Design_12'	1772	-5.32	8.1806		8.26	0.000093	2.22	839.35	120	0.12
1	170.7372	2015_050yr(Surge	Design_in-kind	1772	-5.32	8.1806		8.26	0.000093	2.22	839.35	120	0.12
1	170.7372	2015_050yr(Surge	Design_Exist	1772	-5.32	8.1806		8.26	0.000093	2.22	839.35	120	0.12
1	170.7372	015_100yr(Surge)	Design_20'	2267	-5.32	8.168		8.29	0.000153	2.85	837.84	119.73	0.15
1	170.7372	015_100yr(Surge)	Design_12'	2267	-5.32	8.168		8.29	0.000153	2.85	837.84	119.73	0.15
1	170.7372	015_100yr(Surge)	Design_in-kind	2267	-5.32	8.168		8.29	0.000153	2.85	837.84	119.73	0.15
1	170.7372	015_100yr(Surge)	Design_Exist	2267	-5.32	8.168		8.29	0.000153	2.85	837.84	119.73	0.15
1	136.7287	2018_002yr	Design_20'	254	-7.5	4.77	-6.55	4.77	0.000002	0.34	793.66	96.66	0.02
1	136.7287	2018_002yr	Design_12'	254	-7.5	4.77	-6.55	4.77	0.000002	0.34	793.66	96.66	0.02
1	136.7287	2018_002yr	Design_in-kind	254	-7.5	4.77	-6.55	4.77	0.000002	0.34	793.66	96.66	0.02
1	136.7287	2018_002yr	Design_Exist	254	-7.5	4.77	-6.55	4.77	0.000002	0.34	793.66	96.66	0.02
1	136.7287	2018_010yr	Design_20'	924	-7.5	4.77	-5.29	4.79	0.000028	1.23	793.66	96.66	0.07
1	136.7287	2018_010yr	Design_12'	924	-7.5	4.77	-5.29	4.79	0.000028	1.23	793.66	96.66	0.07
1	136.7287	2018_010yr	Design_in-kind	924	-7.5	4.77	-5.29	4.79	0.000028	1.23	793.66	96.66	0.07
1	136.7287	2018_010yr	Design_Exist	924	-7.5	4.77	-5.29	4.79	0.000028	1.23	793.66	96.66	0.07
1	136.7287	2018_025y	Design_20'	1363	-7.5	4.77	-4.65	4.82	0.000061	1.81	793.66	96.66	0.1
1	136.7287	2018_025y	Design_12'	1363	-7.5	4.77	-4.65	4.82	0.000061	1.81	793.66	96.66	0.1
1	136.7287	2018_025y	Design_in-kind	1363	-7.5	4.77	-4.65	4.82	0.000061	1.81	793.66	96.66	0.1
1	136.7287	2018_025y	Design_Exist	1363	-7.5	4.77	-4.65	4.82	0.000061	1.81	793.66	96.66	0.1
1	136.7287	2018_050yr	Design_20'	1772	-7.5	4.77	-4.12	4.86	0.000104	2.35	793.66	96.66	0.13
1	136.7287	2018_050yr	Design_12'	1772	-7.5	4.77	-4.12	4.86	0.000104	2.35	793.66	96.66	0.13
1	136.7287	2018_050yr	Design_in-kind	1772	-7.5	4.77	-4.12	4.86	0.000104	2.35	793.66	96.66	0.13
1	136.7287	2018_050yr	Design_Exist	1772	-7.5	4.77	-4.12	4.86	0.000104	2.35	793.66	96.66	0.13
1	136.7287	2018_100yr	Design_20'	2267	-7.5	4.77	-3.54	4.91	0.00017	3.01	793.66	96.66	0.16
1	136.7287	2018_100yr	Design_12'	2267	-7.5	4.77	-3.52	4.91	0.00017	3.01	793.66	96.66	0.16
1	136.7287	2018_100yr	Design_in-kind	2267	-7.5	4.77	-3.52	4.91	0.00017	3.01	793.66	96.66	0.16
1	136.7287	2018_100yr	Design_Exist	2267	-7.5	4.77	-3.52	4.91	0.00017	3.01	793.66	96.66	0.16
1	136.7287	2018_500yr	Design_20'	3078	-7.5	4.77	-2.66	5.03	0.000313	4.08	793.66	96.66	0.22
1	136.7287	2018_500yr	Design_12'	3078	-7.5	4.77	-2.66	5.03	0.000313	4.08	793.66	96.66	0.22
1	136.7287	2018_500yr	Design_in-kind	3078	-7.5	4.77	-2.66	5.03	0.000313	4.08	793.66	96.66	0.22
1	136.7287	2018_500yr	Design_Exist	3078	-7.5	4.77	-2.66	5.03	0.000313	4.08	793.66	96.66	0.22
1	136.7287	2018_25yr_MHHW_M	Design_20'	1363.01	-7.5	5.75	-4.65	5.79	0.000046	1.65	893.87	107.84	0.08
1	136.7287	2018_25yr_MHHW_M	Design_12'	1363.01	-7.5	5.75	-4.65	5.79	0.000046	1.65	893.87	107.84	0.08
1	136.7287	2018_25yr_MHHW_M	Design_in-kind	1363.01	-7.5	5.75	-4.65	5.79	0.000046	1.65	893.87	107.84	0.08
1	136.7287	2018_25yr_MHHW_M	Design_Exist	1363.01	-7.5	5.75	-4.65	5.79	0.000046	1.65	893.87	107.84	0.08
1	136.7287	2018_25yr_MSL_Ma	Design_20'	1363	-7.5	0.684	-4.65	0.81	0.000273	2.89	473.24	68.64	0.19
1	136.7287	2018_25yr_MSL_Ma	Design_12'	1363	-7.5	0.684	-4.65	0.81	0.000273	2.89	473.24	68.64	0.19
1	136.7287	2018_25yr_MSL_Ma	Design_in-kind	1363	-7.5	0.684	-4.65	0.81	0.000273	2.89	473.24	68.64	0.19
1	136.7287	2018_25yr_MSL_Ma	Design_Exist	1363	-7.5	0.684	-4.65	0.81	0.000273	2.89	473.24	68.64	0.19
1	136.7287	2100_025yr_Ab1	Design_20'	1930	-7.5	6.77	-3.93	6.84	0.000068	2.13	1009.81	119.48	0.1
1	136.7287	2100_025yr_Ab1	Design_12'	1930	-7.5	6.77	-3.93	6.84	0.000068	2.13	1009.81	119.48	0.1
1	136.7287	2100_025yr_Ab1	Design_in-kind	1930	-7.5	6.77	-3.93	6.84	0.000068	2.13	1009.81	119.48	0.1
1	136.7287	2100_025yr_Ab1	Design_Exist	1930	-7.5	6.77	-3.93	6.84	0.000068	2.13	1009.81	119.48	0.1
1	136.7287	2100_050yr_Ab1	Design_20'	1946	-7.5	6.77	-3.91	6.84	0.00007	2.15	1009.81	119.48	0.11
1	136.7287	2100_050yr_Ab1	Design_12'	1946	-7.5	6.77	-3.91	6.84	0.00007	2.15	1009.81	119.48	0.11
1	136.7287	2100_050yr_Ab1	Design_in-kind	1946	-7.5	6.77	-3.91	6.84	0.00007	2.15	1009.81	119.48	0.11

Reach	River Sta	Profile	Plan	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
1	136.7287	2100_050yr_Ab1	Design_Exist	1946	-7.5	6.77	-3.91	6.84	0.00007	2.15	1009.81	119.48	0.11
1	136.7287	2100_100yr_Ab1	Design_20'	2943	-7.5	6.77	-2.8	6.93	0.000159	3.25	1009.81	119.48	0.16
1	136.7287	2100_100yr_Ab1	Design_12'	2943	-7.5	6.77	-2.8	6.93	0.000159	3.25	1009.81	119.48	0.16
1	136.7287	2100_100yr_Ab1	Design_in-kind	2943	-7.5	6.77	-2.8	6.93	0.000159	3.25	1009.81	119.48	0.16
1	136.7287	2100_100yr_Ab1	Design_Exist	2943	-7.5	6.77	-2.8	6.93	0.000159	3.25	1009.81	119.48	0.16
1	136.7287	2018_025yr(Surge	Design_20'	1363	-7.5	8.2	-4.65	8.23	0.000023	1.34	1199.56	147.66	0.06
1	136.7287	2015_025yr(Surge	Design_12'	1363	-7.5	8.2	-4.65	8.23	0.000023	1.34	1199.56	147.66	0.06
1	136.7287	2015_025yr(Surge	Design_in-kind	1363	-7.5	8.2	-4.65	8.23	0.000023	1.34	1199.56	147.66	0.06
1	136.7287	2015_025yr(Surge	Design_Exist	1363	-7.5	8.2	-4.65	8.23	0.000023	1.34	1199.56	147.66	0.06
1	136.7287	2018_050yr(Surge	Design_20'	1772	-7.5	8.2	-4.12	8.25	0.00004	1.74	1199.56	147.66	0.08
1	136.7287	2015_050yr(Surge	Design_12'	1772	-7.5	8.2	-4.12	8.25	0.00004	1.74	1199.56	147.66	0.08
1	136.7287	2015_050yr(Surge	Design_in-kind	1772	-7.5	8.2	-4.12	8.25	0.00004	1.74	1199.56	147.66	0.08
1	136.7287	2015_050yr(Surge	Design_Exist	1772	-7.5	8.2	-4.12	8.25	0.00004	1.74	1199.56	147.66	0.08
1	136.7287	015_100yr(Surge)	Design_20'	2267	-7.5	8.2	-3.52	8.27	0.000065	2.23	1199.56	147.66	0.1
1	136.7287	015_100yr(Surge)	Design_12'	2267	-7.5	8.2	-3.52	8.27	0.000065	2.23	1199.56	147.66	0.1
1	136.7287	015_100yr(Surge)	Design_in-kind	2267	-7.5	8.2	-3.52	8.27	0.000065	2.23	1199.56	147.66	0.1
1	136.7287	015_100yr(Surge)	Design_Exist	2267	-7.5	8.2	-3.52	8.27	0.000065	2.23	1199.56	147.66	0.1

ATTACHMENT D

Scour Results

SCOUR ANALYSIS - CONTRACTION SCOUR & ABUTMENT SCOUR

Modified Laursen's Equation (1960), Laursens (1963), and NCHRP

Tighe&Bond

Bridge/Culvert Name:	MBTS Central Street Bridge - Proposed 20-Foot Concrete Arch Culvert
Town	Manhcester by the Sea (MBTS)
Lat:	42.575253
Long:	-70.77288
Storm Size:	50-Year
HEC-RAS Proj:	SawmillBrookDownstream
HEC-RAS Geom:	SawmillBrk_Design20'
HEC-RAS XS1	328.7
HEC-RAS XS2	260.6 (just upstream of culvert)

Notes

(1) Governing storms are 50-year for Scour Design and 100-Year for Scour Check (based on Table 1.3.4-1 in the MassDOT LRFD Bridge Manual.

(2) for scour at open-bottom culverts, refer to HEC-18 for equations

(3) left bank and right bank defined from looking downstream

Data Input

Description	Item	LOB	CHANNEL	ROB
Constant for Critical Velocity Calculation (English Units)	Ku (crit)	11.17	11.17	11.17
Constant for Clear-Water Scour Calculations (English Units)	Ku (CW-cont)	0.0077	0.0077	0.0077
Constant for Open Bottom Culvert Contraction Scour Calc	Ku (Open-Bottom)	0.84	0.84	0.84
Hydraulic Depth at XS 1	y_1 (ft)	1.37	8.78	0.16
Hydraulic Depth at XS 1 (for Critical Velocity Calculation)	y (ft)	**1.37**	**8.78**	**0.16**
Hydraulic Depth at XS 2 Prior to Scour	y_0 (ft)		5.8	
Flow at XS 1	Q_1 (ft^3/s)	79.23	1686.97	5.8
Flow at XS 2	Q_2 (ft^3/s)		1772	
Top Width at XS1	W_1 (ft)	22.24	26.6	68.62
Top Width at XS2	W_2 (ft)		22.32	
Unit Discharge at XS1	q_1 (ft^2/s)	**3.56**	**63.42**	**0.08**
Unit Discharge at XS2	q_2 (ft^2/s)		**79.39**	
Velocity at XS1	V_1 (ft/s)	2.61	7.22	0.53
Velocity at XS1 (For Critical Scour Equation V is V1)	V (ft/s)	**2.61**	**7.22**	**0.53**
Energy Grade Line at XS1	S_1	0.002722	0.002722	0.002722
D50 from Sieve Analysis	D50 (mm)	0.275	0.275	0.275
D50 from Sieve Analysis with Convesrion from mm to ft	D50 (ft)	0.000902	0.000902	0.000902

Critical Velocity

$$V_c = K_u y^{1/6} D^{1/3}$$

Input:

	LOB	CHANNEL	ROB	
Ku (crit)	11.17	11.17	11.17	<- constant English units
y (ft)	1.37	8.78	0.16	<- hydraulic depth from HEC-RAS upstream cross section
D50 (ft)	0.000902	0.000902	0.000902	<- based on sieve analysis
V (ft/s)	2.61	7.22	0.53	<- mean channel velocity in HEC-RAS

Output:

	LOB	CHANNEL	ROB
Vc (ft/s)	**1.137**	**1.550**	**0.795**
Clear-Water ??	NO	NO	YES
Live-Bed ??	YES	YES	NO
Construction Scour	**Live-Bed**	**Live-Bed**	**Clear-Water**

SCOUR ANALYSIS - CONTRACTION SCOUR & ABUTMENT SCOUR

Modified Laursen's Equation (1960), Laursens (1963), and NCHRP

Tighe&Bond

Live-Bed Contraction Scour

$$y_2 = y_1 \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k_1} \qquad y_s = y_2 - y_0$$

Input:

	LOB	CHANNEL	ROB	
y1 (ft)	1.37	8.78		
y0 (ft)	0	5.8		<- assumed that this is the same approx. as y1
Q_1 (ft^3/s)	79.23	1686.97		<- flow for design storm assuming all going into channel
Q_2 (ft^3/s)	0	1772		<- assuming no overtopping, all flow goes through
W1 (ft)	22.24	26.6		<- based on upstream cross section top width HEC-RAS at design stor
W2 (ft)	0	22.32		<- based on proposed structure clear span HEC-RAS at design storm
S1	0.002722	0.002722		<- from HEC-RAS
V* (ft/s)	0.347	0.877		<- calculated
D50 (mm)	0.275	0.275		
T (ft/s)	0.036123	0.036123		<- input from figure 6.8 (estimated using polynomial best fit)

Intermediate Calcs:

	LOB	CHANNEL	ROB
k1	0.69	0.69	
y2	N/A No Flow	9.500761239	

Output:

	LOB	CHANNEL	ROB	
ys (ft)	N/A No Flow	3.700761239		<- predicted scour depth for Live-Bed

Clear-Water Contraction Scour

$$y_2 = \left[\frac{K_u Q^2}{D_m^{2/3} W^2}\right]^{3/7} \qquad y_s = y_2 - y_0$$

Input:

	LOB	CHANNEL	ROB	
Q_2 (ft^3/s)			0	
D50 (ft)			0.000902	<- assumed about 0.25"
Dm (ft)	-	-	0.0011275	<- calculated based on D50
W_2 (ft)			0	<- based on HEC-RAS
y0 (ft)			0	<- based on HEC-RAS
Ku (CW-cont)			0.0077	<- constant

Intermediate Calcs:

	LOB	CHANNEL	ROB
y2 (ft)			N/A No Flow

Output:

	LOB	CHANNEL	ROB
ys (ft)			N/A No Flow

Take Live-Bed where applicable and Contraction Scour where applicable.

TOTAL CONTRACTION SCOUR ESTIMATED: (feet)	Left Bank	Channel	Right Bank
	N/A No Flow	3.701	N/A No Flow

Tighe&Bond

SCOUR ANALYSIS - CONTRACTION SCOUR & ABUTMENT SCOUR

Modified Laursen's Equation (1960), Laursens (1963), and NCHRP

Clear-Water Scour Equation for Open-Bottom Culverts (with WingWall)

$$y_{max} = K_u Q_{BI}^{0.28} \left(\frac{Q}{W_C D_{50}^{1/3}} \right)^{0.26}$$

$$y_s = y_2 - y_0$$

		CHANNEL	
Input:	Ku (Open-Bottom)	0.84	<- 0.84 english units; 1.16 SI units
	QBI (cfs)	8.19	<- Discharge blocked by road embankment on one side of culvert (estimated using HEC-RAS Flow Tubes)
	Q_2 (ft^3/s)	1772	
	Wc (ft)	20	<- Culvert Width
	D50 (ft)	0.001	
	y0 (ft)	5.800	
	ymax (ft)	8.917	
	ys (ft)	3.117	

CONTRACTION SCOUR ESTIMATE FOR OPEN BOTTOM CULVERT (feet)	**Open Bottom Culvert Scour**
	3.117

Abutment Scour

$$y_{max} = \alpha_A \, y_c$$

$$y_s = y_{max} - y_0$$

Input:

	LOB	CHANNEL	ROB	
q_1 (ft^2/s)	3.5625	63.41992481	0.084523463	<- Unit Discharge at XS1
q_2 (ft^2/s)		79.390681		<- Unit Discharge at XS2
q_2/q_1		1.25182553		
y0 (ft)		5.8		<- based on HEC-RAS
NCHRP Figure		Figure 8.10		<- based on HEC-RAS
yc		9.501		<- flow depth including scour (maximum y_{max} or y_2)
α_A		1.75		<- From NCHRP Figures
Intermediate Calcs:				
ymax		16.63		
Output:				
ys (ft)	N/A No Flow	10.8	N/A No Flow	<- abutment scour

SCOUR ANALYSIS - CONTRACTION SCOUR & ABUTMENT SCOUR

Modified Laursen's Equation (1960) and Laursens (1963)

Tighe&Bond

Bridge/Culvert Name: MBTS Central Street Bridge - Proposed 20-Foot Concrete Arch Culvert
Town Manhcester by the Sea (MBTS)
Lat: 42.575253
Long: -70.77288

Storm Size: 100-Year
HEC-RAS Proj: SawmillBrookDownstream
HEC-RAS Geom: SawmillBrk_Design20'
HEC-RAS XS1 328.7
HEC-RAS XS2 260.6 (just upstream of culvert)

Notes
(1) Governing storms are 50-year for Scour Design and 100-Year for Scour Check (based on Table 1.3.4-1 in the MassDOT LRFD Bridge Manual.
(2) for scour at open-bottom culverts, refer to HEC-18 for equations
(3) left bank and right bank defined from looking downstream

Data Input

Description	Item	LOB	CHANNEL	ROB
Constant for Critical Velocity Calculation (English Units)	Ku (crit)	11.17	11.17	11.17
Constant for Clear-Water Scour Calculations (English Units)	Ku (CW-cont.)	0.0077	0.0077	0.0077
Constant for Open Bottom Culvert Contraction Scour Calc	Ku (Open-Bottom)	0.84	0.84	0.84
Hydraulic Depth at XS 1	y_1 (ft)	2.08	10.72	1.55
Hydraulic Depth at XS 1 (for Critical Velocity Calculation)	y (ft)	**2.08**	**10.72**	**1.55**
Hydraulic Depth at XS 2 Prior to Scour	y_0 (ft)		6.8	
Flow at XS 1	Q_1 (ft^3/s)	218.41	1519.41	529.18
Flow at XS 2	Q_2 (ft^3/s)		2267	
Top Width at XS1	W_1 (ft)	44.42	26.6	204.43
Top Width at XS2	W_2 (ft)		22.53	
Unit Discharge at XS1	q_1 (ft^2/s)	**4.92**	**57.12**	**2.59**
Unit Discharge at XS2	q_2 (ft^2/s)		**100.62**	
Velocity at XS1	V_1 (ft/s)	2.36	5.33	1.67
Velocity at XS1 (For Critical Scour Equation V is V1)	V (ft/s)	**2.36**	**5.33**	**1.67**
Energy Grade Line at XS1	S_1	0.00427	0.00427	0.00427
D50 from Sieve Analysis	D50 (mm)	0.275	0.275	0.275
D50 from Sieve Analysis with Conversion from mm to ft	D50 (ft)	0.000902	0.000902	0.000902

Critical Velocity

$$V_c = K_u y^{1/6} D^{1/3}$$

Input:

	LOB	CHANNEL	ROB	
Ku (crit)	11.17	11.17	11.17	<- constant English units
y (ft)	2.08	10.72	1.55	<- hydraulic depth from HEC-RAS upstream cross section
D50 (ft)	0.000902	0.000902	0.000902	<- based on sieve analysis
V (ft/s)	2.36	5.33	1.67	<- mean channel velocity in HEC-RAS

Output:

	LOB	CHANNEL	ROB
Vc (ft/s)	**1.219**	**1.603**	**1.161**
Clear-Water ??	NO	NO	NO
Live-Bed ??	YES	YES	YES
Construction Scour	**Live-Bed**	**Live-Bed**	**Live-Bed**

SCOUR ANALYSIS - CONTRACTION SCOUR & ABUTMENT SCOUR

Modified Laursen's Equation (1960) and Laursens (1963)

Tighe&Bond

Live-Bed Contraction Scour

$$y_2 = y_1 \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k_1} \qquad y_s = y_2 - y_0$$

Input:

	LOB	CHANNEL	ROB	
y1 (ft)	2.08	10.72	1.55	
y0 (ft)	0	6.8	0	<- assumed that this is the same approx. as y1
Q_1 (ft^3/s)	218.41	1519.41	529.18	<- flow for design storm assuming all going into channel
Q_2 (ft^3/s)	0	2267	0	<- assuming no overtopping, all flow goes through
W1 (ft)	44.42	26.6	204.43	<- based on upstream cross section top width HEC-RAS at design stor
W2 (ft)	0	22.53	0	<- based on proposed structure clear span HEC-RAS at design storm
S1	0.00427	0.00427	0.00427	<- from HEC-RAS
V* (ft/s)	0.535	1.214	0.462	<- calculated
D50 (mm)	0.275	0.275	0.275	
T (ft/s)	0.036123	0.036123	0.036123	<- input from figure 6.8 (estimated using polynomial best fit)

Intermediate Calcs:

	LOB	CHANNEL	ROB
k1	0.69	0.69	0.69
y2	N/A No Flow	8.531130248	N/A No Flow

Output:

	LOB	CHANNEL	ROB	
ys (ft)	N/A No Flow	1.731130248	N/A No Flow	<- predicted scour depth for Live-Bed

Clear-Water Contraction Scour

$$y_2 = \left[\frac{K_u Q^2}{D_m^{2/3} W^2}\right]^{3/7} \qquad y_s = y_2 - y_0$$

Input:

	LOB	CHANNEL	ROB	
Q_2 (ft^3/s)				
D50 (ft)				<- assumed about 0.25"
Dm (ft)	-	-	-	<- calculated based on D50
W_2 (ft)				<- based on HEC-RAS
y0 (ft)				<- based on HEC-RAS
Ku (CW-cont)				<- constant

Intermediate Calcs:

	LOB	CHANNEL	ROB
y2 (ft)			

Output:

	LOB	CHANNEL	ROB
ys (ft)			

Take Live-Bed where applicable and Contraction Scour where applicable.

TOTAL CONTRACTION SCOUR ESTIMATED: (feet)

Left Bank	Channel	Right Bank
N/A No Flow	1.731	N/A No Flow

SCOUR ANALYSIS - CONTRACTION SCOUR & ABUTMENT SCOUR

Tighe&Bond

Modified Laursen's Equation (1960) and Laursens (1963)

Clear-Water Scour Equation for Open-Bottom Culverts (with WingWall)

$$y_{max} = K_u Q_{BI}^{0.28} \left(\frac{Q}{W_C D_{50}^{1/3}} \right)^{0.26}$$

$$y_s = y_2 - y_0$$

Input:		CHANNEL	
	Ku (Open-Bottom)	0.84	<- 0.84 english units; 1.16 SI units
	QBI (cfs)	13.29	<- Discharge blocked by road embankement on one side of culvert (estimated using HEC-RAS Flow Tubes)
	Q_2 (ft^3/s)	2267	
	Wc (ft)	20	<- Culvert Width
	D50 (ft)	0.001	
	y0 (ft)	6.800	
	ymax (ft)	10.887	
	ys (ft)	4.087	

CONTRACTION SCOUR ESTIMATE FOR OPEN BOTTOM CULVERT (feet)	**Open Bottom Culvert Scour**
	4.087

Abutment Scour

$$y_{max} = \propto_A y_c$$

$$y_s = y_{max} - y_0$$

Input:

	LOB	CHANNEL	ROB	
q_1 (ft^2/s)	4.916929311	57.12067669	2.588563322	<- Unit Discharge at XS1
q_2 (ft^2/s)		100.6213937		<- Unit Discharge at XS2
q_2/q_1		1.761558152		
y0 (ft)	0	6.8	0	<- based on HEC-RAS
NCHRP Figure		Figure 8.10		<- based on HEC-RAS
yc		10.887		<- flow depth including scour (maximum y_{max} or y_2)
α_A		1.25		<- From NCHRP Figures

Intermediate Calcs:

ymax	13.61

ABUTMENT SCOUR		LOB	CHANNEL	ROB	
	ys (ft)	**N/A No Flow**	**6.8**	**N/A No Flow**	<- abutment scour

SCOUR ANALYSIS - LONG-TERM AGGREGATION/DEGRADATION

QUALITATIVE AND QUANTITATIVE APPROACHES

Tighe&Bond

Bridge/Culvert Name: MBTS Central Street Bridge - Proposed 20-Foot Concrete Arch
Town: Manchester by the Sea (MBTS)
Lat: 42.575253
Long: -70.77288

Notes
(1) Governing storms are 50-year for Scour Design and 100-Year for Scour Check (based on Table 1.3.4-1 in the MassDOT LRFD Bridge
(2) Qualitative and Quantitative analyses below reference HEC-20 FHWA approach

HEC-20 (6.26)	Level 1 (Qualitative Geomorphic Analyses)		
	Direct Evidence		
		Land-Use Change?	Not significant (based on historical imagery from 1995
		Exposed Utility Crossings	(No Data)
		Exposed Bridge Foundations	No, existing bridge founded on bedrock.
		Channel Banks Failing Due to Excessive Height	Not Observed
		Comparison of Reference Reach Cross sections	U/S reach channelized D/S reach currently impacted by tide gate (to be
	Dams/Reservoirs Upstream/Downstream ?		Tide gate located downstream (to be removed)
	Changes in Watershed Land-Use ?		
		Urbanization	Not Significant
		Deforestation	Not Significant
		Increased Impervious	Not Significant
	Channelization		The pond and channel leading to the bridge is channelized with vertical walls.
	Cutoffs of Meander Bends (natural or manmade)		The channel has some slight meanders but is generally straight. There is an ogee shaped bend upstream of the bridge.
	Changes in Downstream Hydraulic Control		
		Rocks	(Assumed None)
		Dams	Tide gate to be removed; however, the tide gate
		Culvert	Not Significant
	Diversions of Water In/Out of Stream		None known within project area
HEC-20 (6.26)	Level 2 (Basic Engineering Analyses)		
	Watershed Sediment Yield		Based on sediment transport analysis sediment is anticipated to settle into the pond upstream of the bridge during high tide, and tend to flow out during low tide.
	Incipient Motion		Yes (See Below)
	Armoring		No (See Below)
	Rating Curve Shifts		No Data Available

HEC-20 (6.26) Level 3 (Mathematical or Physical Modeling Studies)

A sediment transport analysis was completed in the area in 2018 as part of Sediment Characterization and Flushing Studies - Sawmill Brook Flood Mitigation and Restoration Project completed in 2018 by Tighe & Bond using HEC-RAS. The analysis evaluated the effects of a bank full "channel forming flow" occurring doing mean higher high water (MHHW) tide conditions and mean lower low water (MLLW) tide conditions.

Sediment Transport/Routing Modeling

Incipient Diameter Analysis

Input:

	LOB	CHANNEL	ROB	
Q (cfs)		1772		
V (f/s)		13.68		
y (ft)		5.8		<- hydraulic depth from HEC-RAS
R (ft)		3.99		<- area / wetted perimeter (HEC-RAS)
D50 (ft)		0.0009		
D84 (ft)		0.0044		
Ku		1.486		<- constant
n		0.033		<- manually enter here, or use the calc below

Intermediate Calcs:

ks	**0.01546**	
n	**0.01243**	<- est of Manning's n based on D50 , Sturm 2001
n	**0.01620**	<- est of Manning's n based on 3.5D84, Sturm 2001
τ_0	**3.633**	

Output:

Dc (ft) **1.2**

Ks=0.03
λ=62.4
λs=(2.65*62.4)

>During design flood, hydraulic forces are adequate to transport bed material up to Dc in diameter. The gradation curve indicates the percentage of bed material that is less than or equal to this particle diameter, therefor, 100 - (this percentage) is coarser than the Dc

>If more than 5% of the bed material is coarser than Dc, then armoring is possible. See section below

Armoring Analysis

(No armoring is anticipated to occur)

Conclusions: Based on the qualitative and quantitative analysis above, the long term aggregation and degradation potential for this reach suggests that there may be potential for both sediment aggradation and degradation over time. It is anticipated that storm events occurring during higher tides will cause sediment to aggregate, while storm events during low tides will tend to cause sediment to degenerate. The shallow bedrock (within 0 to 2 feet of the channel bottom) is anticipated to act as a functional vertical control for degradation. The existing walls on either end of the channel and the pond upstream are anticipated to prevent channel migration.

Appendix D
Geotechnical Report

Central Street Bridge Replacement – Manchester-by-the-Sea, MA
Geotechnical Evaluation

TO: Massachusetts Department of Transportation (MassDOT)

FROM: Dave Brogan, PE and Chris Haker, PE

COPY: Vinod Kalikiri PE, PTOE and David Loring, PE, LEED AP

DATE: August 22, 2019

1. EXECUTIVE SUMMARY

Tighe & Bond, Inc. performed a subsurface exploration program for the Central Street Bridge Replacement project in Manchester-by-the-Sea, Massachusetts. Observed subsurface conditions generally consisted of 14 inches of asphalt pavement overlying 9 feet of fill overlying bedrock.

It is recommended that the proposed bridge and wingwall be supported on spread footings bearing entirely on bedrock. A concrete leveling pad could be placed between uneven bedrock surfaces and the bottom of the footings. However, it is preferable to have the footing bear directly on bedrock. Dowels socketed into bedrock may be required to resist potential sliding of the leveling pad or footings placed on sloped bedrock surfaces. Alternatively, the bedrock may be partially removed to create a level surface. The recommended nominal bearing resistance for bedrock is 200 kips per square foot (ksf), and the factored bearing resistance for bedrock at the strength limit state is 90 ksf based on a bearing resistance factor (φ_b) of 0.45 for spread footings on bedrock. Bedrock bearing surfaces should be cleared of any ponded water, loose rock, or soil prior to foundation construction.

2. INTRODUCTION

The project consists of replacing the existing bridge which spans the Sawmill Brook at the mouth of Manchester Harbor on Central Street (Route 127) in Manchester-by-the-Sea, Massachusetts. The existing bridge supports two lanes of traffic, parking on the downstream (south) side of the bridge, and sidewalks in both directions.

The vertical datum referenced in this memorandum is the North American Vertical Datum of 1988 (NAVD88).

2.1 Scope of Work

Our scope of work included coordinating and conducting a subsurface exploration program, performing geotechnical engineering analyses, and preparing a geotechnical engineering memorandum. The subsurface exploration program consisted of a review of available United States Geologic Society (USGS) mapping of the area, vacuum excavation of potential boring locations for utility clearance, and drilling test borings. Five test borings were planned, however, only one proposed boring location was found to be clear of underground utilities, and due to the congestion of the site, the need to maintain one-way traffic, and the presence of existing utilities, other boring locations were not available. Our geotechnical engineering analyses and geotechnical memorandum have been prepared in general accordance with the Massachusetts Department of Transportation (MassDOT) Load and Resistance Factor Design (LRFD) Bridge Manual (2013 Edition) and the American Association of State Highway and Transportation Officials (AASHTO) LRFD Bridge Design Specifications (8^{th} Edition, 2017).

2.2 Bridge Background and Proposed Construction

Central Street bridge is on the National Historic Registry as the site of historic water powered mills dating back to the 1600's. The bridge consists of a 16-foot span, mortared stone masonry circular arch bridge with stone masonry wingwalls and headwalls. Water, sewer, electric and gas utilities are located within the roadbed over the bridge. Timber cribs functioning as weirs are imbedded into the bottom of the stream bed. The bridge was rebuilt around the mid 1900's and a tide gate was installed on the south side of the bridge to control Sawmill Brook and create Central Pond just upstream. An approximate 10 to 14-foot tall and 35-foot long stone masonry wingwall extends off the southwest side of the bridge and functions as a seawall. A shotcrete facing exists along portions of the bridge and wingwall above the tidal zone.

The passage under the bridge discharges flow from Sawmill Brook via a narrow, channelized reach, with approximately 12-foot- high stone masonry walls and buildings abutting either side. Tidal flow from Manchester Harbor passes under the bridge, depending on the setting of the tide gate and tide height. The tide gate and bridge design have been identified as contributing factors to upstream flooding, due to significant hydraulic restriction when large precipitation events and high tide elevations are concurrent. In addition, the tide gate restricts fish passage. Existing grades range from approximately elevation 9 to 10 feet along the bridge deck, to elevation 0 to -4 feet in the channel below the bridge.

It is planned that the replacement structure will be a three-sided precast concrete arch culvert supported by shallow spread footings, and the southwest wingwall will be replaced with a cast-in-place concrete cantilever retaining wall, with a stone façade to replicate existing aesthetics. It is also anticipated that the tide gate will be removed. Site grades are anticipated to remain relatively unchanged near the bridge.

2.3 Site Reconnaissance and Overall Description

Central Street is an approximately 17 to 18-foot-wide, paved, two-lane roadway. Vehicular traffic generally consists of passenger cars and small trucks. The bridge is located downtown in a commercial and residential area. A site location map is included as Figure 1 in Appendix A.

3. SUBSURFACE CONDITIONS

3.1 Local Geology

Based on information from the United States Geological Survey (USGS) that is available on Oliver, the MassGIS online mapping tool, the surficial soils at the site are mapped as glacial till or bedrock with overburden thickness less than 50 feet, and bedrock is mapped as granite.

3.2 Historic Subsurface Data

Tighe & Bond requested available historic subsurface data from the Town; however, no previous test boring or geotechnical data was available for the site.

3.3 Topographic Survey

A topographic survey was performed for the site and included exposed bedrock elevations.

3.4 Subsurface Exploration Program

3.4.1 Test Borings

One geotechnical test boring (B-1) was drilled by New England Boring Contractors of Derry, NH on August 9, 2018. Although additional borings were planned, they were not advanced due to the numerous underground utilities in the area and physical site constraints. This site constraints limiting the ability to do additional borings were communicated to the MassDOT District Bridge Engineer prior to advancing the design. The test boring was advanced to a depth of 5 feet below the existing ground surface using vacuum excavation methods to check for the presence of underground utilities, and then with 4-inch inner diameter flush joint casing and drive and wash methods to a depth of approximately 20.5 feet. Split-spoon sampling and Standard Penetration Tests (SPTs) were conducted at maximum 5-foot intervals. Test boring B-1 was terminated in bedrock after coring 10 feet of rock. The boring was backfilled upon completion with grout.

A subsurface exploration plan is included as Figure 2 in Appendix A, and the test boring log is included in Appendix B.

3.4.2 Laboratory Testing

Laboratory tests were performed to aid in soil classifications, evaluate soil re-use potential, and estimate bedrock stress-strain parameters. One mechanical Particle Size Analysis tests (ASTM D6913) and one Compressive Strength and Elastic Moduli of Rock test (ASTM D7012 – Method D) were performed on samples taken during the exploration. Laboratory test results are included in Appendix C.

3.5 Verification of Sample Descriptions

Soil samples obtained from the test borings were visually and manually examined on September 24, 2018 by a co-author of this memorandum and select samples were submitted for laboratory testing, as described above. The descriptions presented on the boring log are considered representative of the soils encountered in the test boring.

3.6 Subsurface Profile

The generalized subsurface conditions described in the text below summarizes trends observed in the exploration performed to date. The boundaries between soil strata are approximate and are based on interpretations of widely spaced samples. Actual conditions could be more variable.

In general, subsurface conditions observed in the exploration consisted of approximately 14 inches of asphalt pavement overlying 9 feet of fill overlying bedrock. The top of bedrock was encountered at a depth of approximately 10 feet below the existing ground surface in boring B-1, corresponding to approximately elevation -0.5 feet. Based on the topographic survey, the top of bedrock elevation ranges from approximately 1 to -4 feet along the face of the existing wingwall and from approximately 0 to -4 feet along the west side of the channel beneath the bridge.

Table 1 below presents the general stratigraphy encountered during the subsurface exploration program in descending depth from the ground surface.

Table 1
Description of Subsurface Conditions Encountered

Strata (In Descending Depth)	General Description
FILL	Brown, fine to coarse SAND with up to 40% Gravel and 20% Silt; varying to medium dense to very dense GRAVEL with up to 35% fine to coarse Sand and 20% Silt
BEDROCK	Very hard to hard, moderately to very slightly weathered, slightly fractured to sound, very coarse to coarse-grained GRANITE with close to moderately close, horizontal to moderately dipping fractures; RQD = 95% to 98%

3.7 Seismic Design Category Evaluation

Based on data from the borings, the site is assigned to Site Class C, according to the AASHTO LRFD Bridge Design Specifications, 8th Edition. The design peak seismic ground acceleration coefficient modified by the short-period site factor (A_S) is 0.150, and the design spectral response accelerations at 0.2-second periods (S_{DS}) and at 1-second periods (S_{D1}) are 0.228 and 0.102 respectively. These values were calculated based on the mapped peak ground acceleration and spectral response accelerations provided in the MassDOT LRFD Bridge Manual (2013 Edition) Part I appendix for the 2500-year return period assuming the bridge is a critical/essential structure, and the appropriate magnification factors for Site Class C.

3.8 Liquefaction Potential

Based on the standard penetration test N-values, groundwater levels measured at the site, and the gradation of the soils observed in the exploration, the soils encountered in the test boring are not considered susceptible to liquefaction due to the significant gravel content in the soil.

4. RECOMMENDED FOUNDATION SYSTEM

4.1 Existing Foundation System

The mortared stone masonry of the existing circular arch bridge and southwest wingwall appear to bear directly on bedrock.

4.2 Embankment Considerations

There are no roadway embankments associated with the existing bridge and they are not proposed for the replacement bridge.

4.3 Shallow Foundations

Existing grades range from approximately elevation 0 to -4 feet within the bottom of the channel near the bridge and at the base of the southwest wingwall. Bedrock outcroppings are present along the west side of the channel beneath the bridge, at the base of the southwest wingwall, and downstream of the tide gate. The top of bedrock was encountered at approximately elevation -0.5 feet at boring B-1, and it varied from approximately elevation 1 to -4 feet along the face of the wingwall and along the west side of the channel beneath the bridge based on the topographic survey.

The new bridge and wingwall should be supported on conventional shallow strip footing foundations bearing entirely on bedrock. It is anticipated that the bedrock profile within the area of the footings will likely vary. Therefore, in accordance with the MassDOT LRFD Bridge Manual, cement concrete with a nominal aggregate size of 1-1/2 inches, a minimum compressive strength of 3,000 pounds per square inch (psi), and a minimum thickness of 6 inches could be placed as a leveling pad between the bedrock surfaces and the bottom of the footings to facilitate footing construction. However, it is preferable for the footing to bear directly on bedrock. Dowels socketed into bedrock may be required to resist potential sliding of the leveling pad or footings placed on sloped bedrock surfaces.

In accordance with the AASHTO LRFD Bridge Design Specifications, 8th Edition (2017), the recommended nominal bearing resistance for bedrock is 200 kips per square foot (ksf), and the factored bearing resistance for bedrock at the strength limit state is 90 ksf based on a bearing resistance factor (φ_b) of 0.45 for spread footings on bedrock. Bearing resistance calculations are included in Appendix D. The factored compressive resistance of the footing or leveling slab concrete should be taken as 0.3 times the 28-day compressive strength of the concrete.

At the service limit state bearing resistance, total and differential elastic settlements are anticipated to be less than ½ inch. Most settlement will occur during construction as dead load is applied.

As footings will bear on relatively sound and intact bedrock, embedment for frost protection is not required and scour protection is not required.

Foundation subgrades and required fill to achieve proposed pavement subgrade levels should be prepared, placed, and compacted as recommended later in this memorandum.

4.4 Lateral Earth Pressures

The project includes below-grade restrained culvert side walls and an unrestrained wingwall that will bear on bedrock. As currently planned, the wingwall will be constructed as a cantilever wall. However, a gravity wall constructed in front of the existing wingwall should be considered as an option, if it hasn't already, as it could limit removal of the existing wingwall and backfill, better facilitate installation of a temporary bridge that could be hindered due to excavation into the existing roadway for constructing the heel of a cantilever wall, and reduce the challenges associated with supporting and protecting portions of the southwest channel wall to remain as well as the building behind it. However, the reduced hydraulic capacity of the channel would need to be evaluated and may require additional permitting.

In accordance with the MassDOT LRFD Bridge Manual cantilever or gravity retaining walls founded on bedrock should be designed for at-rest (K_o) earth pressures, as should the culvert. The following soil parameters are recommended for use in design:

- Soil unit weight (γ)=130 pounds per cubic foot
- Angle of internal friction of drained soil (Φ_f) = 32 degrees
- At-rest earth pressure coefficient (K_o) = 0.47

These design values assume the use of three feet of Gravel Borrow or Crushed Stone wrapped in non-woven filter fabric placed behind the walls as part of a drainage system to limit buildup of hydrostatic pressures. Additional drainage recommendations are provided below. Additional fill needed behind the walls should consist of Granular Fill. Where the calculated lateral earth pressure is less than 200 pounds per square foot (psf), it should be increased to 200 psf to account for compaction induced stresses.

The culvert walls and the wingwall should be designed for lateral loads produced by the AASHTO HL-93 vehicular live load, uniformly distributed over the height of each wall.

Based on the "Sawmill Brook Culvert and Green Infrastructure Analysis Task 4 Final Report: Evaluation of Locations for Flood Mitigation" prepared by Tighe & Bond and dated February 2016, a new wider culvert with the tide gate removed would likely result in overtopping of Central Street during the 100-year storm at any time in the future (with anticipated sea level rise) and during the 50-year storm event in the year 2025 and beyond (with anticipated sea level rise and storm surge). To limit unbalanced hydrostatic pressures acting on the culvert walls and wingwall, it is recommended that an engineered drainage system consisting of Crushed Stone wrapped in a non-woven filter fabric be placed above the mean high tide level and at the base of each wall to help drain the wall backfill, with weep holes placed above the mean high tide level based on the design life of the structure and sea level rise projections, with consideration given to weep hole maintenance. Stormwater runoff should be directed away from the walls to the extent possible.

The AASHTO LRFD Bridge Design Specifications, 8^{th} Edition, does not include a geotechnical resistance factor at the strength limit state for sliding of footings on bedrock. A coefficient of friction equal to 0.70 ($\delta = 35$ degrees) is recommended for concrete on clean, sound bedrock.

5. CONSTRUCTION CONSIDERATIONS

5.1 Groundwater Table

Groundwater was encountered approximately 6.3 feet below the existing ground surface corresponding to approximately elevation 3 feet. The water level was taken immediately after drilling and may not reflect stabilized conditions. Water levels can fluctuate with the tides, water levels within Sawmill Brook, season, precipitation, and nearby construction or other below grade activities, such as excavation, dewatering, wells, infiltration basins, etc.

5.2 Water Control During Construction

Except for periods around low tide, water levels will generally be above the bottom of foundation level. It is anticipated that foundation construction will take place around the low tide. Temporary cofferdams around bridge and wingwall foundations with pumping from properly filtered sumps will likely be required to keep excavations dry and allow placement and compaction of fills to be completed in the dry. Groundwater should be discharged according to federal, state, and local regulations. Surface water entering the construction area should be diverted away from excavations.

5.3 Excavations and Fill

Conventional heavy construction equipment should be suitable for excavation in existing soil materials. Excavation should conform to OSHA excavation regulations contained in 29 CFR Part 1926, latest edition. Any soil subgrades for roadway or utility work following culvert and wingwall construction should be excavated in such a way to minimize disturbance, such as using a smooth faced bucket. Bedrock removal, if required for foundation subgrade preparation, could likely be completed with an appropriately sized excavator to remove weathered rock, if encountered but not anticipated, or with a hoe ram to remove bedrock to a limited depth. Fill needed behind the culvert or wingwall should consist of compacted Granular Fill, Gravel Borrow, or Crushed Stone wrapped in a non-woven geotextile separation fabric. Table 2 presents the required gradations for imported materials.

Table 2
Gradation Requirements for Borrow Materials

Sieve Size	**Granular Fill**	**Gravel Borrow (M1.03.0, Type B)**	**1-1/2" Crushed Stone (M2.01.2)**
2/3rd lift thickness	100		
3 inch	--	100	
2 inch	--	--	100
1½ inch	--	--	95-100
1 inch	--	--	35-70
¾ inch	--	--	0-25
½ inch	--	50-85	--
No. 4	--	40-75	--
No. 10	30-95	--	--
No. 40	10-70	--	--
No. 50	--	8-28	--
No. 200	0-15	0-10	--

All backfill should be placed in 12-inch maximum lifts and should be compacted to at least 95 percent of the maximum dry density as determined by the Modified Proctor laboratory test (ASTM D1557). Thinner lifts may be needed depending on the material placed and the type of compactor used. Crushed Stone should be placed in loose lift thicknesses of less than 12 inches and be compacted with heavy compaction equipment to achieve an unyielding subgrade.

5.4 Bearing Surface Preparation

Bedrock bearing surfaces should be cleared of any ponded water, loose rock, or soil prior to foundation construction.

5.5 Reuse of Existing Soils

Existing subsurface materials, excluding topsoil which is not anticipated, may be re-used as Granular Fill, regardless of its gradation, provided it is environmentally appropriate, free of organics, debris, stones greater than two thirds the lift thickness in diameter, or other unsuitable material, and they are placed to the required degree of compaction.

Existing site soils may not be re-used as Gravel Borrow or Crushed Stone unless they meet the gradation requirements presented above, which is unlikely. Existing topsoil/subsoil, if encountered, may be reused in landscaped areas but should be tested for pH, percent organics, and nutrient content and modified as needed to support vegetative growth. Tighe & Bond's scope of work did not include evaluation of the potential for soil contamination with regard to suitability for reuse under the Massachusetts Contingency Plan (MCP) regulations or for off-site disposal purposes. Tighe & Bond did not observe visual or olfactory evidence of contamination in the test boring performed for the geotechnical evaluation. Sampling and analysis of excess soil stockpiles will be required during construction for soil management purposes.

5.6 Obstructions

An approximate 1-foot diameter boulder was encountered in boring B-1 at a depth of 7 to 8 feet below the existing ground surface. Based on this and the possibility that other boulders or buried debris may be present, obstructions, including cobbles and boulders, are anticipated to be encountered during construction. It is anticipated that obstructions which may be encountered will be removed from below foundations as they will bear on bedrock.

5.7 Protection of Adjacent Structures and Utilities

Utilities to remain in the area of the proposed construction should be properly supported and protected during construction activities. The existing building foundations immediately upstream and downstream of the bridge, and portions of the channel walls which will not be removed as part of construction should also be properly braced and protected. Additional investigation by the Contractor is recommended to better understand how the buildings adjacent to the bridge are currently supported as they may be part of the channel walls that could be disturbed during construction. If the buildings are connected to the channel walls, low vibration, minimal disturbance techniques to separate the walls should be employed such as saw cutting.

5.8 Sequence of Construction Activities

The following is a general sequence of construction activities for the bridge replacement. The actual construction sequence will be determined based on the Contractor's means and methods.

- Install sediment and erosion control measures
- Temporarily relocate utilities. It may be possible to temporarily deactivate some utilities prior to bridge construction, subject to input from the Town and utility companies
- Close Central Street to traffic and establish a work zone at the bridge crossing
- Install water diversion structures/cofferdams and dewatering system
- Install support systems to support and protect the channel walls and adjacent structures, as needed
- Excavate and remove existing culvert and tide gate
- Excavate to bedrock and clear off any ponded water, loose rock, or soil
- Install dowels, if needed
- Construct concrete leveling pads, if used
- Construct footings for the new culvert and wingwall
- Construct/install culvert and wingwall
- Backfill behind the culvert and wingwalls
- Install utilities in the roadway
- Install guardrail and pavement
- Install signage and paint roadway lines
- Reopen Central Street to traffic
- During staged construction, complete relocation of utilities to final location

5.9 Special Geotechnical Monitoring and Instrumentation

The following monitoring and instrumentation programs are recommended:

- Pre-excavation surveys of the existing buildings adjacent to and immediately upstream and downstream of the bridge, to document conditions prior to the start of construction
- Monitoring movements of channel walls upstream and downstream within 50 feet of the bridge

- Settlement monitoring of the existing buildings adjacent to and immediately upstream and downstream of the bridge
- Monitoring of construction induced vibrations

Specifications for the recommended monitoring and instrumentation, and movement and vibration thresholds would be included as part of the design documents.

6. LIMITATIONS

The preceding recommendations provided herein are for specific application to the proposed Central Street Bridge Replacement project in Manchester-by-the-Sea, Massachusetts, in accordance with generally accepted soil and foundation engineering practices. No warranty, expressed or implied, is made. In the event that any changes in the design or location of the proposed structure are made, the conclusions and recommendations in this report should not be considered valid unless verified in writing. This report is for design purposes only and may not be sufficient to prepare accurate quantity take-offs. It is discouraged that this report in its entirety be included in the construction documents or be provided to a contractor. Rather, the construction recommendations should be incorporated appropriately into the construction specifications as well as exploration locations, exploration logs, and laboratory test results for the contractor’s use under informational purposes only.

\\tighebond.com\data\Data\Projects\M\M1476 Manchester MA Hydro Study\011-Central Street Bridge\Geotechnical\Memo\Appendix D - Revised Geotechnical Evaluation Memo.doc

Appendix A
Figures

FIGURE 1
SITE LOCATION MAP

Central Street Bridge Replacement
Manchester-by-the-Sea, MA

Tighe&Bond
Engineers | Environmental Specialists

Based on USGS Topographic Map for Marlbehead North, MA Quadrangle. Revised 1985. Circles indicate 500-foot and half-mile radii.

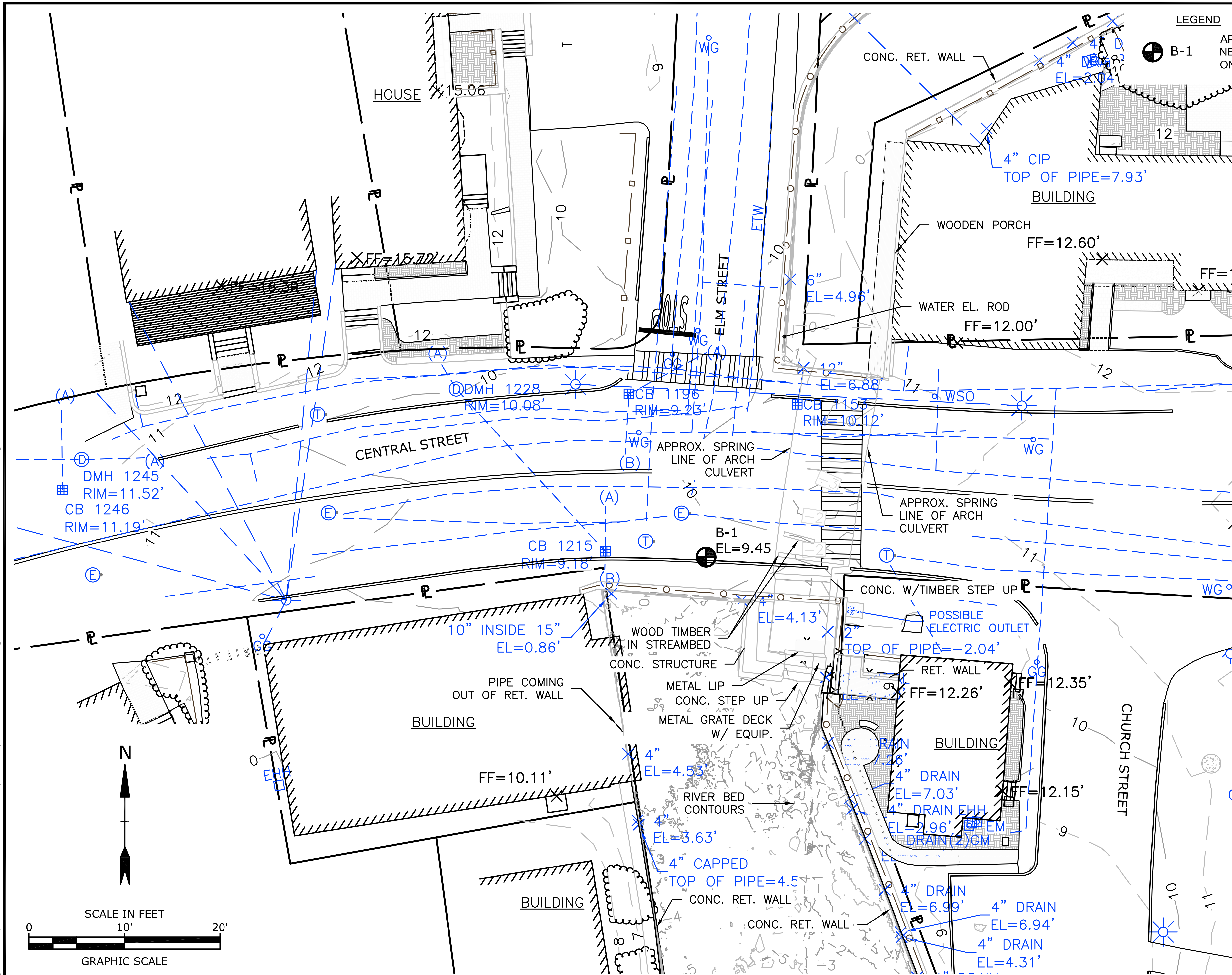
1:24,000
0 1,000 2,000
Feet

N

September 2018

G:\GIS\MA\SiteLocus\Manchester\topo_CentralStBridge.mxd

M-1476-011



LEGEND

B-1 APPROXIMATE LOCATION OF TEST BORING DRILLED BY NEW ENGLAND BORING CONTRACTORS OF DERRY, NH ON AUGUST 8, 2018

SUBSURFACE EXPLORATION LOCATION PLAN

CENTRAL STREET
BRIDGE REPLACEMENT
MANCHESTER-BY-THE-SEA, MA

DATE: 09/19/2018
SCALE: AS SHOWN
FIGURE: #2

Appendix B
Exploration Logs

Tighe&Bond
Engineers | Environmental Specialists

Boring No.	**B-1**
Page	1 of 1
File No.	M-1476011
Checked by:	C. Haker

Project: Central Street Bridge
Location: Central Street, Manchester-by-the-Sea, MA
Client: Town of Manchester-by-the-Sea

Drilling Co.: New England Boring Contractors
Foreman: Mike Porter
T&B Rep.: M. Trovato
Date Start: 08/09/18 End: 08/09/18
Location: See Exploration Location Plan
GS. Elev. 9.45' Datum: NAVD88

	Casing	Sampler
Type	HW	Split Spoon
I.D./O.D.	4"/4.5"	1-3/8"/2"
Hammer Wt.		140#
Hammer Fall		30"
Other		Auto hammer

Groundwater Readings

Date	Time	Depth	Casing	Sta. Time
8/9/2018	13:45	6.3'		End of Boring

Depth (ft.)	Casing Blows Per Ft.	Sample No. / Rec. (in)	Sample Depth (ft.)	Blows Per 6"	Sample Description	General Stratigraphy	Notes	Well Construction
		S-1/–	0-2	––	14-inches of Asphalt, over brown, fine to coarse SAND, some Gravel, trace Silt	ASPHALT 1.2'	1	
				––				
		S-2/–	2-4	––	Brown, fine to coarse SAND and GRAVEL, little Silt			No Well Installed
				––				
5		S-3/8	5-7	9 - 12	Medium dense, brown, GRAVEL, some fine to coarse Sand, trace Silt	FILL		
				2 - 13				
							2	
		S-4/4	8-10	50/6"	Very dense, brown, GRAVEL, little fine to coarse Sand, little Silt			
				––		9.9'	3	
10		C-1/58	10.5-15.5	2:04	Very hard to hard, moderate to slightly weathered, slightly fractured to sound, very coarse to coarse-grained GRANITE, with close to moderately close, horizontal to moderately dipping fractures; RQD = 95%			
				1:37				
				1:53				
				2:09				
				2:12				
15		C-2/60	15.5-20.5	2:17	Very hard to hard, slight to very slightly weathered, slightly fractured to sound, very coarse to coarse-grained GRANITE, with close to moderately close, horizontal to shallow fractures; RQD = 98%	BEDROCK		
				2:09				
				1:44				
				2:12				
				3:09				
20					Bottom of exploration at 20.5'			
25								
30								

Notes:
1) Vacuum excavated to approximately 5 feet below grade. Samples S-1 and S-2 were collected by hand.
2) Boulder encountered from approximately 7 to 8 feet below grade.
2) Refusal encountered at approximately 9.9 feet below grade, telescoped 3-inch casing in an attempt to advance the boring.

Proportions Used

TRACE (TR.)	0 - <10%
LITTLE (LI.)	10 - <20%
SOME (SO.)	20 - <35%
AND	35 - <50%

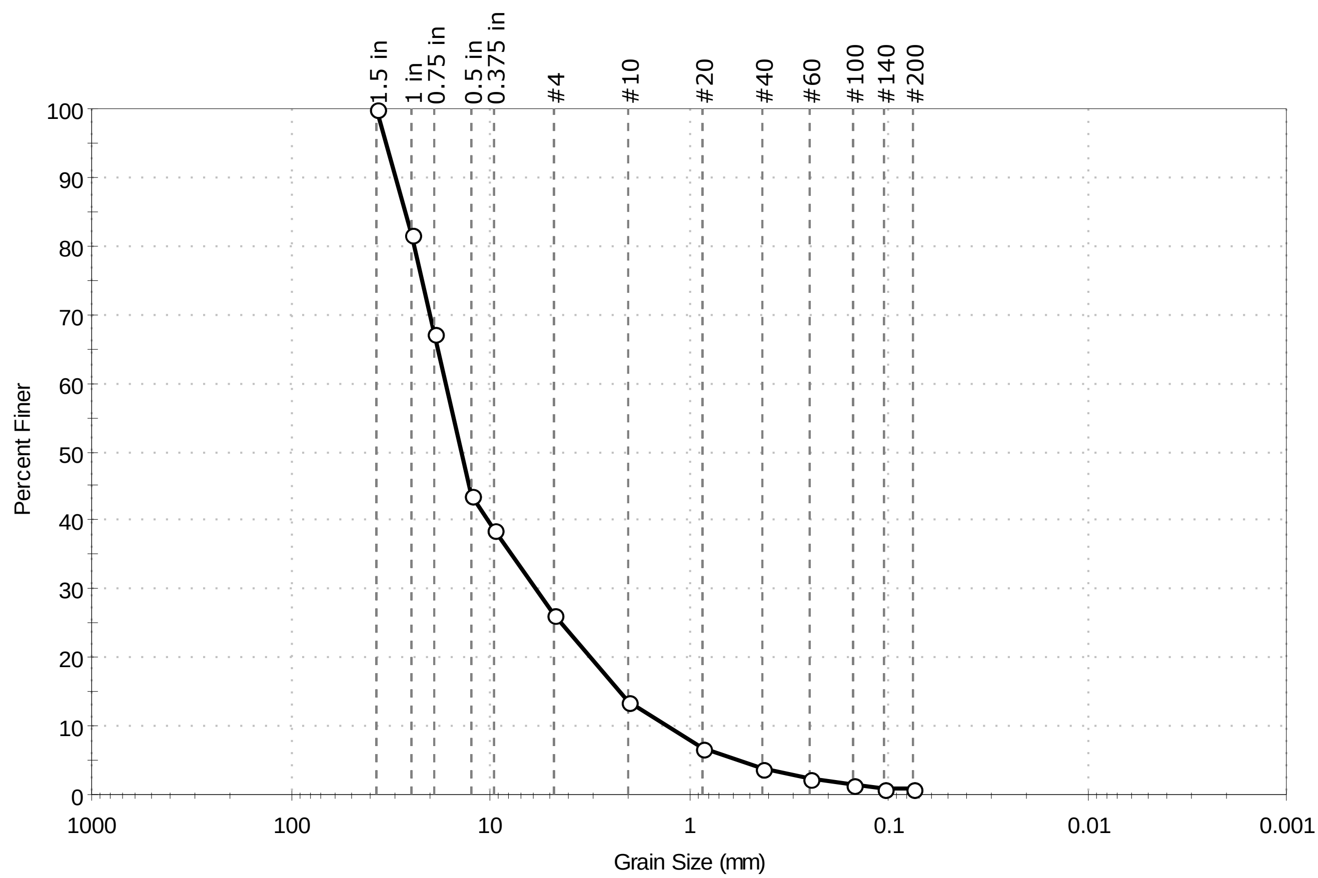
Density/Consistency

VERY LOOSE	0-4	VERY SOFT	<2
LOOSE	4-10	SOFT	2-4
MEDIUM DENSE	10-30	MEDIUM	4-8
DENSE	30-50	STIFF	8-15
VERY DENSE	>50	VERY STIFF	15-30
		HARD	>30

Appendix C
Laboratory Test Results

Client:	Tighe & Bond			
Project:	Central St Bridge			
Location:	Manchester-By-The-Sea, MA		Project No:	GTX-308653
Boring ID:	B-1	Sample Type: bag	Tested By:	jbr
Sample ID:	S-3	Test Date: 08/23/18	Checked By:	jsc
Depth :	5-7 ft	Test Id: 469736		
Test Comment:	---			
Visual Description:	Moist, dark brown gravel with sand			
Sample Comment:	---			

Particle Size Analysis - ASTM D6913



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	73.7	25.5	0.8

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
1.5 in	37.50	100		
1 in	25.00	82		
0.75 in	19.00	67		
0.5 in	12.50	44		
0.375 in	9.50	39		
#4	4.75	26		
#10	2.00	14		
#20	0.85	7		
#40	0.42	4		
#60	0.25	2		
#100	0.15	1		
#140	0.11	1		
#200	0.075	0.8		

Coefficients

D_{85} =26.9444 mm
D_{30} =5.8531 mm
D_{60} =16.7324 mm
D_{15} =2.2027 mm
D_{50} =13.9932 mm
D_{10} =1.2781 mm
C_u =13.092
C_c =1.602

Classification

ASTM Well-graded GRAVEL with Sand (GW)

AASHTO Stone Fragments, Gravel and Sand (A-1-a (1))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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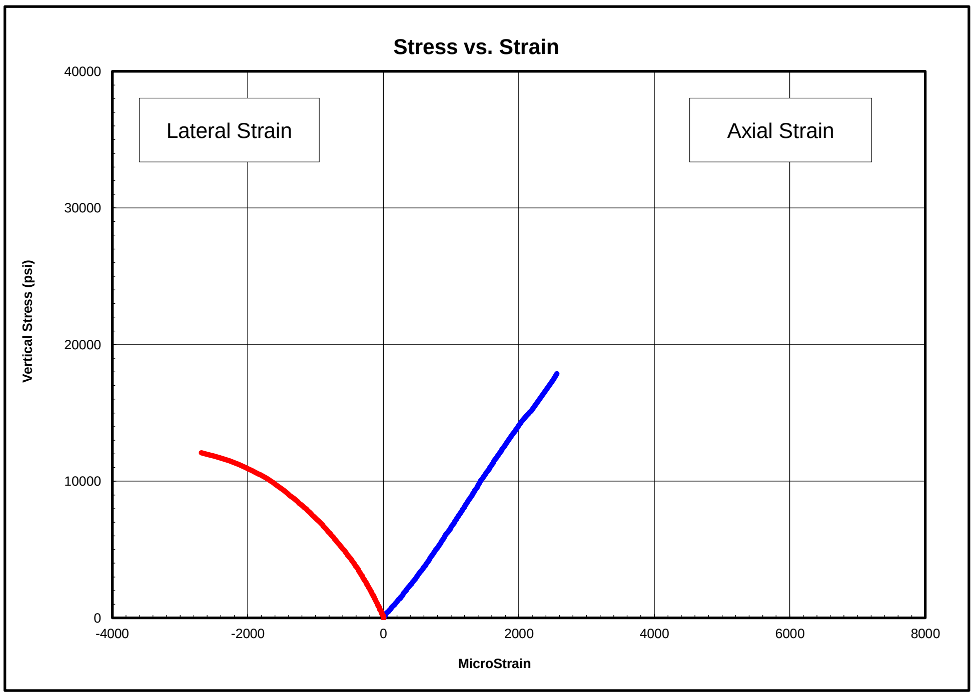
GeoTesting EXPRESS

Client:	Tighe & Bond
Project Name:	Central St Bridge
Project Location:	---
GTX #:	308653
Test Date:	8/29/2018
Tested By:	trm
Checked By:	jsc
Boring ID:	C-1
Sample ID:	B-1, C-1
Depth, ft:	10.5-15.5
Sample Type:	rock core
Sample Description:	See photographs Intact material failure

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 17,870 psi

The lateral strain values recorded for this test produce values of Poisson's Ratio that exceed maximum values found in rocks. The lateral strain gauges failed before the peak value was attained.

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
1800-6600	6,930,000	---
6600-11300	7,670,000	---
11300-16100	6,600,000	---

Notes:
Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	Tighe Bond	Test Date:	8/28/2018
Project Name:	Central St Bridge	Tested By:	crs
Project Location:	---	Checked By:	jsc
GTX #:	308653		
Boring ID:	C-1		
Sample ID:	B-1, C-1		
Depth:	10.5-15.5 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average
Specimen Length, in:	4.05	4.05	4.05
Specimen Diameter, in:	1.98	1.98	1.98
Specimen Mass, g:	537.46		
Bulk Density, lb/ft^3	164		
Length to Diameter Ratio:	2.0		

Minimum Diameter Tolerence Met? YES

Length to Diameter Ratio Tolerance Met? YES

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap $\leq$ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? YES

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00040	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
Diameter 2, in (rotated 90°)	-0.00040	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00020	-0.00030	-0.00040	-0.00050	-0.00060

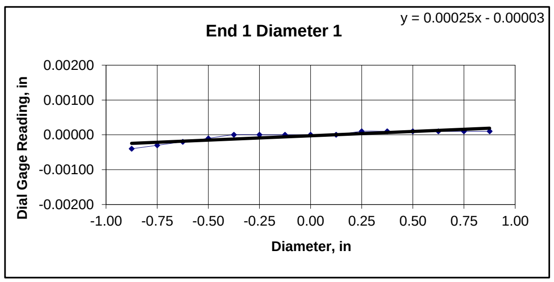
Difference between max and min readings, in:
0° = 0.00050 90° = 0.00060

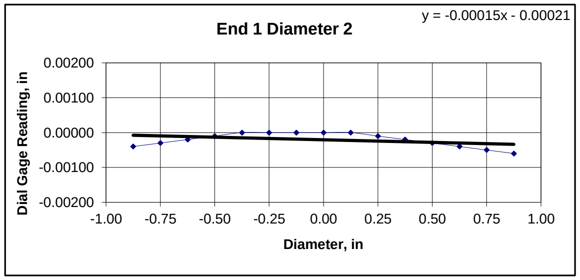
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00050	-0.00040	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00010	0.00010
Diameter 2, in (rotated 90°)	-0.00040	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00020	-0.00030	-0.00040	-0.00050	-0.00060

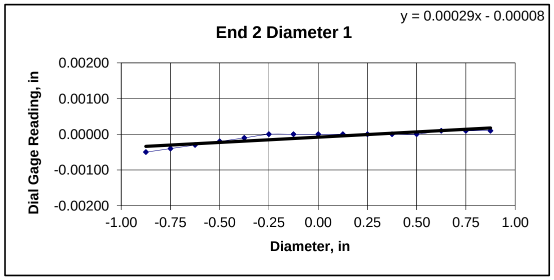
Difference between max and min readings, in:
0° = 0.0006 90° = 0.0006

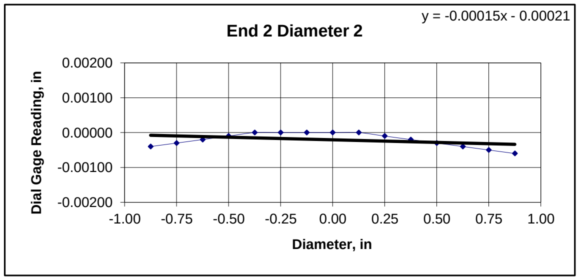
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00030

Flatness Tolerance Met? YES









DIAMETER 1

End 1:	
Slope of Best Fit Line	0.00025
Angle of Best Fit Line:	0.01424
End 2:	
Slope of Best Fit Line	0.00029
Angle of Best Fit Line:	0.01686
Maximum Angular Difference:	0.00262

Parallelism Tolerance Met? YES
Spherically Seated

DIAMETER 2

End 1:	
Slope of Best Fit Line	0.00015
Angle of Best Fit Line:	0.00851
End 2:	
Slope of Best Fit Line	0.00015
Angle of Best Fit Line:	0.00851
Maximum Angular Difference:	0.00000

Parallelism Tolerance Met? YES
Spherically Seated

PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00050	1.980	0.00025	0.014	YES
Diameter 2, in (rotated 90°)	0.00060	1.980	0.00030	0.017	YES
END 2					
Diameter 1, in	0.00060	1.980	0.00030	0.017	YES
Diameter 2, in (rotated 90°)	0.00060	1.980	0.00030	0.017	YES

Maximum angle of departure must be $\leq$ 0.25°

Perpendicularity Tolerance Met? YES

Client:	Tighe & Bond
Project Name:	Central Street Bridge
Project Location:	---
GTX #:	308653
Test Date:	8/29/2018
Tested By:	trm
Checked By:	jsc
Boring ID:	C-1
Sample ID:	B-1, C-1
Depth, ft:	10.5-15.5 ft

After cutting and grinding

After break

Appendix D
Bearing Resistance Calculations

Central Street Bridge Replacement
Central Street - Manchester-by-the-Sea, MA
M-1476011-01
Prepared by: Dave Brogan Date: 9/25/18
Checked by: Date:

Bearing Resistance of Bedrock

Method: AASHTO LRFD Bridge Design Specifications, 8th Edition, 2017

Basis: Determine the bearing resistance of bedrock for spread footing support. Based on bedrock cores C-1 and C-2 obtained from boring B-1 the bedrock is described as very hard to hard, moderately to very slightly weathered, slightly fractured to sound, very coarse to coarse-grained GRANITE with close to moderately close, horizontal to moderately dipping fractures, with RQD values ranging from approximately 95% to 98%. A peak compressive strength of 17,870 pounds per square inch (psi) was measured from the Compressive Strength and Elastic Moduli of Rock (ASTM D7012-Method D) test performed on a bedrock sample taken from core C-1 recovered from a depth of 10.5 to 15.5 feet below the existing ground surface.

Bearing Resistance
Based on the referenced document, uniaxial compressive rock strength and RQD may be relied upon for design of footings bearing on competent rock.

Method 1 - Chart Solution for Footings Supported on Competent Rock

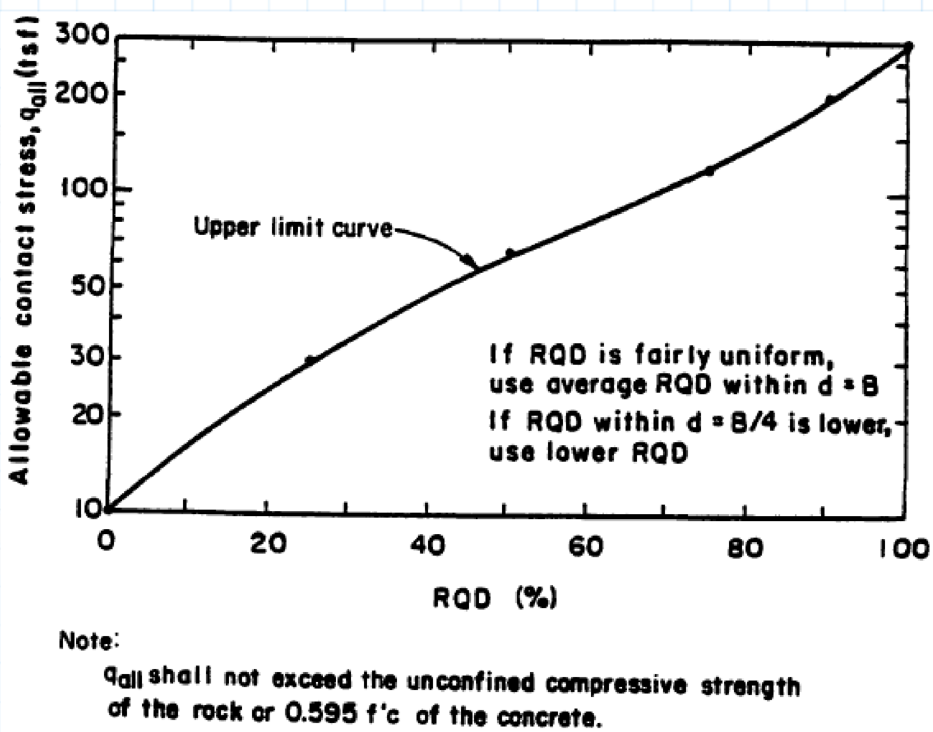


FIGURE 4.4.8.1.1A Allowable Contact Stress for Footings on Rock with Tight Discontinuities
Peck, et al. (1974)

Based on the Figure 4.4.8.1.1A above, the allowable contact stress for a footing bearing on rock which has an RQD=95% would be about 220 tsf, say 200 tsf (400 ksf).

Method 2 - Use the Rock Mass Rating (RMR) system to account for discontinuities in the overall rock mass

Based on Table 4.4.8.1.2B below, granite is assigned to Rock Category E

TABLE 4.4.8.1.2B Typical Range of Uniaxial Compressive Strength (C_o) as a Function of Rock Category and Rock Type

Rock Category	General Description	Rock Type	C_o[1] (ksf)	C_o[1] (psi)
A	Carbonate rocks with well-developed crystal cleavage	Dolostone	700- 6,500	4,800-45,000
		Limestone	500- 6,000	3,500-42,000
		Carbonatite	800- 1,500	5,500-10,000
		Marble	800- 5,000	5,500-35,000
		Tactite-Skarn	2,700- 7,000	19,000-49,000
B	Lithified argillaceous rock	Argillite	600- 3,000	4,200-21,000
		Claystone	30- 170	200- 1,200
		Marlstone	1,000- 4,000	7,600-28,000
		Phyllite	500- 5,000	3,500-35,000
		Siltstone	200- 2,500	1,400-17,000
		Shale[2]	150- 740	1,000- 5,100
		Slate	3,000- 4,400	21,000-30,000
C	Arenaceous rocks with strong crystals and poor cleavage	Conglomerate	700- 4,600	4,800-32,000
		Sandstone	1,400- 3,600	9,700-25,000
		Quartzite	1,300- 8,000	9,000-55,000
D	Fine-grained igneous crystalline rock	Andesite	2,100- 3,800	14,000-26,000
		Diabase	450-12,000	3,100-83,000
E	Coarse-grained igneous and metamorphic crystalline rock	Amphibolite	2,500- 5,800	17,000-40,000
		Gabbro	2,600- 6,500	18,000-45,000
		Gneiss	500- 6,500	3,500-45,000
		Granite	300- 7,000	2,100-49,000
		Quartzdiorite	200- 2,100	1,400-14,000
		Quartzmonzonite	2,700- 3,300	19,000-23,000
		Schist	200- 3,000	1,400-21,000
		Syenite	3,800- 9,000	26,000-62,000

[1] Range of Uniaxial Compressive Strength values reported by various investigations.
[2] Not including oil shale.

Based on Table 4.4.8.1.2A below, a Rock Category E and RQD between 90% and 95%, coefficient Nms would be 2.3.

However, considering the presence of moderately weathered and close (2 inches to 1-foot) to moderately close (1-foot to 3 feet) joints observed in the rock core from the only boring completed an Nms value of 0.081 may be more appropriate.

TABLE 4.4.8.1.2A Values of Coefficient N_{ms} for Estimation of the Ultimate Bearing Capacity of Footings on Broken or Jointed Rock (Modified after Hoek, (1983))

Rock Mass Quality	General Description	RMR[1] Rating	NGI[2] Rating	RQD[3] (%)	N_{ms}[4] A	B	C	D	E
Excellent	Intact rock with joints spaced > 10 feet apart	100	500	95-100	3.8	4.3	5.0	5.2	6.1
Very good	Tightly interlocking, undisturbed rock with rough unweathered joints spaced 3 to 10 feet apart	85	100	90-95	1.4	1.6	1.9	2.0	2.3
Good	Fresh to slightly weathered rock, slightly disturbed with joints spaced 3 to 10 feet apart	65	10	75-90	0.28	0.32	0.38	0.40	0.46
Fair	Rock with several sets of moderately weathered joints spaced 1 to 3 feet apart	44	1	50-75	0.049	0.056	0.066	0.069	0.081
Poor	Rock with numerous weathered joints spaced 1 to 20 inches apart with some gouge	23	0.1	25-50	0.015	0.016	0.019	0.020	0.024
Very poor	Rock with numerous highly weathered joints spaced < 2 inches apart	3	0.01	<25	Use q_{ult} for an equivalent soil mass				

[1] Geomechanics Rock Mass Rating (RMQ) System—Bieniawski, 1988.
[2] Norwegian Geotechnical Institute (NGI) Rock Mass Classification System, Barton, et al., 1974.
[3] Range of RQD values provided for general guidance only; actual determination of rock mass quality should be based on RMR or NGI rating systems.
[4] Value of N_{ms} as a function of rock type; refer to Table 4.4.8.1.2B for typical range of values of C_o for different rock type in each category.

$N_{ms} := 0.081$

$C_0 := 17870\ psi$ — Uniaxial compressive strength of bedrock

$q_n := N_{ms} \cdot C_0 = 1447\ psi$ — Nominal bearing resistance of bedrock

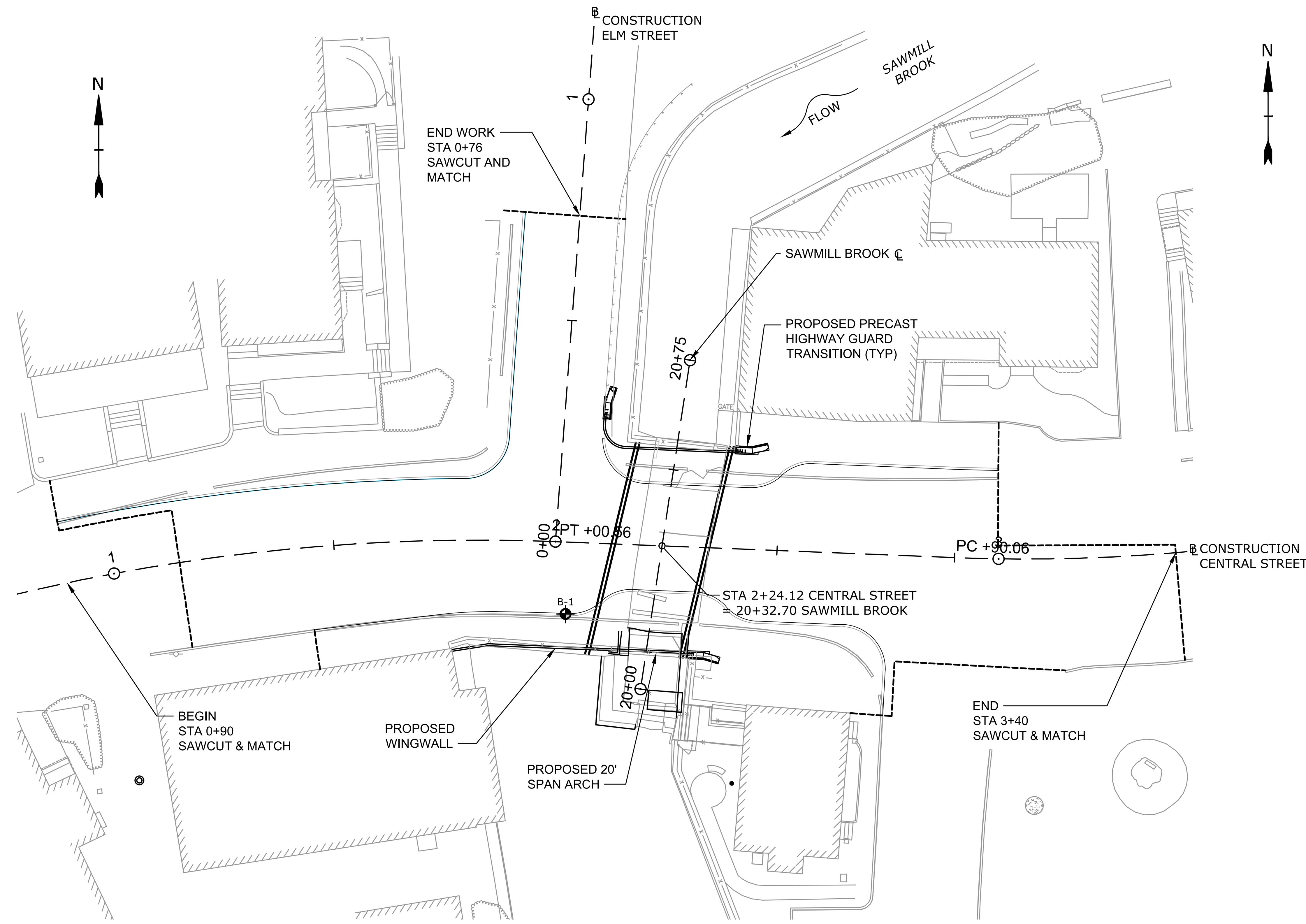
$q_n = 208\ ksf$

$\varphi_b := 0.45$ — Resistance factor for footings on rock per Table 10.5.5.2.2-1 in the referenced document

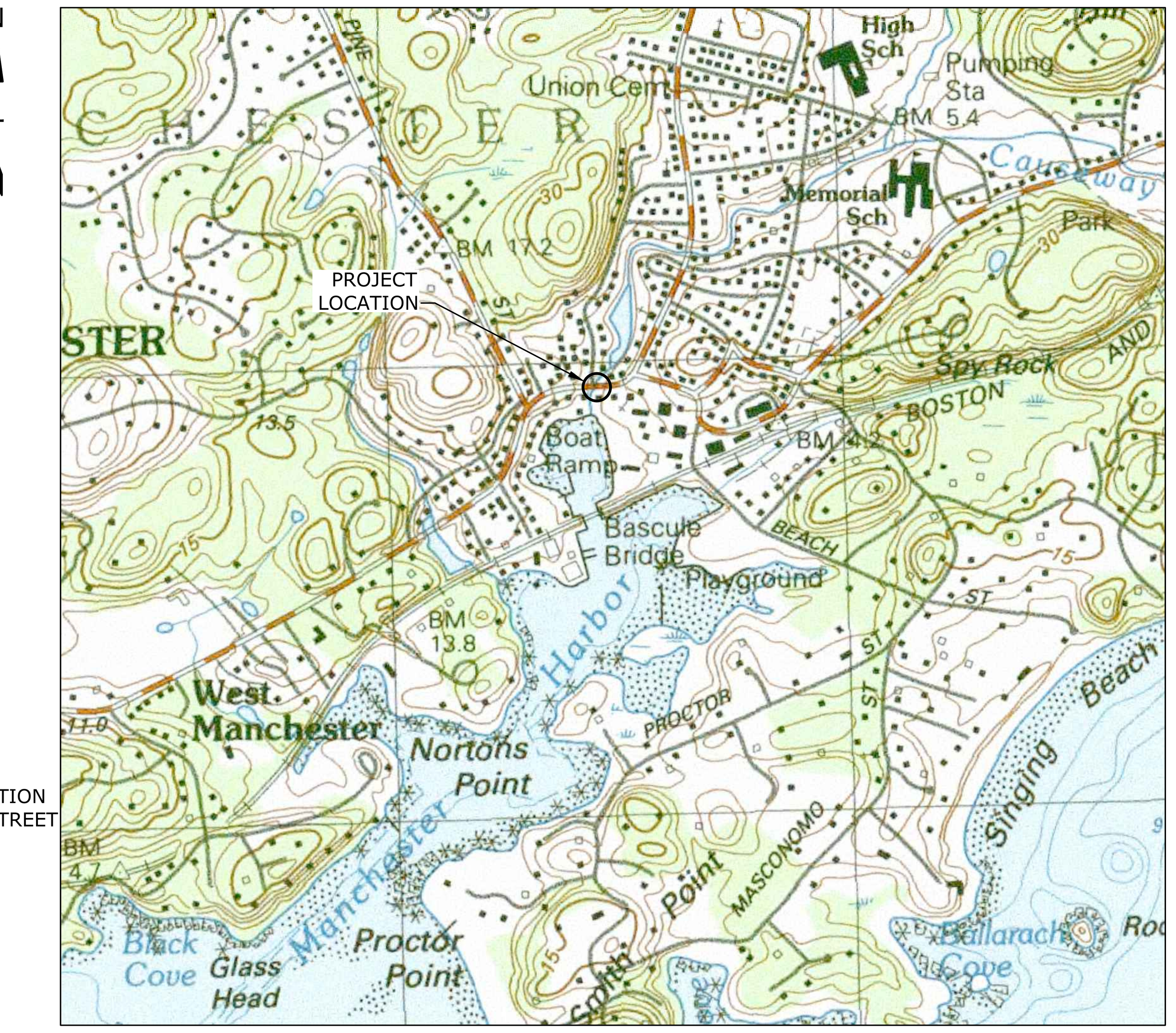
$q_R := \varphi_b \cdot q_n = 94\ ksf$ — Factored bearing resistance at the strength limit state

Using the lower value from the two methods above, recommend a nominal bearing resistance of 200 ksf and a factored bearing resistance of 90 ksf.

Appendix E
25% Design Drawings



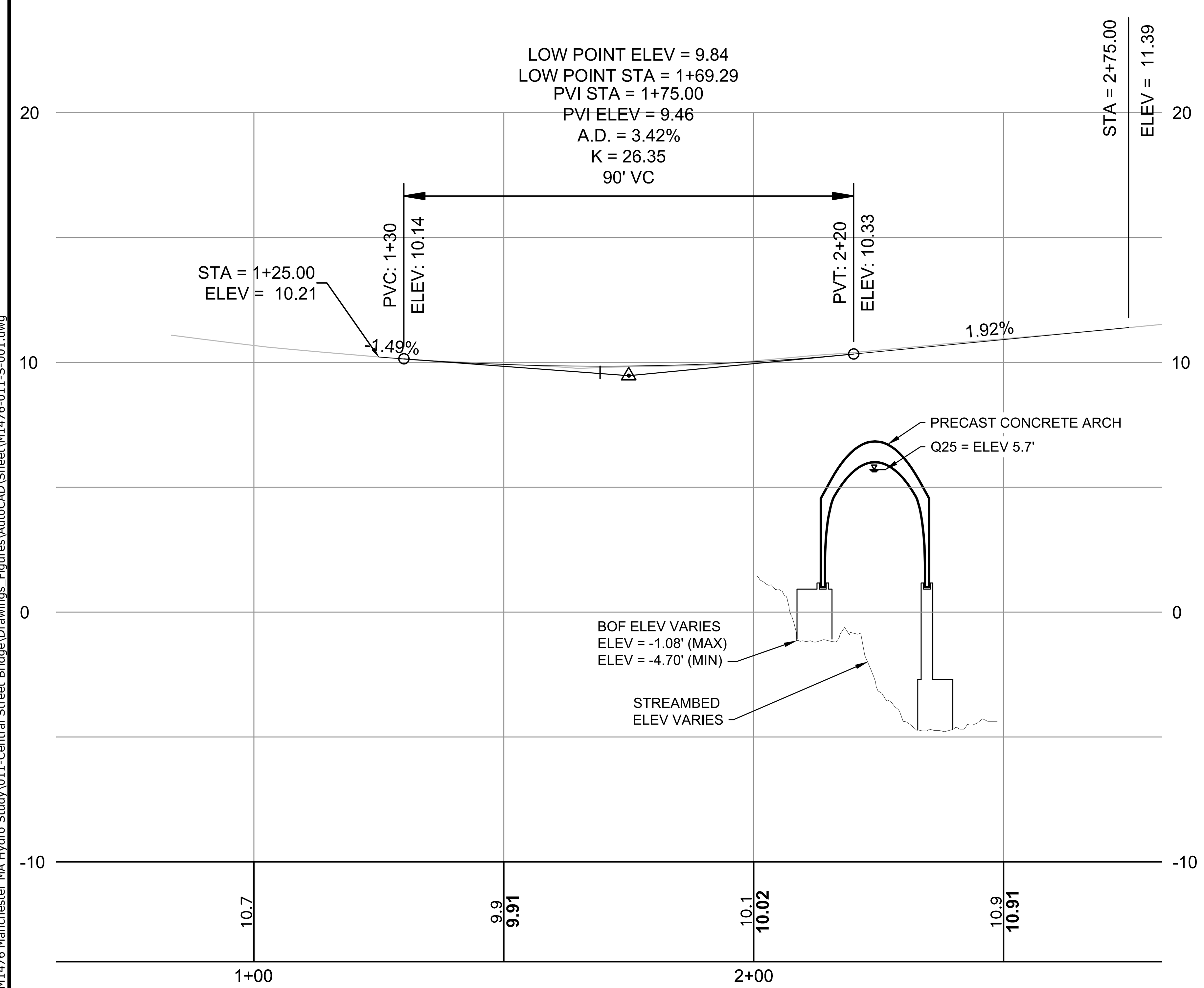
KEY PLAN
1" = 20'



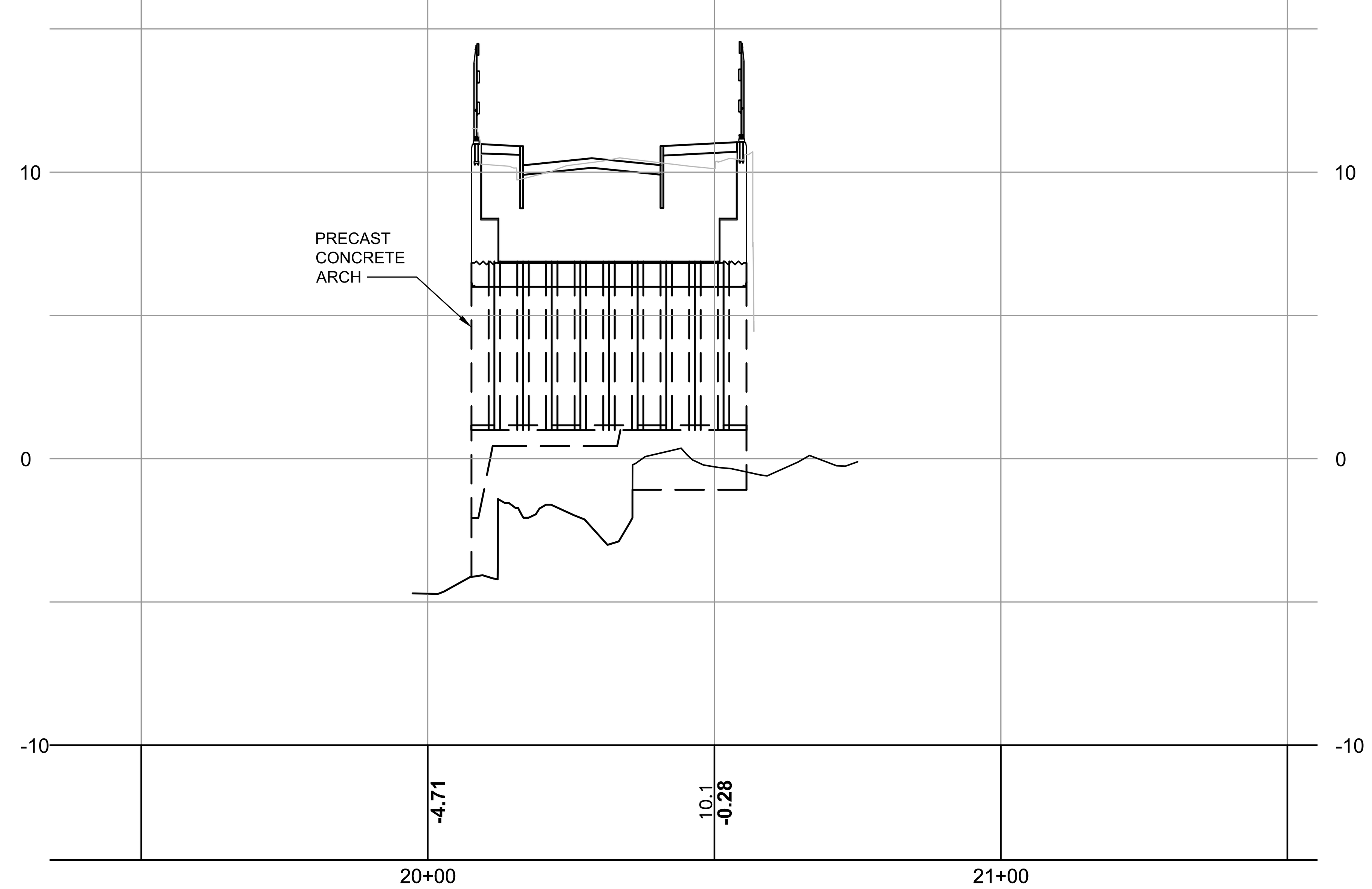
LOCUS PLAN
SCALE: 1"=1000'

BRIDGE DRAWING INDEX

HYDRAULIC DATA	
DRAINAGE AREA	5.0 SQ. MILES
WATER CONTROL FLOOD DISCHARGE (2 YR)	254 CFS
DESIGN FLOOD DISCHARGE (25 YR)	1,363 CFS
DESIGN FLOOD ANNUAL CHANCE (RETURN FREQUENCY)	4% (25-YEARS)
DESIGN FLOOD VELOCITY (25 YR)	7.5 FPS
DESIGN FLOOD ELEVATION (25 YR)	5.7 FEET
BASE (100-YR) FLOOD DATA	
BASE FLOOD DISCHARGE (100 YR)	2,267 CFS
BASE FLOOD ELEVATION (100 YR)	7.7 FEET
DESIGN AND CHECK SCOUR DATA	
SCOUR DESIGN FLOOD ANNUAL CHANCE (RETURN FREQUENCY)	2% (50-YEARS)
DESIGN FLOOD ABUTMENT SCOUR DEPTH	LEFT: 2 FT RIGHT: 2 FT
SCOUR CHECK FLOOD ANNUAL CHANCE (RETURN FREQUENCY)	1% (100-YEARS)
CHECK FLOOD ABUTMENT SCOUR DEPTH	LEFT: 2 FT RIGHT: 2 FT
FLOOD OF RECORD	
DISCHARGE	UNKNOWN
FREQUENCY (IF KNOWN)	N/A
MAXIMUM ELEVATION	N/A
DATE	N/A
HISTORY OF ICE FLOES	UNKNOWN
EVIDENCE OF SCOUR AND EROSION	UNKNOWN



PROFILE - CENTRAL STREET
SCALE: 1" = 20'H, 1"=4'V



PROFILE - SAWMILL BROOK
SCALE: 1" = 20'H, 1"=4'V

COMMONWEALTH OF MASSACHUSETTS
MassDOT, Highway Division
CONCEPTUAL DESIGN IS ACCEPTABLE
TO MASSDOT FOR CONTRACTING

DISTRICT BRIDGE ENGINEER DATE

Tighe&Bond
Engineers | Environmental Specialists

Draft 25% Plans Not For Construction

Central Street Bridge Replacement

Department of Public Works

MassDOT Bridge No. M-02-001, BIN 8AM

Town of Manchester-By-The-Sea, Massachusetts

MARK	DATE	DESCRIPTION

PROJECT NO:	M1476 - 011
DATE:	JUNE 2019
FILE: M1476-011-S-001.dwg	
DRAWN BY:	D.BISHOP
CHECKED:	X
APPROVED:	X

BRIDGE KEY PLAN, PROFILES, LOCUS AND INDEX

SCALE: AS NOTED

S-001
SHEET 1 OF 6

Last Saved: 8/22/2019
Plotted On:Aug 22, 2019-4:21pm By: EOhanian
Tighe & Bond:J:\M\M1476 Manchester MA Hydro Study\011-Central Street Bridge\Drawings_Figures\AutoCAD\Sheet\M1476-011-S-001.dwg

DESIGN LOADS AND SPECIFICATIONS:

1.	DESIGN LOADING:	HL-93
2.	DESIGN:	LOAD AND RESISTANCE FACTOR DESIGN (LRFD) IN ACCORDANCE WITH: AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS, 8TH ED., 2017 AS AMENDED MASSDOT 2013 LRFD BRIDGE DESIGN MANUAL, AS AMENDED
3.	SPECIFICATIONS:	MASSDOT 1988 STANDARD SPECIFICATIONS AS AMENDED
4.	FOUNDATION DATA:	ABUTMENTS AND U-WINGWALL: SPREAD FOOTINGS SUPPORTED ON SOUND BEDROCK WITH A NOMINAL BEARING CAPACITY OF 100.0 TSF IN COMBINATION WITH A RESISTANCE FACTOR OF 0.45. PRECAST GUARD TRANSITION: TRANSITION BASE ON CONTROLLED DENSITY FILL (NON EXCAVATABLE) ON COMPACTED GRAVEL BORROW OR UNDISTURBED SOIL.
5.	REINFORCING STEEL:	AASHTO M31 (ASTM A 615) GRADE 60 ALL BARS SHALL BE HOT-DIPPED GALVANIZED (ASTM A767 & ASTM A1094)
6.	CONCRETE:	PRECAST ACRH, PEDESTAL FOOTINGS, CURBS/HEADWALLS, GUARD TRANSITIONS, U-WINGWALL, AND U-WINGWALL FOOTINGS: 5000 PSI, ¾", 685 HP CEMENT CONCRETE
7.	SEISMIC:	PEAK GROUND ACCELERATION (PGA) = 0.125g SITE CLASS = C SEISMIC DESIGN CATEGORY = A

GENERAL NOTES:

1. PLANS OF THE EXISTING BRIDGE ARE NOT AVAILABLE.
2. BORINGS WERE MADE BY NEW ENGLAND BORING CONTRACTORS ON 9/8/2018.
3. ALL EXISTING BRONZE DISCS REPRESENTING STATE BENCHMARKS OR SURVEY TRIANGULATION POINTS MUST NOT BE DISTURBED. WHEN THE WORK CALLED FOR INVOLVES DISTURBING A BRONZE DISC THE CONTRACTOR SHALL NOTIFY THE ENGINEER SUFFICIENTLY IN ADVANCE OF THE WORK TO PERMIT THE STATE TO TEMPORARILY RELOCATE THE AFFECTED MARKER.
4. ALL WORK SHALL COMPLY WITH OSHA'S LATEST STANDARDS. ALL REQUIREMENTS OF OSHA'S EXCAVATION STANDARDS SHALL BE PROVIDED BY THE CONTRACTOR INCLUDING, BUT NOT LIMITED TO, THE PROVISION FOR A COMPETENT PERSON ON SITE AND ANY REQUIRED DOCUMENTATION THAT MAY REQUIRE CERTIFICATION BY A PROFESSIONAL ENGINEER.
5. IT SHALL BE THE CONTRACTOR'S RESPONSIBILITY TO MAINTAIN ALL UTILITIES FUNCTIONING PROPERLY IN THE AREAS UNDER CONSTRUCTION PRIOR TO COMPLETION OF THE PROJECT. ALL PIPES AND STRUCTURES WITHIN THE LIMITS OF THIS CONTRACT SHALL BE LEFT IN A CLEAN AND OPERABLE CONDITION AT THE COMPLETION OF THE WORK. THE CONTRACTOR SHALL TAKE ALL NECESSARY PRECAUTIONS TO PREVENT SAND AND SILT FROM DISTURBED AREAS FROM ENTERING THE SYSTEM. CONTRACTOR IS RESPONSIBLE FOR DAMAGE SUSTAINED TO ANY EXISTING UTILITIES AND IT IS HIS RESPONSIBILITY TO MAKE REPAIRS TO THE REQUIREMENTS OF THE TOWN OR RESPECTIVE UTILITY COMPANY.
6. ANY AND ALL DEMOLISHED BUILDING MATERIALS, STRUCTURES, PIPES, PAVEMENT, CURBING, SURPLUS MATERIAL, AND SITE RUBBLE SHALL BE DISPOSED OF BY THE CONTRACTOR OFF-SITE AT HIS EXPENSE AND IN ACCORDANCE WITH ALL APPLICABLE STATE AND FEDERAL ENVIRONMENTAL REGULATIONS.
7. THE CONTRACTOR SHALL TAKE ALL NECESSARY MEASURES TO ENSURE THAT DEBRIS DOES NOT FALL ON ANY ROADWAY, RAILROAD, OR WATERWAY BELOW THE EXISTING STRUCTURE. ALL COSTS INCLUDING ERECTION, MAINTENANCE AND REMOVAL OF TEMPORARY STRUCTURES OR OTHER SUCH APPROVED METHODS, SHALL BE SUBSIDIARY TO THE APPROPRIATE ITEMS OF WORK BEING PERFORMED.
8. ALL MATERIALS AND METHODS ARE TO COMPLY WITH THE MASSDOT STANDARD SPECIFICATIONS FOR HIGHWAYS AND BRIDGES, DATED 1988, AND ITS LATEST REVISIONS.
9. ALL DISTURBED AREAS SHALL BE LOAMED & SEEDED UNLESS OTHERWISE SPECIFIED. OVER EXCAVATE LOAM & SEED AREAS AS REQUIRED TO MEET GRADE.
10. IF THERE ARE REVISIONS TO APPROVED PLANS, THE CONTRACTOR SHALL SUBMIT THESE CHANGES TO THE DESIGNER OF RECORD FOR REVIEW AND APPROVAL PRIOR TO CONSTRUCTION. ONCE THESE REVISIONS ARE APPROVED BY THE MUNICIPALITY'S DESIGNER OF RECORD, THEY SHALL THEN BE SUBMITTED TO MASSDOT FOR FILING.
11. ALL DIMENSIONS ARE HORIZONTAL AND VERTICAL, AND ARE GIVEN AT 68 DEGREES FAHRENHEIT.
12. ALL WORK PERFORMED BY THE CONTRACTOR SHALL COMPLY WITH ALL FEDERAL, STATE, AND LOCAL REGULATIONS AND REQUIREMENTS.
13. THE CONTRACTOR SHALL REVIEW AND UNDERSTAND ALL APPLICABLE ENVIRONMENTAL PERMITS AND ENSURE THAT ALL CONSTRUCTION CONDITIONS ARE MET.
14. THE CONTRACTOR SHALL BE RESPONSIBLE FOR CONSTRUCTION SAFETY, AND MEANS AND METHODS TO PERFORM AND COMPLETE THE WORK.
15. THE CONTRACTOR SHALL BE RESPONSIBLE FOR REPAIRING ANY DAMAGE TO PRIVATE OR PUBLIC PROPERTY OUTSIDE THE LIMITS OF CONSTRUCTION SHOWN ON THE PLANS CAUSED BY THE CONTRACTOR, AT THE SOLE COST TO THE CONTRACTOR.
16. THE CONTRACTOR MUST COORDINATE ALL WORK WITH THE TOWN OF MANCHESTER-BY-THE-SEA, ALL UTILITY COMPANIES, THE ENGINEER, AND ANY AFFECTED ABUTTERS. WORK SHALL NOT PROCEED WITHOUT WRITTEN APPROVAL FROM THE TOWN OF MANCHESTER-BY-THE-SEA.
17. THE CONTRACTOR SHALL SUBMIT LITERATURE (MANUFACTURER'S LITERATURE, CUT SHEETS, APPLICATION PROCEDURES, ETC.) FOR ALL PRODUCTS PROPOSED FOR USE ON THE PROJECT, FOR APPROVAL BY THE ENGINEER. APPROVAL OF MATERIALS SHALL BE IN ACCORDANCE WITH THE APPLICABLE REQUIREMENTS OF MASSDOT STANDARD SPECIFICATIONS FOR HIGHWAYS AND BRIDGES, LATEST EDITION AS AMENDED, SUBSECTION 5.03 AND SECTION 6.00, CONTROL OF MATERIALS.
18. DETAIL OR SHOP DRAWINGS SHALL BE SUBMITTED AND APPROVED IN ACCORDANCE WITH THE APPLICABLE REQUIREMENTS OF MASSDOT STANDARD SPECIFICATIONS FOR HIGHWAYS AND BRIDGES, LATEST EDITION AS AMENDED, SUBSECTION 5.02, PLANS AND DETAIL DRAWINGS.
19. TAKE ALL NECESSARY MEASURES AND PROVIDE ALL NECESSARY CONTINUOUS BARRIERS OF SUFFICIENT TYPE, SIZE AND STRENGTH TO PREVENT ACCESS TO ALL OPEN EXCAVATIONS AT THE COMPLETION OF EACH DAY'S WORK.
20. ALL EXPOSED EDGES OF CONCRETE SHALL BE CHAMFERED 3/4", UNLESS OTHERWISE NOTED.
21. SHEAR KEYS SHALL BE 3" HIGH BY ONE-THIRD THE WIDTH OF THE CONCRETE ELEMENT, CENTERED, WITH 3" MIN. CLEAR EACH SIDE.
22. PEEL AND STICK BARRIER MEMBRANE SHALL BE 2' WIDE WITH PROTECTION BOARD (SUBSIDIARY) AND PLACED CENTERED OVER ALL HORIZONTAL AND VERTICAL EXPANSION AND CONSTRUCTION JOINTS.
23. APPLY PAVEMENT JOINT ADHESIVE ALONG ALL LONGITUDINAL JOINTS BETWEEN PAVEMENT PASSES AND ALONG BRIDGE CURB LINES AND EXPANSION JOINT ARMORING PRIOR TO PLACING ALL PAVEMENT COURSES.
24. FOR SURVEY CONTROLS SEE SHEETS C-001 TO C-004 (CIVIL SHEETS).
25. FOR BORING NOTES SEE SHEET S-003.
26. FOR HYDRAULIC DATA SEE SHEET S-001.
27. FOR ROAD CLOSURE TRAFFIC MANAGEMENT PLAN SEE SHEET C-702 (CIVIL SHEETS).

BRIDGE REMOVAL NOTES:

1. THE CONTRACTOR'S METHOD FOR REMOVAL OF THE EXISTING BRIDGE SHALL BE SUBMITTED TO THE ENGINEER FOR REVIEW AND ACCEPTANCE PRIOR TO THE COMMENCEMENT OF ANY REMOVAL OPERATIONS.
2. REMOVAL OF EXISTING BRIDGE STRUCTURE SHALL INCLUDE THE COMPLETE REMOVAL OF THE ARCH, FOOTINGS, HEADWALLS, AND WINGWALL. REFER TO SHEET C-005 (CIVIL SHEETS) FOR DEMOLITION PLAN.
3. REFER TO SHEET [FILL-IN FOR FINAL DESIGN] (CIVIL SHEETS) FOR WATER CONTROL SEQUENCING.

FOUNDATION NOTES:

1. FOUNDATION MAY BE ALTERED, IF NECESSARY, TO SUIT CONDITIONS ENCOUNTERED DURING CONSTRUCTION, WITH THE APPROVAL OF THE ENGINEER.
2. CONCRETE SHALL NOT BE PLACED IN WATER OR ON FROZEN GROUND.
3. BOTTOM OF FOUNDATION ELEVATIONS PROVIDED ON DRAWINGS SHALL BE CONSIDERED MINIMUM DEPTHS. CONTRACTOR SHALL REMOVE UNSUITABLE MATERIAL AS REQUIRED.
4. ALL FINISHED EXCAVATIONS SHALL BE VERIFIED AND APPROVED BY THE ENGINEER PRIOR TO PLACEMENT OF FORMWORK FOR CONCRETE FOUNDATION.
5. ALL EXCAVATIONS FOR FOOTINGS SHALL BE FINISHED BY HAND FOR THE LAST 6". ALL FINISHED EXCAVATIONS SHALL BE INSPECTED BY THE ENGINEER PRIOR TO ANY CONCRETE PLACEMENT.
6. ALL BACKFILL UNDER OR ADJACENT TO ANY PORTION OF THE STRUCTURE SHALL BE PLACED IN ACCORDANCE WITH MASSDOT STANDARD SPECIFICATIONS.
7. PRIOR TO PLACEMENT OF FOOTINGS, REVIEW IN-SITU CONDITIONS WITH THE OWNER'S DESIGNATED ENGINEER.

GEOTECHNICAL DESIGN PARAMETERS

1. MINIMUM EMBEDMENT FOR FROST PROTECTION = 4 FEET BELOW ADJACENT GROUND SURFACE.
2. FACTORED STRENGTH LIMIT STATE BEARING RESISTANCE = 45.0 TONS PER SQUARE FOOT
   a. THE BRIDGE DESIGNER SHALL VERIFY THE BEARING RESISTANCE BASED ON THE FINAL BRIDGE AND WINGWALL FOUNDATION DIMENSIONS AND EMBEDMENT
3. MAXIMUM ALLOWABLE SETTLEMENT = 1 INCH TOTAL, ½ INCH DIFFERENTIAL
4. MINIMUM LATERAL EARTH PRESSURES FOR RESTRAINED ARCH WALLS:
   a. STATIC = 61 POUNDS PER SQUARE FOOT PER FOOT (PSF/FT) AS AN EQUIVALENT FLUID PRESSURE, 200 PSF/FT MINIMUM
   b. SURCHARGE = 0.5 TIMES THE VERTICAL SURCHARGE LOAD UNIFORMLY DISTRIBUTED OVER THE HEIGHT OF THE WALL. THE MINIMUM VERTICAL SURCHARGE SHALL BE AN AASHTO HL-93 VEHICULAR LOAD.
   c. SEISMIC = $3.9H^2$ DISTRIBUTED AS AN INVERSE TRIANGLE OVER THE HEIGHT OF THE WALL
5. MINIMUM LATERAL EARTH PRESSURES FOR UNRESTRAINED WING WALLS:
   a. STATIC = 35 PSF/FT AS AN EQUIVALENT FLUID PRESSURE, 200 PSF/FT MINIMUM
   b. SURCHARGE = 0.28 TIMES THE VERTICAL SURCHARGE LOAD UNIFORMLY DISTRIBUTED OVER THE HEIGHT OF THE WALL. THE MINIMUM VERTICAL SURCHARGE SHALL BE AN AASHTO HL-93 VEHICULAR LOAD. THE DESIGN SHALL ACCOUNT FOR SLOPING GROUND SURFACE ABOVE THE WALLS.
   c. SEISMIC = $3.9H^2$ DISTRIBUTED AS AN INVERSE TRIANGLE OVER THE HEIGHT OF THE WALL
6. MINIMUM BACKFILL UNIT WEIGHT = 130 POUNDS PER CUBIC FOOT (PCF)
7. MAXIMUM BACKFILL ANGLE OF INTERNAL FRICTION = 32 DEGREES
8. MAXIMUM COEFFICIENT OF FRICTION FOR CONCRETE ON CLEAN, SOUND BEDROCK = 0.70 (DELTA= 35 DEGREES)
9. SITE CLASS = C
10. DESIGN PEAK SEISMIC GROUND ACCELERATION MODIFIED BY THE SHORT-PERIOD SITE FACTOR (A_S) = 0.103
11. DESIGN SPECTRAL RESPONSE ACCELERATION AT 0.2-SECOND PERIODS (S_{DS}) = 0.202
12. DESIGN SPECTRAL RESPONSE ACCELERATION AT 1-SECOND PERIODS (S_{D1}) = 0.068

PRECAST CONCRETE BRIDGE STRUCTURE NOTES:

1. ITEM 995.01, BRIDGE STRUCTURE - STRUCTURE NO. 1, SHALL INCLUDE THE PRECAST CONCRETE ARCH, CURBS/HEADWALLS, PEDESTAL FOOTINGS USED TO SUPPORT THE RIGID FRAME, U-WINGWALL, AND WINGWALL FOOTING. JOINT MATERIALS, MEMBRANE, AND ANY OTHER MATERIALS REQUIRED FOR INSTALLATION OF THE PRECAST CONCRETE BRIDGE OR WINGWALL STRUCTURE SHALL BE SUBSIDIARY.
2. THE CONTRACTOR SHALL SUBMIT SHOP DRAWINGS AND DESIGN CALCULATIONS, SEALED AND SIGNED BY A CURRENTLY REGISTERED MASSACHUSETTS PROFESSIONAL ENGINEER TO THE MUNICIPALITY'S DESIGNER OF RECORD FOR REVIEW AND ACCEPTANCE FOR REVIEW TO ENSURE CONFORMANCE WITH THE CONTRACT DOCUMENTS. SHOP DRAWINGS AND CALCULATIONS SHALL BE SUBMITTED PRIOR TO FABRICATION FOR ALL PRECAST CONCRETE ELEMENTS. SHOP DRAWINGS SHALL SHOW JOINT DETAILS AND REINFORCEMENT SIZE AND LOCATION.
3. CHANGES OR MODIFICATIONS DURING THE FABRICATION PROCESS MUST BE SUBMITTED TO THE MUNICIPALITY'S DESIGNER OF RECORD FOR ACCEPTANCE AND INCORPORATED INTO THE FINAL AS-BUILT DRAWINGS.
4. DIMENSIONS SHOWN FOR THE PRECAST CONCRETE ELEMENTS ARE ASSUMED AND ARE BELIEVED TO BE PRACTICABLE. NO ADJUSTMENTS TO QUANTITIES OR PAYMENTS WILL BE MADE AS A RESULT OF PROVIDING PRECAST UNITS SIZED DIFFERENTLY THAN SHOWN ON THE PLANS.
5. THE QUALITY OF MATERIALS, THE PROCESS OF MANUFACTURE, AND THE FINISHED PRECAST UNITS SHALL BE SUBJECT TO INSPECTION AND APPROVAL BY THE ENGINEER.
6. JOINTS BETWEEN ABUTTING PRECAST UNITS SHALL BE MECHANICALLY CONNECTED, WATERTIGHT, GROUTED, AND MEMBRANED.
7. JOINTS BETWEEN ABUTTING PRECAST ARCH, WINGWALL, AND CURB/HEADWALL ELEMENTS SHALL BE MECHANICALLY CONNECTED, WATER TIGHT, AND MEMBRANED.
8. WATERPROOF MEMBRANE SHALL BE PROVIDED OVER THE STRUCTURE ACROSS THE ENTIRE ROADWAY WIDTH.
9. MEMBRANED SURFACES TO BE BACKFILLED AGAINST SHALL BE PROTECTED BY A PROTECTION BOARD.
10. EXPOSED CONCRETE SURFACES SHALL BE TREATED WITH WATER REPELLENT (SILANE/SILOXANE).
11. PRECAST CONCRETE CURB/HEADWALL ANCHORAGES, CURB, U-WINGWALL, AND ARCH SECTIONS SHALL BE DESIGNED TO ACCOUNT FOR ALL EARTH PRESSURE, LIVE LOAD SURCHARGES, AND BRIDGE RAILING LIVE LOAD AS SPECIFIED IN THE AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS FOR NCHRP 350 TL-2 TEST LEVEL.
12. WEEP HOLES SHALL BE PLACED 1'-0" (TYP.) ABOVE THE TOP OF THE PEDESTAL FOOTING AND ONE (1) WEEP PROVIDED ON BOTH SIDES OF EACH ARCH OR WINGWALL UNIT OR 10'-0" (MAX.) SPACING ALONG FOOTING.
13. FOOTINGS SHALL HAVE A KEYWAY WITH THE SPECIFIED DIMENSIONS. GROUT SHALL BE PLACED AROUND THE BOTTOM OF THE ARCH OR WINGWALL AND TO THE TOP OF THE KEYWAY.
14. TOP SURFACES OF FOOTING UNITS SHALL BE SET UNIFORMLY TRUE & LEVEL TO A TOLERANCE OF +/- 1/8". PRECAST UNITS SHALL UNIFORMLY BEAR ON SUPPORTING MATERIAL.
15. ANY UNSUITABLE MATERIALS SUCH AS BOULDERS, ROOTS, ORGANIC SOILS, SILT/CLAY, OR FRACTURED BEDROCK ENCOUNTERED AT THE PROPOSED BOTTOM OF EXCAVATION ELEVATION SHALL BE REMOVED AND REPLACED WITH CONCRETE, AS DIRECTED BY THE ENGINEER.
16. DEWATERING SHALL BE REQUIRED AT EACH FOUNDATION LOCATION TO CONTROL THE WATER INFLOW AND ADEQUATELY DEWATER THE FOOTING EXCAVATION. SUMP PUMPING AREAS AROUND THE ENTIRE PERIMETER SHALL BE REQUIRED TO ADEQUATELY CONTROL THE GROUNDWATER WITHIN THE EXCAVATION AREAS. DEWATERING SHALL BE CONTINUOUS UNTIL THE PRECAST CONCRETE ARCH AND WINGWALLS ARE BACKFILLED EVENLY ON BOTH SIDES TO THE ELEVATIONS OF THE SURROUNDING WATER TABLE, UNLESS OTHERWISE DIRECTED.
17. ANY PROPOSED DEWATERING AND SHORING PROCEDURES SHALL BE SUBMITTED TO THE ENGINEER OF RECORD FOR REVIEW AND ACCEPTANCE.
18. WATER PUMPED FROM DEWATERING LOCATIONS SHALL BE FILTERED ADEQUATELY TO REMOVE FINE MATERIALS PRIOR TO RETURNING THE WATER TO THE RIVER/BROOK. ACTUAL LOCATION OF SEDIMENTATION BASIN TO BE DETERMINED BY CONTRACTOR AND APPROVED BY THE ENGINEER PRIOR TO INSTALLATION.
19. ANY FOUNDATION MATERIALS WEAKENED AS A RESULT OF INSUFFICIENT CARE WHILE MAINTAINING A DEWATERED CONDITION SHALL BE REMOVED AND REPLACED WITH CONCRETE AT NO EXPENSE TO THE OWNER.
20. REINFORCEMENT SHALL HAVE A 2" MINIMUM CLEAR COVER.
21. A CORROSION INHIBITOR CONCRETE ADDITIVE SHALL BE USED FOR ALL CONCRETE.
22. DATE TO BE PLACED ON THE INSIDE NORTHEAST FACE AND INSIDE SOUTHWEST FACE HIGHWAY GUARDRAIL TRANSITIONS. A SHEET SHOWING SIZE AND CHARACTER OF NUMERALS WILL BE FURNISHED. THE DATE USED SHALL BE THE LATEST YEAR OF CONTRACT COMPLETION AS OF THE DATE THE FIRST HIGHWAY GUARDRAIL TRANSITION IS CONSTRUCTED. ALL HIGHWAY GUARDRAIL TRANSITIONS SHALL FEATURE THE SAME DATE.

CHAPTER 85 SECTION 35 REVIEW AND APPROVAL NOTES:

1. IN ACCORDANCE AND COMPLIANCE WITH THE REQUIREMENTS OF CHAPTER 85 SECTION 35 OF THE MASSACHUSETTS GENERAL LAWS, THE CONTRACTOR SHALL SUBMIT TO THE MASSACHUSETTS DEPARTMENT OF TRANSPORTATION ALL CONSTRUCTION DRAWINGS AND DESIGN CALCULATIONS THAT SHALL BE USED TO FABRICATE AND CONSTRUCT THE STRUCTURE DENOTED ON THESE PLANS FOR REVIEW AND APPROVAL. THIS APPROVAL SHALL CONSTITUTE THE FINAL APPROVAL AS STIPULATED BY CHAPTER 85 SECTION 35 OF THE MASSACHUSETTS GENERAL LAWS.

COMMONWEALTH OF MASSACHUSETTS
MassDOT, Highway Division
CONCEPTUAL DESIGN IS ACCEPTABLE TO MASSDOT FOR CONTRACTING

DISTRICT BRIDGE ENGINEER DATE

Tighe&Bond
Engineers | Environmental Specialists

Draft 25% Plans Not For Construction

Central Street Bridge Replacement

Department of Public Works

MassDOT Bridge No. M-02-001, BIN 8AM

Town of Manchester-By-The-Sea, Massachusetts

MARK	DATE	DESCRIPTION

PROJECT NO:	M1476 - 011
DATE:	JUNE 2019
FILE: M1476-011-S-002.dwg	
DRAWN BY:	D.BISHOP
CHECKED:	EAO
APPROVED:	DLL

BRIDGE NOTES

SCALE: AS NOTED

S-002
SHEET 2 OF 6

Last Saved: 8/22/2019
Plotted On:Aug 22, 2019-3:57pm By: EOhanian
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Tighe&Bond
Engineers | Environmental Specialists

Project: Central Street Bridge
Location: Central Street, Manchester-by-the-Sea, MA
Client: Town of Manchester-by-the-Sea

Boring No. B-1
Page 1 of 1
File No. M-1476011
Checked by: C. Haker

Drilling Co.: New England Boring Contractors
Foreman: Mike Porter
T&B Rep.: M. Trovato
Date Start: 08/09/18 End: 08/09/18
Location: See Exploration Location Plan
GS. Elev. 9.45' Datum: NAVD88

	Casing	Sampler
Type	HW	Split Spoon
I.D./O.D.	4"/4.5"	1-3/8"/2"
Hammer Wt.		140#
Hammer Fall		30"
Other		Auto hammer

Groundwater Readings

Date	Time	Depth	Casing	Sta. Time
8/9/2018	13:45	6.3'		End of Boring

Depth (ft.)	Casing Blows Per Ft.	Sample No. / Rec. (in)	Sample Depth (ft.)	Blows Per 6"	Sample Description	General Stratigraphy	Notes	Well Construction
		S-1/–	0-2	--, --	14-inches of Asphalt, over brown, fine to coarse SAND, some Gravel, trace Silt	ASPHALT (to 1.2')	1	No Well Installed
		S-2/–	2-4	--, --	Brown, fine to coarse SAND and GRAVEL, little Silt	FILL		
5		S-3/8	5-7	9 - 12, 2 - 13	Medium dense, brown, GRAVEL, some fine to coarse Sand, trace Silt	FILL	2	
		S-4/4	8-10	50/6", --	Very dense, brown, GRAVEL, little fine to coarse Sand, little Silt	FILL (to 9.9')	3	
10		C-1/58	10.5-15.5	2:04, 1:37, 1:53, 2:09, 2:12	Very hard to hard, moderate to slightly weathered, slightly fractured to sound, very coarse to coarse-grained GRANITE, with close to moderately close, horizontal to moderately dipping fractures; RQD = 95%	BEDROCK		
15		C-2/60	15.5-20.5	2:17, 2:09, 1:44, 2:12, 3:09	Very hard to hard, slight to very slightly weathered, slightly fractured to sound, very coarse to coarse-grained GRANITE, with close to moderately close, horizontal to shallow fractures; RQD = 98%	BEDROCK		
20					Bottom of exploration at 20.5'			
25								
30								

Notes:
1) Vacuum excavated to approximately 5 feet below grade. Samples S-1 and S-2 were collected by hand.
2) Boulder encountered from approximately 7 to 8 feet below grade.
2) Refusal encountered at approximately 9.9 feet below grade, telescoped 3-inch casing in an attempt to advance the boring.

Proportions Used

TRACE (TR.)	0 - <10%
LITTLE (LI.)	10 - <20%
SOME (SO.)	20 - <35%
AND	35 - <50%

Density/Consistency

VERY LOOSE	0-4	VERY SOFT	<2
LOOSE	4-10	SOFT	2-4
MEDIUM DENSE	10-30	MEDIUM	4-8
DENSE	30-50	STIFF	8-15
VERY DENSE	>50	VERY STIFF	15-30
		HARD	>30

BORING LOG B-1

BORING LOCATIONS

BORING	STATION	OFFSET
B-1	0+52.3	RT. 16.2'

BORING NOTES:

1. LOCATION OF BORINGS SHOWN ON SHEET S-001 THUS: B–1
2. BORINGS WERE TAKEN FOR PURPOSE OF DESIGN AND SHOW CONDITIONS AT BORING POINTS ONLY, BUT DO NOT NECESSARILY SHOW THE NATURE OF MATERIALS TO BE ENCOUNTERED DURING CONSTRUCTION.
3. WATER LEVELS SHOWN ON THE BORING LOGS WERE OBSERVED AT THE TIME OF TAKING BORINGS AND DO NOT NECESSARILY SHOW THE TRUE GROUND WATER LEVEL.
4. FIGURES IN COLUMNS INDICATE NUMBER OF BLOWS REQUIRED TO DRIVE A 1⅜" I.D. SPLIT SPOON SAMPLER 6" USING A 140 POUND WEIGHT FALLING 30".
5. BORING SAMPLES ARE STORED AT TIGHE & BOND'S OFFICE, 53 SOUTHAMPTON ROAD, WESTFIELD, MA 01085. THE CONTRACTOR MAY EXAMINE THE SOIL AND ROCK SAMPLES BY CONTACTING THE DESIGN ENGINEER.
6. ALL BORINGS WERE MADE IN SEPTEMBER 2018.
7. BORINGS WERE MADE BY NEW ENGLAND BORING CONTRACTORS OF DERRY, NEW HAMPSHIRE.
8. THE NORTH AMERICAN VERTICAL DATUM (NAVD) OF 1988 IS USED THROUGHOUT.
9. THE SURFACE ELEVATION ON EACH BORING LOG IS THE ELEVATION OF THE EXISTING GROUND AT THE TIME THE BORING WAS TAKEN.
10. SEE SHEET S-002 FOR GEOTECHNICAL DESIGN PARAMETERS.
11. ENGINEERING JUDGEMENT WAS EXERCISED IN PREPARING THE SUBSURFACE INFORMATION PRESENTED HEREIN. ANALYSIS AND INTERPRETATION OF SUBSURFACE DATA WAS PERFORMED FOR DESIGN AND ESTIMATING PURPOSES. PRESENTATION OF THE INFORMATION IN THE CONTRACT IS INTENDED TO PROVIDE THE CONTRACTOR ACCESS TO THE SAME DATA AVAILABLE TO THE OWNER. THE SUBSURFACE INFORMATION IS PRESENTED IN GOOD FAITH AND IS NOT INTENDED AS A SUBSTITUTE FOR PERSONAL INVESTIGATION, INDEPENDENT INTERPRETATION, INDEPENDENT ANALYSIS OR JUDGEMENT BY THE CONTRACTOR.

COMMONWEALTH OF MASSACHUSETTS
MassDOT, Highway Division
CONCEPTUAL DESIGN IS ACCEPTABLE TO MASSDOT FOR CONTRACTING

DISTRICT BRIDGE ENGINEER DATE

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Tighe&Bond
Engineers | Environmental Specialists

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Central Street Bridge Replacement

Department of Public Works

MassDOT Bridge No. M-02-001, BIN 8AM

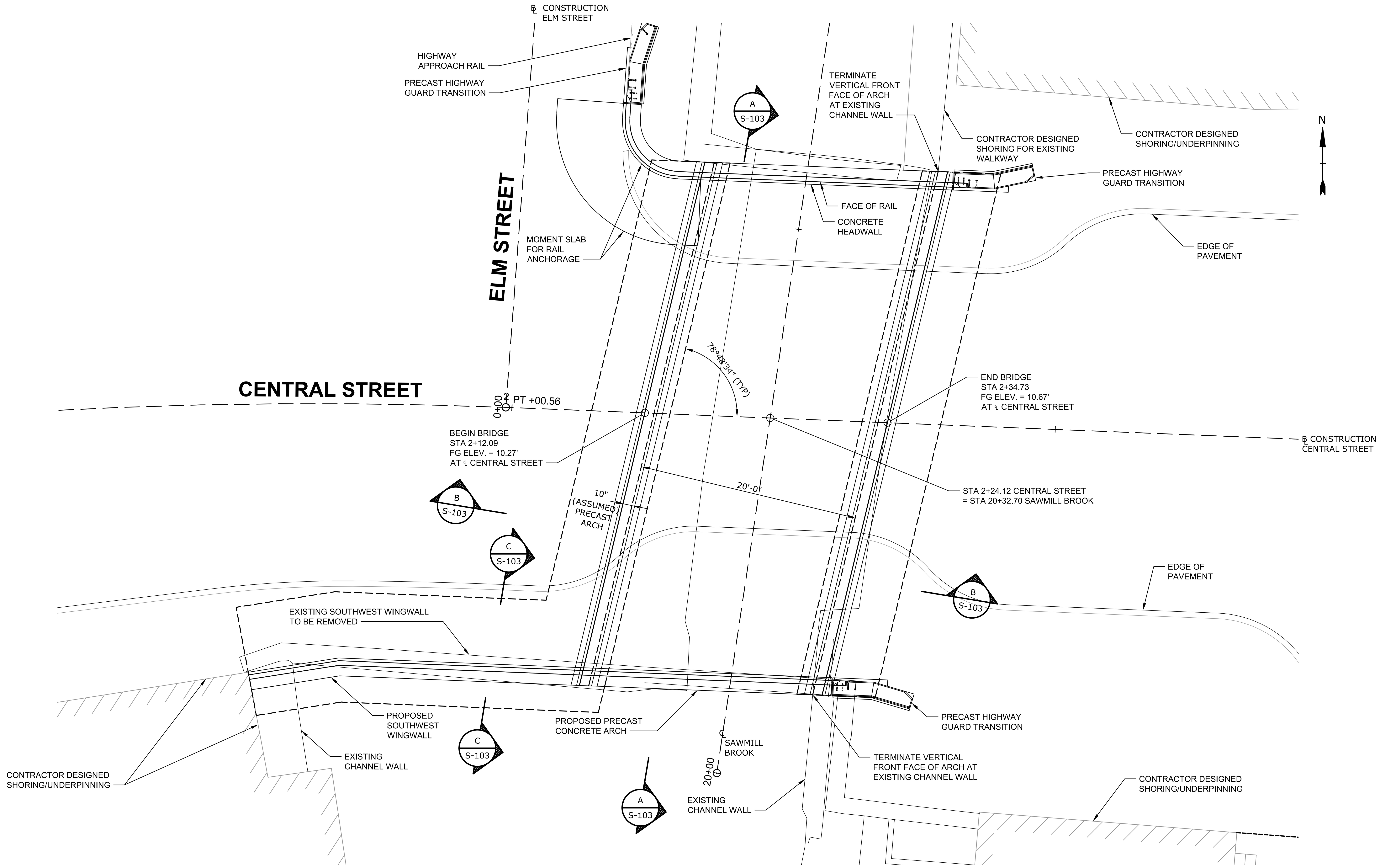
Town of Manchester-By-The-Sea, Massachusetts

MARK	DATE	DESCRIPTION

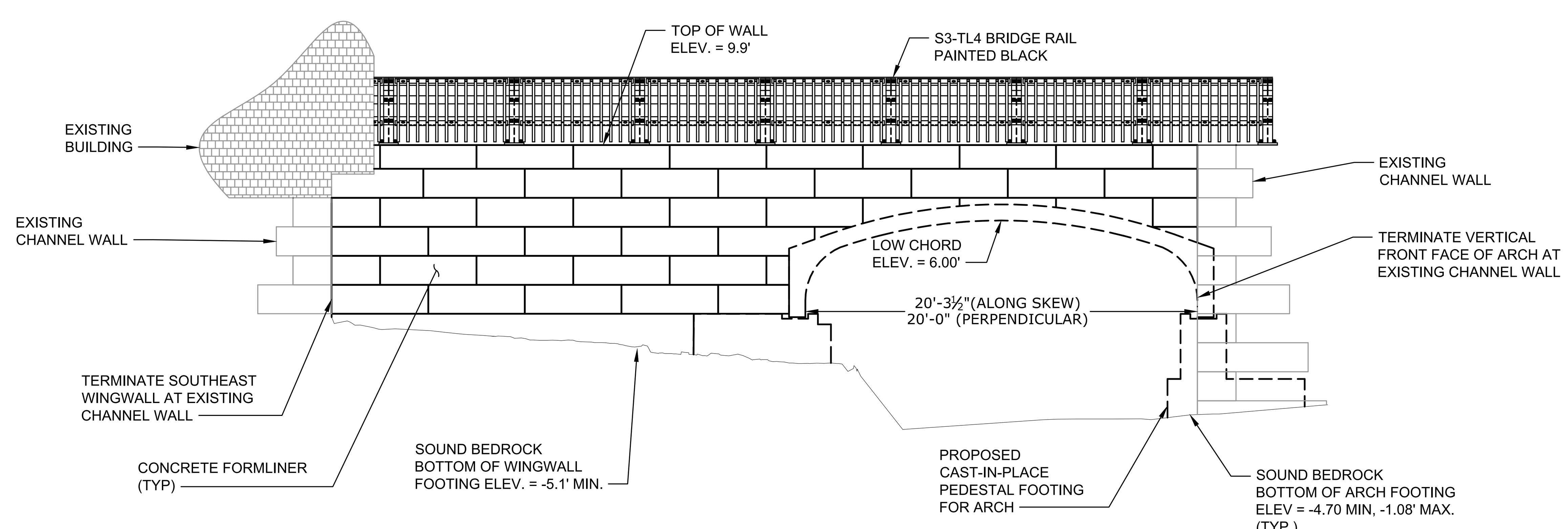
PROJECT NO: M1476 - 011
DATE: JUNE 2019
FILE: M1476-011-S-003.dwg
DRAWN BY: D.BISHOP
CHECKED: EAO
APPROVED: DLL

BORING LOGS AND BORING NOTES

SCALE: AS NOTED



GENERAL BRIDGE PLAN
3/16" = 1'-0"



ELEVATION (LOOKING NORTH)
3/16" = 1'-0"

COMMONWEALTH OF MASSACHUSETTS
MassDOT, Highway Division
CONCEPTUAL DESIGN IS ACCEPTABLE TO MASSDOT FOR CONTRACTING

DISTRICT BRIDGE ENGINEER | DATE

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Town of Manchester-By-The-Sea, Massachusetts

MARK	DATE	DESCRIPTION

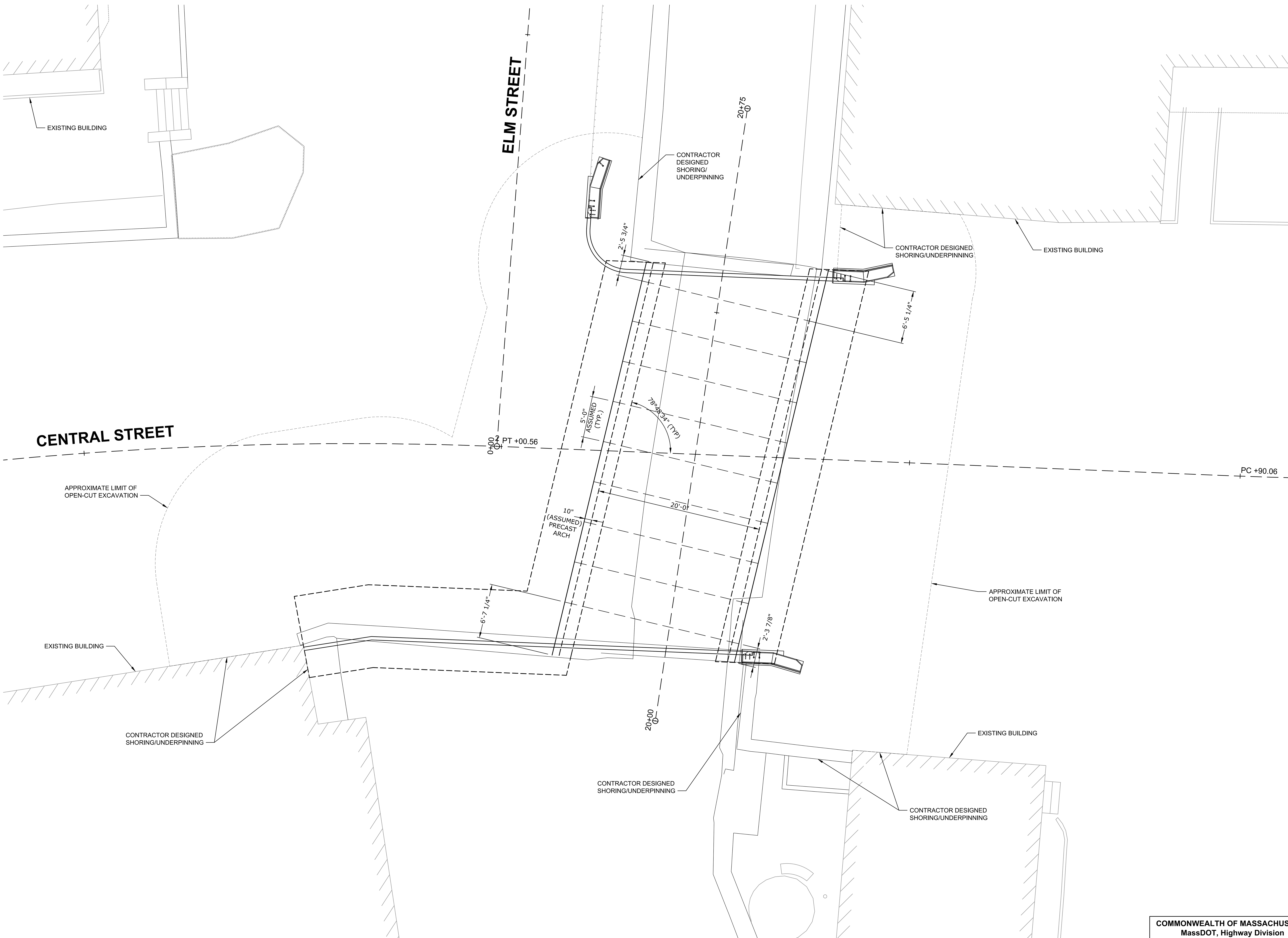
PROJECT NO:	M1476 - 011
DATE:	JUNE 2019
FILE: M1476-011-S-101_102.dwg	
DRAWN BY:	D.BISHOP
CHECKED:	EAO
APPROVED:	DLL

GENERAL BRIDGE PLAN AND ELEVATION

SCALE: AS NOTED

S-101
SHEET 4 OF 6

Last Saved: 8/22/2019
Plotted On:Aug 22, 2019-4:14pm By: EOhanian
Tighe & Bond:J:\M\M1476 Manchester MA Hydro Study\011-Central Street Bridge\Drawings_Figures\AutoCAD\Sheet\M1476-011-S-101_102.dwg



BRIDGE FRAMING AND LAYOUT PLAN
3/16" = 1'-0"

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Central Street Bridge Replacement

Department of Public Works

MassDOT Bridge No. M-02-001, BIN 8AM

Town of Manchester-By-The-Sea, Massachusetts

MARK	DATE	DESCRIPTION

PROJECT NO:	M1476 - 011
DATE:	JUNE 2019
FILE: M1476-011-S-101_102.dwg	
DRAWN BY:	D.BISHOP
CHECKED:	EAO
APPROVED:	DLL

BRIDGE FRAMING AND LAYOUT PLAN

SCALE: AS NOTED

S-102
SHEET 5 OF 6

COMMONWEALTH OF MASSACHUSETTS
MassDOT, Highway Division
CONCEPTUAL DESIGN IS ACCEPTABLE TO MASSDOT FOR CONTRACTING

DISTRICT BRIDGE ENGINEER DATE

Last Saved: 8/23/2019
Plotted On:Aug 23, 2019-10:40am By: EOhanian
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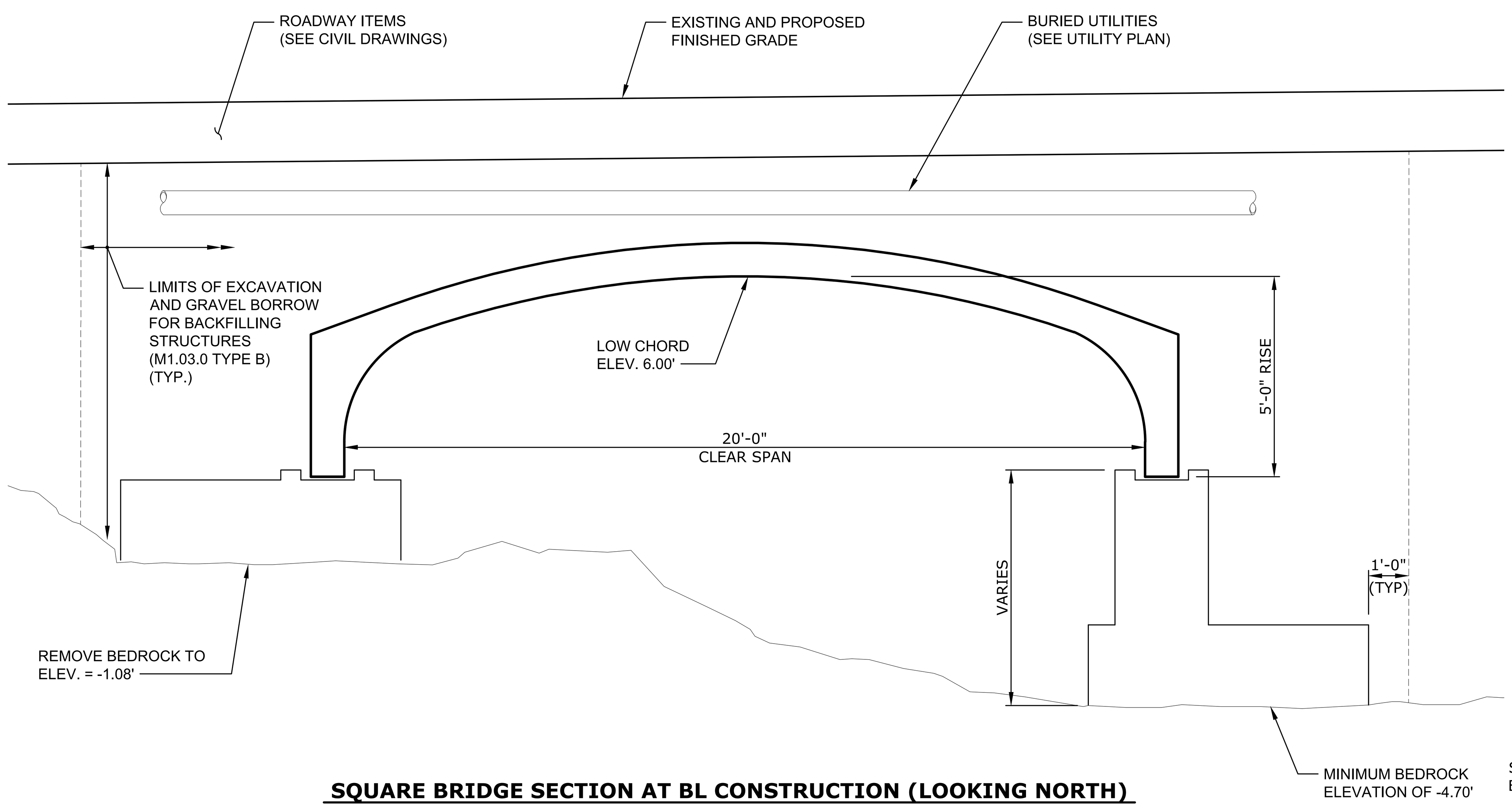
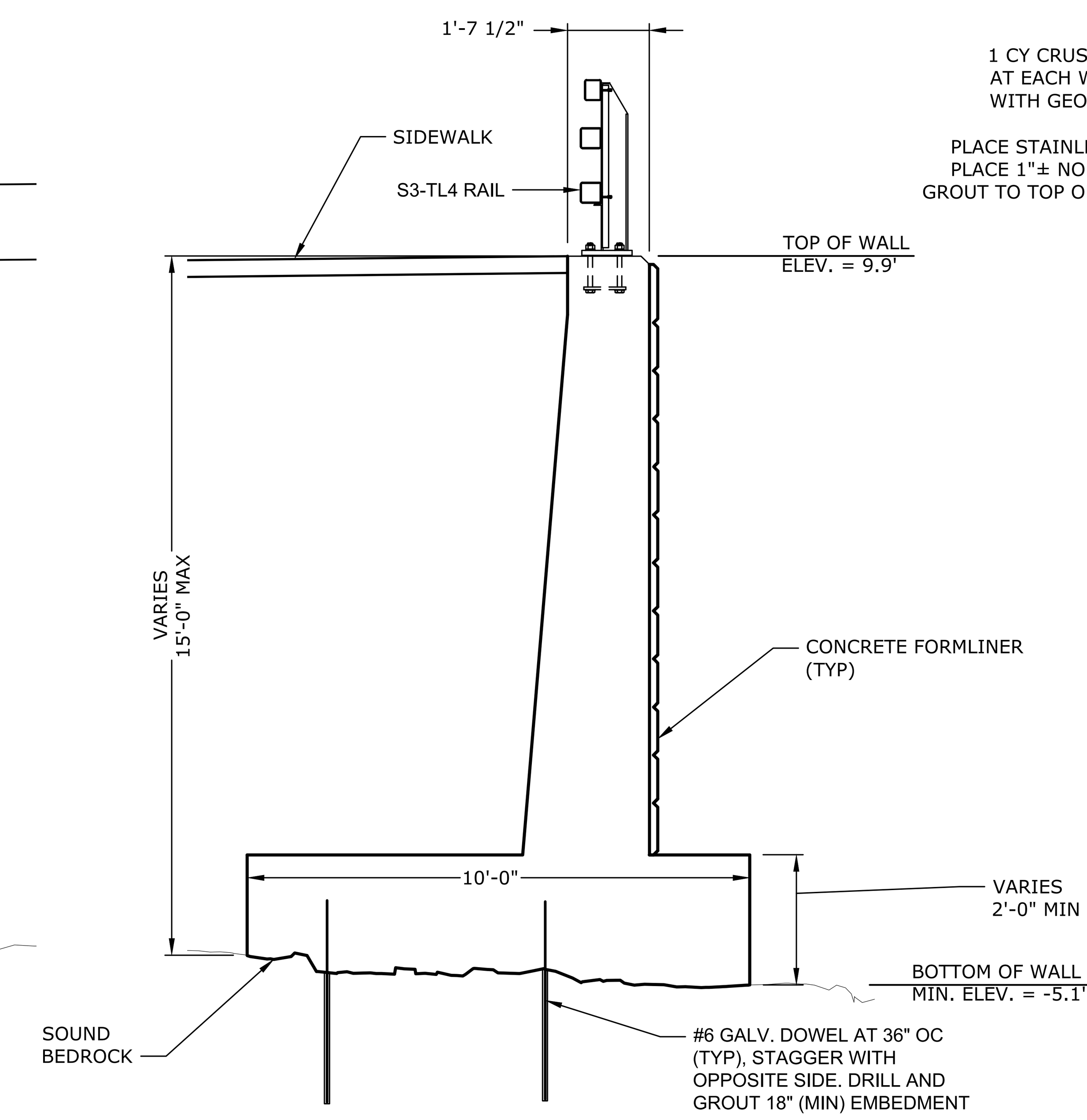


SQUARE BRIDGE SECTION AT BL CONSTRUCTION (LOOKING NORTH)

SECTION B S-101
3/8" = 1'-0"

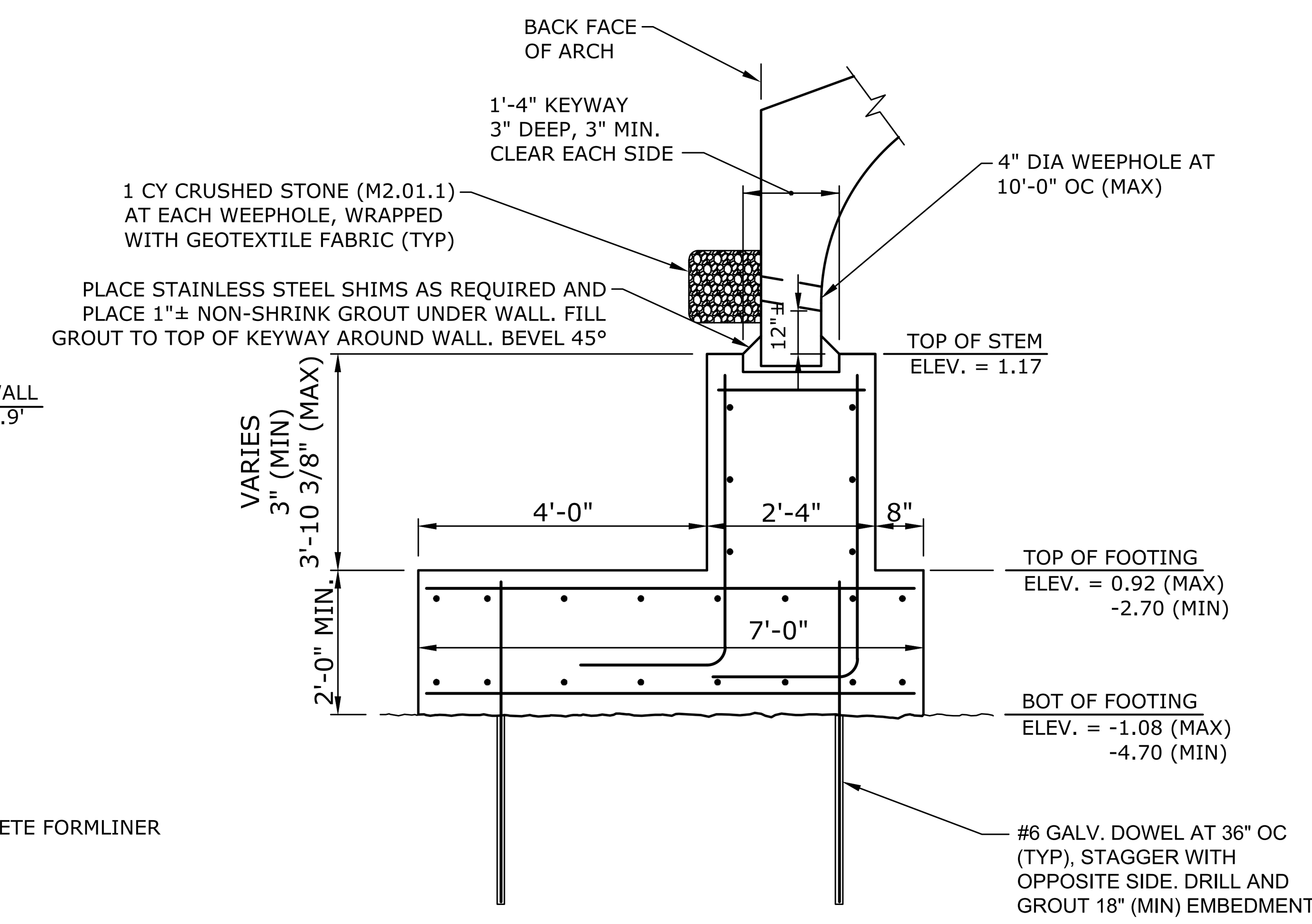
NOTE:

1. SECTION REFLECTS MAXIMUM AND MINIMUM ANTICIPATED BEDROCK ELEVATIONS. CONTRACTOR TO EVALUATE FIELD CONDITIONS AFTER DEMOLITION OF EXISTING BRIDGE AND REPORT TO ENGINEER PRIOR TO CASTING OF ARCH FOOTINGS.

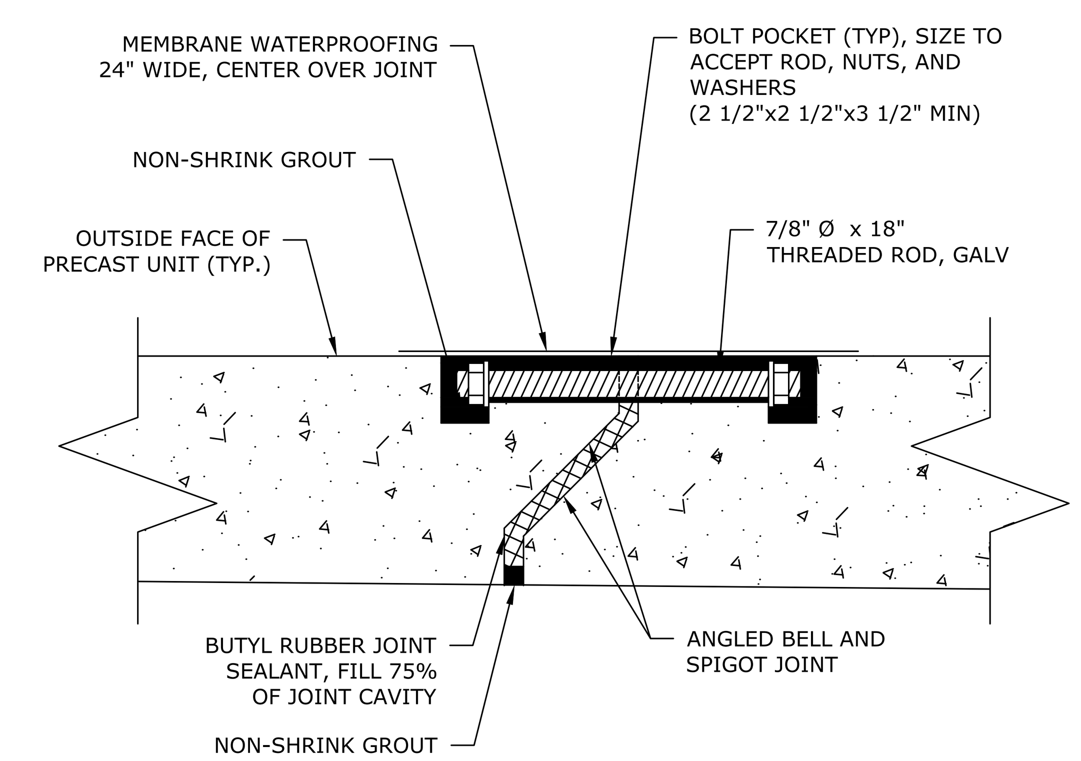


SOUTHWEST WINGWALL

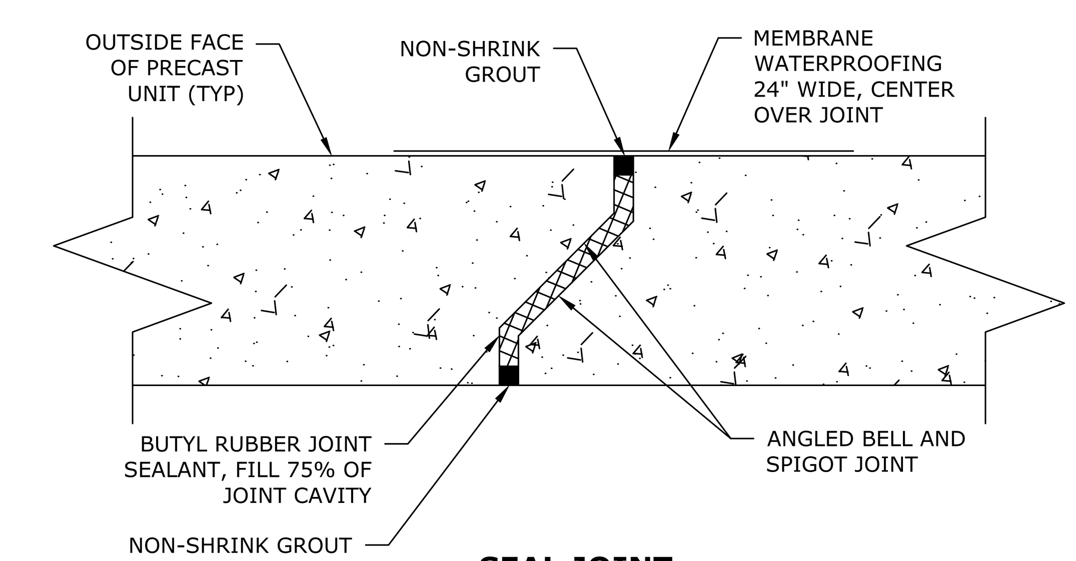
SECTION C S-101
3/8" = 1'-0"



TYPICAL PRECAST ABUTMENT SECTION
1/2" = 1'-0"



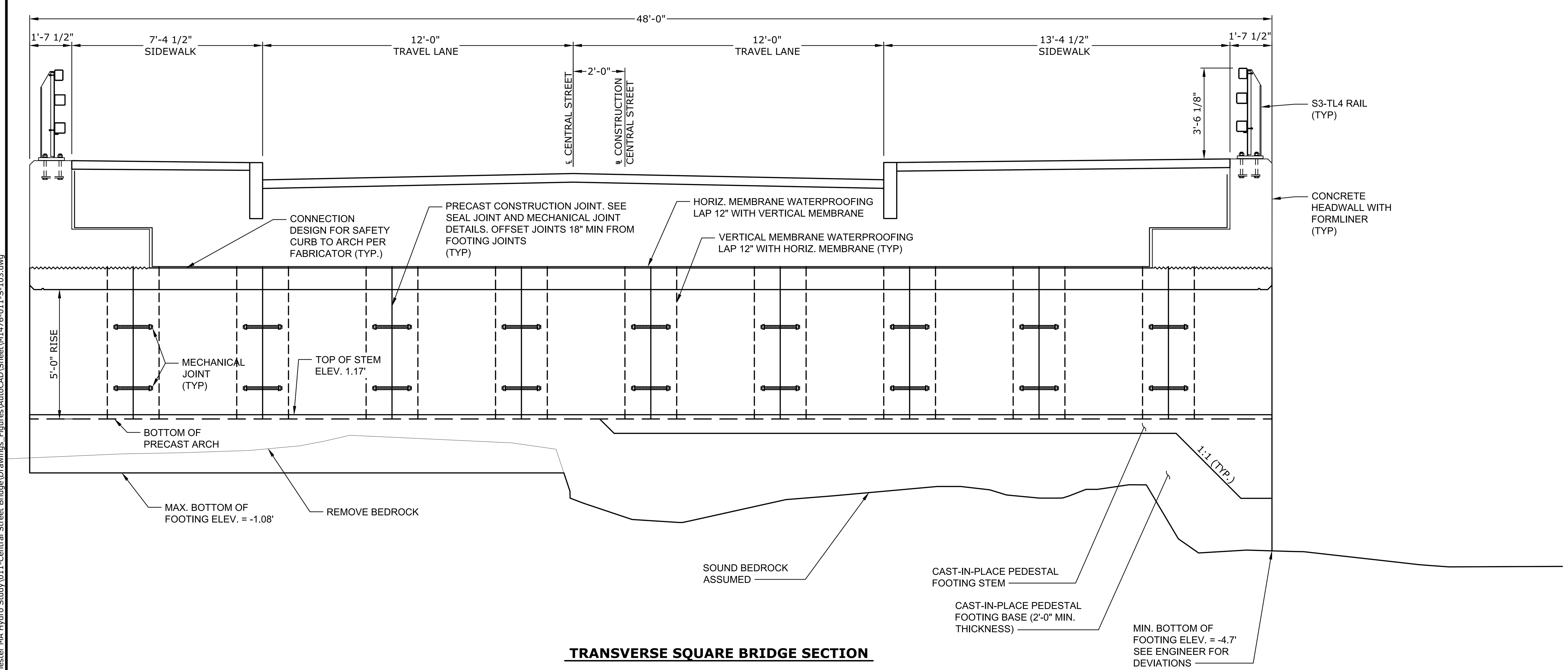
MECHANICAL JOINT
NO SCALE



SEAL JOINT
NO SCALE

JOINT SEALANT NOTES:

1. PROVIDE BUTYL RUBBER JOINT SEALANT (ASTM C-990 & AASHTO M-198) BETWEEN PRECAST CONCRETE UNITS.
2. PROVIDE A MINIMUM OF 7 MECHANICAL CONNECTORS BETWEEN EACH ARCH UNIT (3 ON TOP AND 2 ON EACH SIDE).
3. ALL BOLT POCKETS SHALL BE FILLED WITH NON-SHRINK GROUT.
4. PEEL AND STICK BARRIER MEMBRANE SHALL BE PLACED IN 2-FOOT WIDE STRIPS, CENTERED OVER THE TOP AND/OR SIDES OF EACH JOINT.



TRANSVERSE SQUARE BRIDGE SECTION

SECTION A S-101
3/8" = 1'-0"

COMMONWEALTH OF MASSACHUSETTS
MassDOT, Highway Division
CONCEPTUAL DESIGN IS ACCEPTABLE TO MASSDOT FOR CONTRACTING

DISTRICT BRIDGE ENGINEER | DATE

Tighe&Bond
Engineers | Environmental Specialists

Draft 25% Plans Not For Construction

Central Street Bridge Replacement

Department of Public Works

MassDOT Bridge No. M-02-001, BIN 8AM

Town of Manchester-By-The-Sea, Massachusetts

MARK	DATE	DESCRIPTION

PROJECT NO:	M1476 - 011
DATE:	JUNE 2019
FILE: M1476-011-S-103.dwg	
DRAWN BY:	D.BISHOP
CHECKED:	EAO
APPROVED:	DLL

BRIDGE SECTION AND DETAILS

SCALE: AS NOTED

S-103
SHEET 6 OF 6

Last Saved: 8/22/2019
Plotted On:Aug 22, 2019-3:25pm By: EOhanian
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Appendix F
Opinion of Probable Construction Cost

Engineer's Opinion of Probable Construction Cost
25% Design Submission
Central Street Bridge
Town of Manchester-by-the-Sea, MA

ITEM	MASSDOT DESCRIPTION	QTY	UNITS	UNIT PRICE[1]	AMOUNT
115.1	Demolition of Bridge No. 1	1	LS	$ 175,000.00	$ 175,000.00
120.	Earth Excavation	670	CY	$ 35.00	$ 23,450.00
140.	Bridge Excavation	700	CY	$ 55.00	$ 38,500.00
144.	Class B Rock Excavation	1	LS	$ 30,000.00	$ 30,000.00
146.	Drainage Structure Removed	3	EA	$ 600.00	$ 1,800.00
151.	Gravel Borrow	380	CY	$ 45.00	$ 17,100.00
151.1	Gravel Borrow for for Backfilling Structures and Pipes	550	CY	$ 51.00	$ 28,050.00
170.	Fine Grading and Compacting	1540	SY	$ 7.00	$ 10,780.00
201.	Catch Basin	2	EA	$ 4,500.00	$ 9,000.00
202.	Manhole	2	EA	$ 4,500.00	$ 9,000.00
203.	Special Manhole (Stormwater Treatment Unit)	1	EA	$ 15,000.00	$ 15,000.00
210.	Sanitary Sewer Manhole	3	EA	$ 4,500.00	$ 13,500.00
221.	Frame and Cover	5	EA	$ 800.00	$ 4,000.00
222.2	Frame and Grate - Municiple Standard	2	EA	$ 950.00	$ 1,900.00
224.15	12 Inch Hood	2	EA	$ 500.00	$ 1,000.00
250.06	6 Inch Polyvinyl Chloride Sanitary Sewer Pipe	50	FT	$ 95.00	$ 4,750.00
250.15	15 Inch Polyvinyl Chloride Sanitary Sewer Pipe	250	FT	$ 120.00	$ 30,000.00
252.12	12 Inch Corrugated Plastic Pipe	30	FT	$ 80.00	$ 2,400.00
252.15	15 Inch Corrugated Plastic Pipe	50	FT	$ 85.00	$ 4,250.00
302.06	6 Inch Ductile Iron Water Pipe (Rubber Gasket)	20	FT	$ 120.00	$ 2,400.00
302.12	12 Inch Ductile Iron Water Pipe (Rubber Gasket)	150	FT	$ 150.00	$ 22,500.00
309.	Ductile Iron Fittings for Water Pipe	500	LB	$ 8.00	$ 4,000.00
350.12	12 Inch Gate and Gate Box	1	EA	$ 3,750.00	$ 3,750.00
402.	Dense Graded Crushed Stone for Sub-base	120	CY	$ 75.00	$ 9,000.00
415.	Pavement Micromilling	100	SY	$ 5.00	$ 500.00
450.23	Superpave Surface Course - 12.5 (SSC - 12.5)	120	TON	$ 130.00	$ 15,600.00
450.32	Superpave Intermediate Course - 19.0 (SIC - 19.0)	210	TON	$ 135.00	$ 28,350.00
580.	Curb Removed and Reset	600	FT	$ 30.00	$ 18,000.00
621.12	Guardrail - TL-2 (Single Faced)	80	FT	$ 34.00	$ 2,720.00
627.82	Guardrail End Treatment, TL-2	3	EA	$ 3,750.00	$ 11,250.00
628.24	Transition to Bridge Rail	3	EA	$ 4,200.00	$ 12,600.00
697.	Sedimentation Fence	250	FT	$ 6.00	$ 1,500.00
697.2	Floating Silt Fence	100	FT	$ 35.00	$ 3,500.00
701.	Cement Concrete Sidewalk	200	SY	$ 65.00	$ 13,000.00
701.2	Cement Concrete Wheelchair Ramp	20	SY	$ 95.00	$ 1,900.00
748.	Mobilization	1	LS	$ 59,000.00	$ 59,000.00
756.	NPDES Stormwater Pollution Prevention Plan	1	LS	$ 5,000.00	$ 5,000.00
860.112	12 Inch Reflectorized White Line	120	LF	$ 2.50	$ 300.00
861.104	4 Inch Reflectorized Yellow Line	580	LF	$ 2.00	$ 1,160.00
993.1	Temporary Bridge	1	LS	$ 65,000.00	$ 65,000.00
991.1	Control of Water, Structure No. 1	1	LS	$ 150,000.00	$ 150,000.00
995.01	Bridge Structure, Bridge No. 1	1	LS	$ 765,000.00	$ 765,000.00
996.01	Wall Structure, Wall No. 1	1	LS	$ 450,500.00	$ 450,500.00
	Maintenance of Traffic - Central Street Detour (During Closure)	1	LS	$ 10,000.00	$ 10,000.00
	Maintenance of Traffic - Central Street Phasing (Temp. Signal)	1	LS	$ 60,000.00	$ 60,000.00
	Elm Street Shoring system	1	LS	$ 65,000.00	$ 65,000.00
	Temporary Utility Relocation - Water	1	LS	$ 20,000.00	$ 20,000.00
	Temporary Utility Relocation - Sewer	1	LS	$ 50,000.00	$ 50,000.00
	Temporary Utility Relocation - Gas	1	LS	$ 20,000.00	$ 20,000.00
	Temporary Utility Relocation - Electric	1	LS	$ 50,000.00	$ 50,000.00
				SUBTOTAL	**$ 2,341,010**

Construction Contingency	20%	$	468,202
Bidding & Material Contingency	25%	$	585,253
Police Details	5%	$	117,051
Utility Relocation - National Grid (Gas)		$	20,000
Utility Relocation - National Grid (Power)		$	80,000
Utility Relocation - Verizon/Comcast		$	85,000
	Total	**$**	**3,696,515**
	Say	**$**	**3,700,000**

Notes:

1. Unit prices are based on MassDOT Weighted Bid Prices as of June 2019.
2. OPCC does not include ancillary costs such as shoring of buildings, costs associated with low tide only work or one month road closure, ROW acquisition, etc.

This is an engineer's Opinion of probable Construction Cost (OPCC). Tighe & Bond has no control over the cost or availability of labor, equipment or materials, market conditions, or the Contractor's method of pricing. The OPCC is made on the basis of Tighe & Bond's professional judgment and experience. Tighe & Bond makes no guarantee nor warranty, expressed or implied, that the bids or the negotiated cost of the Work will not vary from this OPCC.

Appendix G
Backup Calculations

CONCEPTUAL ARCH FRAME CALCULATIONS

INDEX OF SHEETS

REFERENCES

1 2017 AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS, 8th EDITION, WITH INTERIM REVISIONS

2 2013 MASSDOT BRIDGE DESIGN MANUAL

ASSUMPTIONS

1 FINAL CALCULATIONS TO BE PERFORMED BY MANUFACTURER.

METHODOLOGY

1 DESIGN IN ACCORDANCE WITH AASHTO LRFD REFERENCE 1

2 DESIGN IN ACCORDANCE WITH MASSDOT BDM REFERENCE 2

3 DETERMINE MAXIMUM REACTIONS FOR FOOTING DESIGN.

4 USE ERIKSSON CULVERT SOFTWARE BY ERIKSSON TECHNOLOGIES, INC. TO PERFOM CONCEPTUAL FRAME DESIGN.

5 FOR SOFTWARE CONVENIENCE, EVALUATE ARCH AS A 3-SIDED RIGID FRAME WITH OVERSIZED HAUNCHES

MATERIALS AND DESIGN PARAMETERS

DESIGN LIVE LOAD:	HL-93	
CONCRETE UNIT WEIGHT (AASHTO 3.5.1-1):	150	PCF
CONCRETE STRENGTH:	5000	PSI
SOIL UNIT WEIGHT (GEOTECHNICAL RECOMMENDATIONS):	130	PCF
REINFORCING YIELD STRENGTH, F_Y:	60000	PSI
REINFORCING MODULUS OF ELASTICITY, E_S:	29000	KSI
CLEAR SPAN:	20.00	FT

Spec.: LRFD 8th ed.
Type of Culvert: Precast

Physical Dimensions

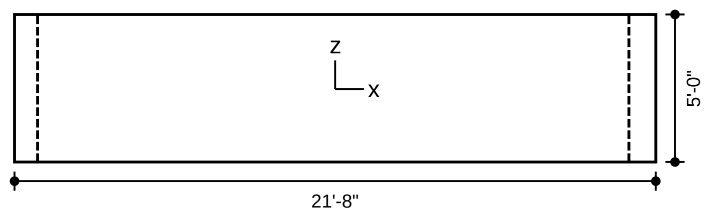
Clear Span:	20'-0"
Clear Height:	5'-0"
Top Slab:	10"
Ext. Wall:	10"
Fill Depth Range	
Maximum:	4.00 ft
Minimum:	3.00 ft
Increment:	1.00 ft
Length:	5'-0"
Skew Angle:	0.00 deg
Bottom Slab Support:	Pinned
Top Haunch, Width:	9'-6"
Top Haunch, Height:	3'-0"

Material Properties

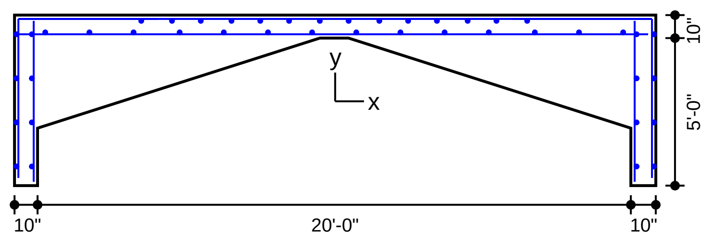
Concrete	
Strength, f'c:	5.000 ksi
Density:	0.150 kcf
Elasticity, Ec:	4287 ksi
Type:	Normal wt
Steel	
Yield, fy:	60 ksi
Allow Stress:	24 ksi
Elasticity, Es:	29000 ksi
Soil	
Density:	0.130 kcf
Exposure Factor	
Class 1 Exposure	
Reinforcement Covers	
Ext. Cover Top Slab:	2"
Ext. Cover Walls	1 1/2"
Int. Cover Walls	1 1/2"
Int. Top Slab	1 1/2"

Loads

Live Load	
Vehicle Names:	HL-93
Traffic Direction:	Parallel
Eq. Height of Soil:	2.00 ft (Entered)
Max No. of Lanes:	2
Dead Load	
Future Wearing Surface:	0.100 klf
Additional Dead Load:	0.000 klf
Concentrated Loads:	none
Lateral Soil Loads	
Eq. Fluid Press. Max:	60.00 pcf
Eq. Fluid Press. Min:	30.00 pcf
Consider Int. Water Press.:	no



Plan View



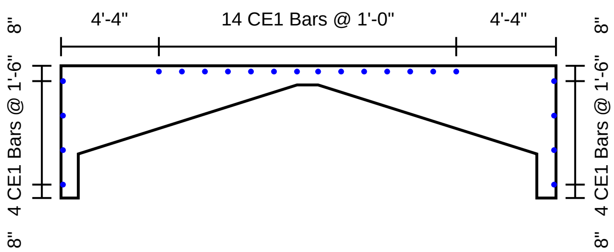
Typical Section

Concrete Summary

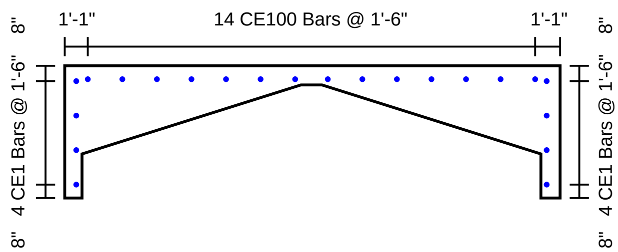
Volume of Concrete: 1.311 cy/ft Total Volume of Concrete: 6.553 cy

Reinforcing Steel Bar Schedule (lb)

Location	Mark	Qty	Size	Spacing	Type	Length	Hor.Leg	Ver.Leg	Tot.Weight
Top Slab(Int)	AE100	10	10	6"	S	21'-4"	--	--	918.0
Top Slab(Ext)	AE300	6	4	10"	S	21'-4"	--	--	86.0
Corner(Top)	AE1	12	5	11"	L	10'-2"	4'-9"	5'-5"	127.0
Wall(Int)	BE1	12	4	10"	S	5'-6"	--	--	44.0
Longit. Top (Ext)	CE1	14	1	1'-0"	S	4'-11"	--	--	0.0
Longit. Top (Int)	CE100	14	3	1'-6"	S	4'-11"	--	--	26.0
Longit. Wall (Ext)	CE1	8	3	1'-6"	S	4'-11"	--	--	15.0
Longit. Wall (Int)	CE1	8	3	1'-6"	S	4'-11"	--	--	15.0
									1231



Section Ext. Longit. Reinf.



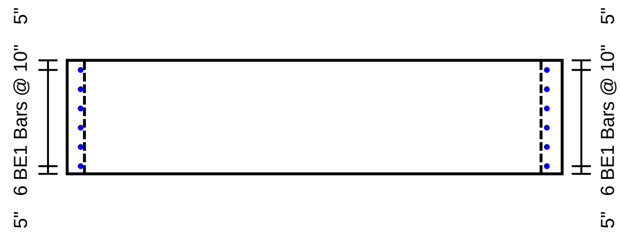
Section Int. Longit. Reinf.

TIGHE & BOND, INC.

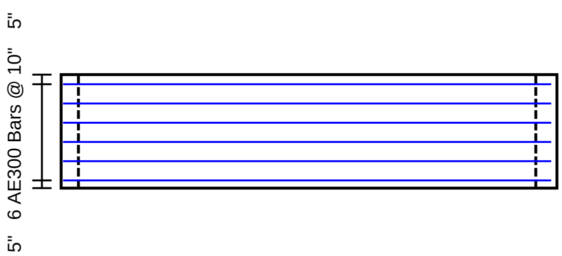
Sht_____of_____
By:EAO
Ck:________
1/2/2019 5:01:46 PM

Project : Central St Bridge Replaement
Task : Conceptual Frame Design
Client: Town of MBTS, MA
Job No. : M1476-011
File: Eriksson Culvert_Central Street Bridge.etcx

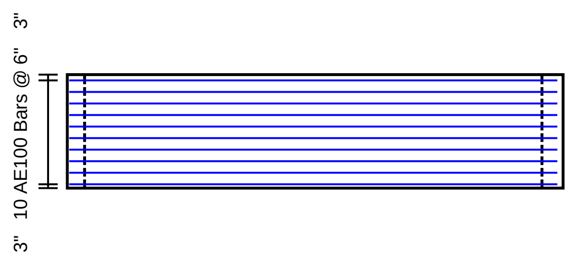
Ext. Wall Reinf.



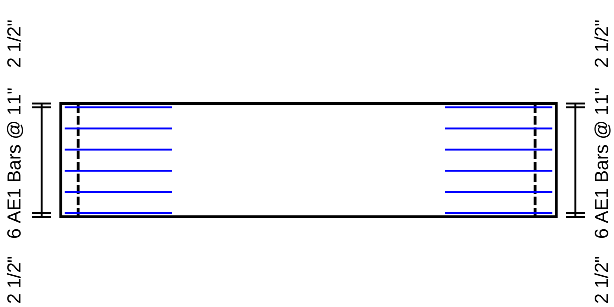
Int. Wall Reinf.



Top Slab Ext. Reinf.



Top Slab Int. Reinf.



Top Slab Corner Reinf.

```
Project: Central St Bridge Replaement
Task   : Conceptual Frame Design
Client : Town of MBTS, MA
Job No.: M1476-011


CULVERT PROPERTIES
==================
Type of Culvert: Precast                Specification : LRFD 8th Edition
Operating Mode : Design

Physical Dimensions
-------------------
No. of Boxes: 1              Name: ThreeSidedCulvert
Clear Span  : 20.0000 ft
Clear Height:  5.0000 ft     Skew Angle  :  0.00 deg
Length      :  5.0000 ft     Bottom Slab Support: No Bottom Slab, Pinned Supports
Fill Depth Range:            Maximum :  4.00 ft        Minimum  :  3.00 ft     Increment :  1.00 ft
Haunches: Top, Length:114.0000 in     Height: 36.0000 in
Minimum Thicknesses:         Top Slab: 10.0000 in      Bot Slab:  0.0000 in
                             Ext Wall: 10.0000 in
Wall Joint: None

Material Properties
-------------------
Concrete: Strength,f'c :  5.000 ksi   Density     :  0.150 kcf   Elasticity,Ec:   4287 ksi
          Type         : Normal Weight            Density Modification Factor :   1.00
          Fr Factor    :   0.24       Gamma1      :   1.60       Gamma3       :   0.75
Steel:    Yield,fy     :  60.00 ksi   fss Limit   :   0.60fy     Elasticity,Es:  29000 ksi
          Yield,fyv    :  60.00 ksi   Diameter    :  1.125 in    Type         : Rebar
Soil:     Density      :  0.130 kcf   Slope Factor:  1.150 (B1 Installation)
          Poisson's    :  0.5
          Fe Factor    :  1.150 (Maximum for Compacted Fill)
Serviceability, Gamma-e:  1.00

Loads
-----
Live Load:  Vehicle: (AA) HL-93 - Design Vehicle
                     Axle No.    Weight(k)   Dist. From Previous(ft)
                        1           8.00            0.00
                        2          32.00           14.00
                        3          32.00           14.00
                     Gage Width: 6.00 ft, Tread Width: 20.00 in, Tread Length: 10.00 in
                     Include Tandem: yes
                     Tandem: Axle 1: 25.00 k, Axle 2: 25.00 k, Axle Spacing: 4.00 ft
                     Lane Load: 0.64 klf, P-Moment: 0.00 k, P-Shear: 0.00 k
                     Combine: Truck + Lane Or Tandem + Lane
                     Inventory Rating Load Factor: 1.75  Operating Rating Load Factor: 1.35
                     Design Load Combinations: Strength I
                     Override MPF: no
                     Override DLA: no
            Include Lane Load      : yes         Max. No. of Lanes: 2
            Traffic Direction      : Lanes Parallel to Main Reinforcement
            Neglect Live Load for Large Fill Depths: yes
            Apply Surcharge at Fill Depths > 2 ft  : yes
            Compute Surcharge Depth: no          Surcharge Depth  :  2.00 ft
Dead Load:  Future Wearing Surface :  0.10 klf   Add. Dead Load   :  0.00 klf
            Concentrated Loads     : none
Lateral Soil Loads: Max. Equiv. Fluid Press.: 60.00 pcf   Min. Equiv. Fluid Press.  : 30.00 pcf
Buoyancy Check    : no
Fluid Pressures: Apply Water Press.  : no

Load and Resistance Factors
---------------------------
     Max      Min
DC: 1.250    0.900
DW: 1.500    0.650
EV: 1.300    0.900
EH: 1.350    0.900
WA: 1.000
LL I      : 1.750   LL II     : 1.350
Ductility: 1.000   Importance: 1.000   Redundancy, non-earth: 1.000   Redundancy, earth: 1.050
Condition: 1.000   System    : 1.000
Phi Shear: 0.900   Phi Moment: 0.950   PM Compression: 0.750   PM Tension    : 0.900
Load Factor Multipliers, Design Mode: 1.00 Analysis Mode: 1.00

Reinforcement
-------------
Reinforcement Covers  :  Exterior      Interior
              Top Slab:  2.0000 in     1.5000 in
              Walls   :  1.5000 in     1.5000 in
```

```
Design Options
--------------
Member Thick.: Top Slab : Fixed        Bottom Slab: Variable
               Ext. Wall: Fixed
LL Analysis  : Automatically Set Traffic Direction to Account for Skew Effects: no
               Limit Distribution Width to Culvert Length for Fills < 2 ft: yes
               Limit Distribution Width to Culvert Length for Fills > 2 ft: no
               Combine Longitudinal Axle Overlaps for Fills > 2 ft: yes
               Combine Transverse Axle Overlaps for Fills > 2 ft: no
               Axle Placement Increment for Moving Load Analysis: 20
               Always Distribute Wheel Load: yes
Reinforcement: Always Include Distribution Steel: no
               Distribution Slab Provided: no
               User Defined Longitudinal Steel: no, Follow Specification
               Max. As used in Vc Calcs: 2.00 in2/ft
               Distribute Minimum Reinforcement per Face: yes
               Use individual Member Thicknesses for Min Steel: no
               Epoxy coat steel: all bars
Slenderness  : Checked       K Factor: 2.00
Analysis Modeling     : Use Haunches in the Structural Analysis Model: yes
               Left Node on Rollers for 3-Sided Frames: no
Crit. Section: Consider Haunches when Selecting Critical Section Locations: yes
               Extend Critical Section for Shear Beyond the End of the Haunch: no
               Use Max. Moment with Max. Shear at the Critical Section for Shear: yes
Flexure      : Ignore Axial Thrust: no
               Use Eq. 12.10.4.2.4a-1: no
Shear        : Check Iterative Beta Method Only When Appropriate
Environmental: Apply envirnomental duribility factors: no
Live Load Deflection Criteria: 1/1000
```

DESIGN RESULTS

Top Slab Thickness = 10.00 in
Exterior Wall Thickness = 10.00 in

Modular Ratio (N) = 6.76 Max. Steel Ratio = 0.025
Design Span = 20.83 ft Design Height = 5.42 ft

Volume of Concrete: 1.311 cy/ft Weight of Steel: 249 lb/ft

M dimension = 4.80 ft (method of equivalent capacity)
= 5.20 ft (method of contraflexure - ASTM)

Reinforcing Steel Schedule

Location	Bar Mark	Qty	Size	Type	Spacing (in)	As,prv (in2/ft)	As,rqd (in2/ft)	Length (ft-in)	Wgt (lbs)	H Leg (ft-in)	V Leg (ft-in)	Truck	Fill (ft)
Top Slab (int)	AE100(AS2)	10	10	STR	6.00	2.540	2.402	21- 4	918			AA	3.00
Top Slab (ext)	AE300(AS7)	6	4	STR	10.00	0.240	0.240	21- 4	86			AA	3.00
Corner (Top)	AE1 (AS1)	12	5	L-BAR	11.00	0.338	0.240	10- 2	127	4- 9	5- 5	AA	3.00
Ext Wall (int)	BE1 (AS4)	12	4	STR	10.00	0.240	0.240	5- 6	44			AA	3.00
Temperature (1)	CE1 (AS6)	14	1	STR	12.00	0.000	0.030	4-11	0			AA	3.00
Top Slab (int- 1)	CE100(AS5)	14	3	STR	18.00	0.073	0.030	4-11	26			AA	3.00
Temperature (1)	CE1 (AS6)	8	3	STR	18.00	0.073	0.030	4-11	15			AA	3.00
Temperature (1)	CE1 (AS6)	8	3	STR	18.00	0.073	0.030	4-11	15			AA	3.00
								Total	1231				

Note: A denotes flexural steel, B denotes vertical steel, C denotes longitudinal steel

AS Bar Marks

Location	Controling Case	Req Area in2/ft
Transverse Side Wall - Outside Face (AS1)	c	0.24
Transverse Top Slab - Inside Face (AS2)	a	2.402
Transverse Bottom Slab - Inside Face (AS3)	a	0
Transverse Side Wall - Inside Face (AS4)	c	0.24
Distribution Top Slab - Inside Face (AS5)		0.03
Distribution Top Slab - OutSide Face (AS6)		0.03
Transverse Top Slab - Outside Face (AS7)	c	0.24
Transverse Bottom Slab - Outside Face (AS8)	c	0

As Controlled By: a - Flexure, b - Crack Control, c - Minimum Steel, d - Fatigue

Splice Lengths Table:

Bar Mark	Size	Splice Length (ft-in)
B1	4	1- 5
C1	3	1- 4
CE1	3	1- 7
C100	3	1- 4

>>>Warning: This is a three sided culvert, therefore foundation has not been design by this program. Engineer should design the foundation. This program output reflects final service load conditions only. Handling, shipping and erection stresses are neither checked nor incorporated into program design and must be analyzed by the producer's engineer. External bracing is an acceptable method to mitigate overstress and possible product damage during the course of handling, shipping and erection.

Summary of Ratings Table:

	Flexure					Shear				
Truck	Fill	Member	Location	IR	OR	Fill	Member	Location	IR	OR
(AA) HL-93	4.00	1	MID-	0.62	0.81	4.00	1	TOP	2.47	3.20

Critical Sections Summary: Flexure

Member 1: (Exterior Wall), Thickness = 10.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings IR	Load Ratings OR	Truck	Fill Depth (ft)
BOT	0.00	0.00	11.79	0.00	8.19	3.34	0.90	0.00c	10.73	NC	NC	AA	3.00
MID	26.00	0.00	7.52	9.24	8.25	10.80	0.90	0.24c	10.73	NC	NC	AA	3.00
MID-	32.50	-19.79	21.74	12.93	8.25	18.06*	0.90	0.34a	10.73	0.62	0.81	AA	4.00
TOP	36.00	-1.81	21.74	12.83	8.19	17.98	0.90	0.34b	10.73	27.24	35.31	AA	4.00

Member 2: (Top Slab), Thickness = 10.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings IR	Load Ratings OR	Truck	Fill Depth (ft)
LT	36.00	-1.43	9.79	54.13	33.90	51.08	0.90	0.34b	10.73	NC	NC	AA	4.00
MID	125.00	68.02	5.62	76.86	7.86	66.19*	0.82	2.54a	10.73	0.95	1.24	AA	3.00
RT	36.00	-3.02	9.79	54.13	33.90	51.08	0.90	0.34b	10.73	27.70	35.91	AA	4.00

As Controlled By: a - Flexure, b - Crack Control, c - Minimum Steel, d - Fatigue

Critical Sections Summary: Vertical Shear

Member 1: (Exterior Wall), Thickness = 10.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn	Beta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	Load Ratings OR	Truck	Fill Depth (ft)
BOT	0.00	-1.48	1.1	13.76	8.19	12.50	2.000	13.88b	0.00	0.00	0.00	NC	NC	AA	4.00
MID	32.50	4.01	0.0	8.75	8.11	12.38	2.000	13.75b	0.00	0.00	0.00	NC	NC	AA	4.00
MID-	32.50	4.01	-19.8	21.74	8.05	12.29	2.000	13.65b	0.00	0.00	0.00	3.72	4.82	AA	4.00
TOP	12.20	-9.15	-1.8	21.74	7.99	12.19	2.000	13.55b	0.00	0.00	0.00	2.47	3.20	AA	4.00

Member 2: (Top Slab), Thickness = 10.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn	Beta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	Load Ratings OR	Truck	Fill Depth (ft)
LT	27.89	16.92	-1.4	9.79	33.70	51.43	2.000	57.15b	0.00	0.00	0.00	6.10	7.90	AA	4.00
MID	125.00	3.36	68.0	5.62	7.20	10.99	2.000	12.21b	0.00	0.00	0.00	3.27	4.24	AA	3.00
RT	27.89	16.92	-3.0	9.79	33.70	51.43	2.000	57.15b	0.00	0.00	0.00	6.10	7.90	AA	4.00

Vc Calculation By: a - Iterative Beta, b - Constant Beta, c - Box Culvert, d - Standard/Arema

Design Results: Fill Depth = 3.00 ft

Load Parameters:

Fe = 1.03

Applied Horizontal Loads: (k/ft)

Load Description	Bottom of Wall	Top of Wall
Horizontal Earth Load	0.530	0.205
Live Load Surcharge	0.120	0.120
Internal Water Pressure	0.000	0.000

Unfactored Moments due to All Loads: (k-ft)

M-PT	Mdc	Mev	Mdw	Meh	Mls	Mwa
Member 1: (Exterior Wall)						
Bottom						
1- 0	0.00	0.00	0.00	0.00	0.00	0.00
1- 1	-0.71	-1.05	-0.26	0.51	0.15	0.00
1- 2	-1.43	-2.11	-0.53	0.86	0.26	0.00
1- 3	-2.14	-3.16	-0.79	1.09	0.33	0.00
1- 4	-2.85	-4.21	-1.05	1.18	0.37	0.00
1- 5	-3.56	-5.27	-1.32	1.16	0.37	0.00
1- 6	-4.28	-6.32	-1.58	1.03	0.34	0.00
1- 7	-4.99	-7.38	-1.84	0.81	0.28	0.00
1- 8	-5.70	-8.43	-2.10	0.49	0.18	0.00
1- 9	-6.41	-9.48	-2.37	0.09	0.04	0.00
1-10	-7.13	-10.54	-2.63	-0.37	-0.13	0.00
Top						
Member 2: (Top Slab)						
Left						
2- 0	-7.13	-10.54	-2.63	-0.38	-0.13	0.00
2- 1	-0.76	-2.71	-0.68	-0.38	-0.13	0.00
2- 2	3.47	3.37	0.84	-0.38	-0.13	0.00
2- 3	5.97	7.72	1.93	-0.38	-0.13	0.00
2- 4	7.18	10.33	2.58	-0.38	-0.13	0.00
2- 5	7.50	11.20	2.80	-0.38	-0.13	0.00
2- 6	7.18	10.33	2.58	-0.38	-0.13	0.00
2- 7	5.97	7.72	1.93	-0.38	-0.13	0.00
2- 8	3.47	3.37	0.84	-0.38	-0.13	0.00
2- 9	-0.76	-2.71	-0.68	-0.38	-0.13	0.00
2-10	-7.13	-10.54	-2.63	-0.38	-0.13	0.00
Right						

Unfactored Shears due to All Loads: (k)

M-PT	Vdc	Vev	Vdw	Veh	Vls	Vwa
Member 1: (Exterior Wall)						
Bottom						
1- 0	-1.32	-1.95	-0.49	1.07	0.30	0.00
1- 1	-1.32	-1.95	-0.49	0.79	0.24	0.00
1- 2	-1.32	-1.95	-0.49	0.53	0.17	0.00
1- 3	-1.32	-1.95	-0.49	0.29	0.11	0.00
1- 4	-1.32	-1.95	-0.49	0.06	0.04	0.00
1- 5	-1.32	-1.95	-0.49	-0.14	-0.02	0.00
1- 6	-1.32	-1.95	-0.49	-0.33	-0.09	0.00
1- 7	-1.32	-1.95	-0.49	-0.51	-0.15	0.00
1- 8	-1.32	-1.95	-0.49	-0.66	-0.22	0.00
1- 9	-1.32	-1.95	-0.49	-0.80	-0.28	0.00
1-10	-1.32	-1.95	-0.49	-0.92	-0.35	0.00
Top						
Member 2: (Top Slab)						
Left						
2- 0	3.63	4.17	1.04	0.00	0.00	0.00
2- 1	2.49	3.34	0.83	0.00	0.00	0.00
2- 2	1.56	2.50	0.63	0.00	0.00	0.00
2- 3	0.84	1.67	0.42	0.00	0.00	0.00
2- 4	0.32	0.83	0.21	0.00	0.00	0.00
2- 5	0.00	0.00	0.00	0.00	0.00	0.00
2- 6	-0.32	-0.83	-0.21	0.00	0.00	0.00
2- 7	-0.84	-1.67	-0.42	0.00	0.00	0.00
2- 8	-1.56	-2.50	-0.63	0.00	0.00	0.00
2- 9	-2.49	-3.34	-0.83	0.00	0.00	0.00
2-10	-3.63	-4.17	-1.04	0.00	0.00	0.00
Right						

Unfactored Thrusts due to All Loads: (k) (Fill Depth = 3.00 ft)

Member	Pdc	Pev	Pdw	Peh	Pls	Pwa
1	3.63	4.17	1.04	0.00	0.00	0.00
2	1.32	1.95	0.49	0.92	0.35	0.00

Analysis Truck, HL-93

Vehicle	Axle No.	Weight (k/ft)	Length (ft)	Dist. From Previous (ft)
Truck	1	0.219	4.28	
	2	0.878	4.28	14.00
	3	0.878	4.28	14.00
Tandem	1	0.709	8.28	

***Distributed loads may have been intensified due to axle overlap between lanes

Live Load Parameters:

Traffic Direction is Parallel to Main Reinforcement
Distribution Width : 12.32 ft
Impact Factor : 1.21
Distribution Width : 13.45 ft
Lane Load: 0.057 k/ft

Pinned Reactions Applied to Structure: (service load values, k/unit width) (Fill Depth = 3.00 ft)

Eriksson Culvert v4.0.8

Filename: Eriksson Culvert_Central Street Bridge.etcx

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           ____________
          |            |
          |            |
          |            |
          |            |
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          A            A
          |            |
          |            |
```

	Vertical	Horizontal
DC	4.30	1.32
DW	1.04	0.49
EV	4.17	1.95
EH	0.00	-1.07
LS	0.00	-0.30
WA	0.00	0.00
LL	5.30	1.16
Without LL	9.52	2.37
With LL	14.82	3.54

Note: Reactions as shown - positive

Truck Positions That Cause Maximum Results:

Maximum +Moment in Top Slab

Vehicle	Axle No.	Weight (k)	Length (ft)	Dist. From Left End (ft)
Truck	1	0.219	4.28	26.44
	2	0.878	4.28	12.44
	3	0.878	4.28	-1.56

Maximum +Moment : 15.47 k-ft
Corresponding Moment at End : -1.40 k-ft

Maximum -Moment in Top Slab

Vehicle	Axle No.	Weight (k)	Length (ft)	Dist. From Left End (ft)
Truck	1	0.219	4.28	36.28
	2	0.878	4.28	22.28
	3	0.878	4.28	8.28

Maximum -Moment : -4.84 k-ft
Corresponding Moment at Mid : 10.83 k-ft

Maximum +Shear in Top Slab

Truck	1	0.219	4.28	30.14
	2	0.878	4.28	16.14
	3	0.878	4.28	2.14

Maximum +Shear : 4.22 k
Corresponding Shear at Mid : 0.46 k

Maximum -Shear in Top Slab

Truck	1	0.219	4.28	32.69
	2	0.878	4.28	18.69
	3	0.878	4.28	4.69

Maximum -Shear : -4.22 k
Corresponding Shear at Mid : -0.46 k

Maximum Deflection in Top Slab = 0.009 in

Vehicle	Axle No.	Weight (k)	Dist. From Left End (ft)
Truck	1	0.00	44.61
	2	0.00	30.61
	3	0.00	16.61

Maximum +Moment in Top Slab

Tandem	1	0.709	8.28	11.43

Maximum +Moment : 19.97 k-ft
Corresponding Moment at End : -4.18 k-ft

Maximum -Moment in Top Slab

Tandem	1	0.709	8.28	7.32

Maximum -Moment : -5.76 k-ft
Corresponding Moment at Mid : 15.35 k-ft

Maximum +Shear in Top Slab

Tandem	1	0.709	8.28	4.14

Maximum +Shear : 4.71 k
Corresponding Shear at Mid : -1.17 k

Maximum -Shear in Top Slab

Tandem	1	0.709	8.28	16.69

Maximum -Shear : -4.71 k
Corresponding Shear at Mid : 1.17 k

Maximum Deflection in Top Slab = 0.024 in

Vehicle	Axle No.	Weight (k)	Dist. From Left End (ft)
Tandem	1	0.00	16.69

Unfactored Moments and Shears due to Truck Loads: (k-ft, k)

	Truck				Tandem				Lane			
M-PT	Mll+	Mll-	Vll+	Vll-	Mll+	Mll-	Vll+	Vll-	Mll+	Mll-	Vll+	Vll-
Member 1: (Exterior Wall)												
Bottom												
1- 0	0.00	0.00	0.00	-0.89	0.00	0.00	0.00	-1.06	0.00	0.00	0.00	-0.10
1- 1	0.00	-0.48	0.00	-0.89	0.00	-0.58	0.00	-1.06	0.00	-0.05	0.00	-0.10
1- 2	0.00	-0.97	0.00	-0.89	0.00	-1.15	0.00	-1.06	0.00	-0.11	0.00	-0.10
1- 3	0.00	-1.45	0.00	-0.89	0.00	-1.73	0.00	-1.06	0.00	-0.16	0.00	-0.10
1- 4	0.00	-1.93	0.00	-0.89	0.00	-2.30	0.00	-1.06	0.00	-0.22	0.00	-0.10
1- 5	0.00	-2.42	0.00	-0.89	0.00	-2.88	0.00	-1.06	0.00	-0.27	0.00	-0.10
1- 6	0.00	-2.90	0.00	-0.89	0.00	-3.46	0.00	-1.06	0.00	-0.33	0.00	-0.10
1- 7	0.00	-3.39	0.00	-0.89	0.00	-4.03	0.00	-1.06	0.00	-0.38	0.00	-0.10
1- 8	0.00	-3.87	0.00	-0.89	0.00	-4.61	0.00	-1.06	0.00	-0.44	0.00	-0.10
1- 9	0.00	-4.35	0.00	-0.89	0.00	-5.18	0.00	-1.06	0.00	-0.49	0.00	-0.10

1-10	0.00	-4.84	0.00	-0.89	0.00	-5.76	0.00	-1.06	0.00	-0.55	0.00	-0.10
Top												

Member 2: (Top Slab)

Left												
2- 0	0.00	-4.84	4.22	0.00	0.00	-5.76	4.71	0.00	0.00	-0.55	0.59	0.00
2- 1	6.02	-0.07	3.47	-0.09	4.73	0.00	4.12	-0.07	0.57	0.00	0.48	-0.01
2- 2	10.55	0.00	2.77	-0.37	10.73	0.00	3.53	-0.30	1.43	0.00	0.38	-0.02
2- 3	12.45	0.00	2.25	-0.74	14.85	0.00	2.95	-0.67	2.05	0.00	0.29	-0.05
2- 4	12.71	0.00	1.87	-1.12	18.17	0.00	2.36	-1.18	2.43	0.00	0.21	-0.10
2- 5	15.12	0.00	1.49	-1.49	19.97	0.00	1.77	-1.77	2.55	0.00	0.15	-0.15
2- 6	15.47	0.00	1.12	-1.87	19.96	0.00	1.18	-2.36	2.43	0.00	0.10	-0.21
2- 7	14.65	0.00	0.74	-2.25	18.01	0.00	0.67	-2.95	2.05	0.00	0.05	-0.29
2- 8	11.53	0.00	0.37	-2.77	14.85	0.00	0.30	-3.53	1.44	0.00	0.02	-0.38
2- 9	6.74	-1.70	0.09	-3.47	9.61	-1.74	0.07	-4.12	0.71	-0.14	0.01	-0.48
2-10	0.00	-4.84	0.00	-4.22	0.00	-5.76	0.00	-4.71	0.00	-0.55	0.00	-0.59
Right												

Note: Unfactored live load results computed at 3.00 ft and 0 ft fill depths, per LRFD 3.6.1.2.6

Serviceability Check: Crack Control

Bar Mark	Location	Moment (k-ft)	Thrust (k)	Fss (ksi)	Spacing (in)	Allow (in)
A100	Top Slab (int)	43.8	4.21	30.11	6.00	12.48

Serviceability Check: Live Load Deflection

Deflection Ratio of Top Slab = 1/19860 (Limit = 1/1000)

Strength Limit State at Critical Sections: Flexure

Member 1: (Exterior Wall), Thickness = 10.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings IR	Load Ratings OR
BOT	0.00	0.00	11.79	0.00	8.19	3.34	0.90	0.00c	10.73	NC	NC
MID	26.00	0.00	7.52	9.24	8.25	10.80	0.90	0.24c	10.73	NC	NC
MID-	32.50	-18.39	21.07	12.93	8.25	17.88*	0.90	0.34a	10.73	0.91	1.18
TOP	36.00	-1.76	21.07	12.83	8.19	17.80	0.90	0.34b	10.73	27.12	35.16

Member 2: (Top Slab), Thickness = 10.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings IR	Load Ratings OR
LT	36.00	-1.13	8.98	54.13	33.90	51.09	0.90	0.34b	10.73	99.99	99.99
MID	125.00	68.02	5.62	76.86	7.86	66.19*	0.82	2.54a	10.73	0.95	1.24
RT	36.00	-2.90	8.98	54.13	33.90	51.09	0.90	0.34b	10.73	24.25	31.43

As Controlled By: a - Flexure, b - Crack Control, c - Minimum Steel, d - Fatigue

Note: Mu - Resisting moment under pure flexure, Ma - Allowable moment under applied axial load

Strength Limit State at Critical Sections: Vertical Shear

Member 1: (Exterior Wall), Thickness = 10.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	Load Ratings OR
BOT	0.00	-1.12	1.0	11.79	8.19	12.50	2.000	45.00	13.88b	0.00	0.00	0.00	NC	NC
MID	32.50	3.41	0.0	7.52	8.11	12.38	2.000	45.00	13.75b	0.00	0.00	0.00	NC	NC
MID-	32.50	3.41	-18.4	21.07	8.05	12.29	2.000	45.00	13.65b	0.00	0.00	0.00	3.52	4.56
TOP	12.20	-8.42	-1.8	21.07	7.99	12.19	2.000	45.00	13.55b	0.00	0.00	0.00	2.55	3.30

Member 2: (Top Slab), Thickness = 10.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	Load Ratings OR
LT	27.89	16.54	-1.1	8.98	33.70	51.43	2.000	45.00	57.15b	0.00	0.00	0.00	5.41	7.01
MID	125.00	3.36	68.0	5.62	7.20	10.99	2.000	45.00	12.21b	0.00	0.00	0.00	3.27	4.24
RT	27.89	16.54	-2.9	8.98	33.70	51.43	2.000	45.00	57.15b	0.00	0.00	0.00	5.41	7.01

Vc Calculation By: a - Iterative Beta, b - Constant Beta, c - Box Culvert, d - Standard/Arema
>>>Warning: Overstress due to fixed thickness

Load Combination Results at Tenth Points: (k-ft, k)(Fill Depth = 3.00 ft)

M-PT	+Moment	-Moment	+Axial	-Axial	+Shear	-Shear
Member 1: (Exterior Wall)						
Bottom						
1- 0	0.000	0.000	11.793	21.073	-1.121	-6.377
1- 1	-0.745	-3.502	7.519	21.073	-1.629	-6.555
1- 2	-1.758	-7.099	7.519	21.073	-2.112	-6.723
1- 3	-3.027	-10.783	7.519	21.073	-2.571	-6.879
1- 4	-4.536	-14.548	7.519	21.073	-3.004	-7.024
1- 5	-6.274	-18.389	7.519	21.073	-3.413	-7.311
1- 6	-8.227	-22.300	7.519	21.073	-3.796	-7.695
1- 7	-10.380	-26.273	7.519	21.073	-4.154	-8.053
1- 8	-12.721	-30.304	7.519	21.073	-4.488	-8.387
1- 9	-15.235	-34.385	7.519	21.073	-4.797	-8.695
1-10	-17.910	-39.028	7.519	21.073	-5.080	-8.979
Top						
Member 2: (Top Slab)						
Left						
2- 0	-17.921	-39.040	5.080	8.979	21.073	7.519
2- 1	5.612	-6.560	5.619	8.979	16.980	5.649
2- 2	31.241	5.792	5.619	5.080	13.159	3.960
2- 3	50.232	12.477	5.619	5.080	9.617	2.457
2- 4	62.741	16.222	5.619	5.080	6.352	-0.384
2- 5	68.021	17.395	5.619	5.080	3.358	-3.358
2- 6	65.862	16.222	5.619	5.080	0.384	-6.352
2- 7	55.768	12.477	5.619	5.080	-2.457	-9.617
2- 8	38.450	5.792	5.619	5.080	-3.960	-13.159
2- 9	12.144	-9.732	5.619	8.979	-5.649	-16.980
2-10	-17.921	-39.040	5.080	8.979	-7.519	-21.073
Right						

Design Results: Fill Depth = 4.00 ft

Load Parameters:

Fe = 1.04

Applied Horizontal Loads: (k/ft)

Load Description	Bottom of Wall	Top of Wall
Horizontal Earth Load	0.590	0.265
Live Load Surcharge	0.120	0.120
Internal Water Pressure	0.000	0.000

Unfactored Moments due to All Loads: (k-ft)

M-PT	Mdc	Mev	Mdw	Meh	Mls	Mwa
Member 1: (Exterior Wall)						
Bottom						
1- 0	0.00	0.00	0.00	0.00	0.00	0.00
1- 1	-0.71	-1.42	-0.26	0.58	0.15	0.00
1- 2	-1.43	-2.83	-0.53	0.99	0.26	0.00
1- 3	-2.14	-4.25	-0.79	1.25	0.33	0.00
1- 4	-2.85	-5.67	-1.05	1.37	0.37	0.00
1- 5	-3.56	-7.09	-1.32	1.35	0.37	0.00
1- 6	-4.28	-8.50	-1.58	1.20	0.34	0.00
1- 7	-4.99	-9.92	-1.84	0.94	0.28	0.00
1- 8	-5.70	-11.34	-2.10	0.58	0.18	0.00
1- 9	-6.41	-12.76	-2.37	0.11	0.04	0.00
1-10	-7.13	-14.17	-2.63	-0.44	-0.13	0.00
Top						
Member 2: (Top Slab)						
Left						
2- 0	-7.13	-14.17	-2.63	-0.45	-0.13	0.00
2- 1	-0.76	-3.65	-0.68	-0.45	-0.13	0.00
2- 2	3.47	4.54	0.84	-0.45	-0.13	0.00
2- 3	5.97	10.39	1.93	-0.45	-0.13	0.00
2- 4	7.18	13.89	2.58	-0.45	-0.13	0.00
2- 5	7.50	15.06	2.80	-0.45	-0.13	0.00
2- 6	7.18	13.89	2.58	-0.45	-0.13	0.00
2- 7	5.97	10.39	1.93	-0.45	-0.13	0.00
2- 8	3.47	4.54	0.84	-0.45	-0.13	0.00
2- 9	-0.76	-3.65	-0.68	-0.45	-0.13	0.00
2-10	-7.13	-14.17	-2.63	-0.45	-0.13	0.00
Right						

Unfactored Shears due to All Loads: (k)

M-PT	Vdc	Vev	Vdw	Veh	Vls	Vwa
Member 1: (Exterior Wall)						
Bottom						
1- 0	-1.32	-2.62	-0.49	1.22	0.30	0.00
1- 1	-1.32	-2.62	-0.49	0.91	0.24	0.00
1- 2	-1.32	-2.62	-0.49	0.62	0.17	0.00
1- 3	-1.32	-2.62	-0.49	0.34	0.11	0.00
1- 4	-1.32	-2.62	-0.49	0.08	0.04	0.00
1- 5	-1.32	-2.62	-0.49	-0.16	-0.02	0.00
1- 6	-1.32	-2.62	-0.49	-0.38	-0.09	0.00
1- 7	-1.32	-2.62	-0.49	-0.58	-0.15	0.00
1- 8	-1.32	-2.62	-0.49	-0.77	-0.22	0.00
1- 9	-1.32	-2.62	-0.49	-0.94	-0.28	0.00
1-10	-1.32	-2.62	-0.49	-1.09	-0.35	0.00
Top						
Member 2: (Top Slab)						
Left						
2- 0	3.63	5.61	1.04	0.00	0.00	0.00
2- 1	2.49	4.49	0.83	0.00	0.00	0.00
2- 2	1.56	3.37	0.63	0.00	0.00	0.00
2- 3	0.84	2.25	0.42	0.00	0.00	0.00
2- 4	0.32	1.12	0.21	0.00	0.00	0.00
2- 5	0.00	0.00	0.00	0.00	0.00	0.00
2- 6	-0.32	-1.12	-0.21	0.00	0.00	0.00
2- 7	-0.84	-2.25	-0.42	0.00	0.00	0.00
2- 8	-1.56	-3.37	-0.63	0.00	0.00	0.00
2- 9	-2.49	-4.49	-0.83	0.00	0.00	0.00
2-10	-3.63	-5.61	-1.04	0.00	0.00	0.00
Right						

Unfactored Thrusts due to All Loads: (k) (Fill Depth = 4.00 ft)

Member	Pdc	Pev	Pdw	Peh	Pls	Pwa
1	3.63	5.61	1.04	0.00	0.00	0.00
2	1.32	2.62	0.49	1.09	0.35	0.00

Analysis Truck, HL-93

Vehicle	Axle No.	Weight (k/ft)	Length (ft)	Dist. From Previous (ft)
Truck	1	0.153	5.43	
	2	0.611	5.43	14.00
	3	0.611	5.43	14.00
Tandem	1	0.550	9.43	

***Distributed loads may have been intensified due to axle overlap between lanes

Live Load Parameters:

Traffic Direction is Parallel to Main Reinforcement
Distribution Width : 13.47 ft
Impact Factor : 1.17
Distribution Width : 14.60 ft
Lane Load: 0.053 k/ft

Pinned Reactions Applied to Structure: (service load values, k/unit width) (Fill Depth = 4.00 ft)

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	Vertical	Horizontal
DC	4.30	1.32
DW	1.04	0.49
EV	5.61	2.62
EH	0.00	-1.22
LS	0.00	-0.30
WA	0.00	0.00
LL	4.56	0.96
Without LL	10.96	2.89
With LL	15.52	3.85

Note: Reactions as shown - positive

Truck Positions That Cause Maximum Results:

Maximum +Moment in Top Slab

Vehicle	Axle No.	Weight (k)	Length (ft)	Dist. From Left End (ft)
Truck	1	0.153	5.43	26.91
	2	0.611	5.43	12.91
	3	0.611	5.43	-1.09

Maximum +Moment : 13.15 k-ft
Corresponding Moment at End : -1.34 k-ft

Maximum -Moment in Top Slab

Vehicle	Axle No.	Weight (k)	Length (ft)	Dist. From Left End (ft)
Truck	1	0.611	5.43	7.70
	2	0.611	5.43	-6.30
	3	0.153	5.43	-20.30

Maximum -Moment : -4.05 k-ft
Corresponding Moment at Mid : 8.74 k-ft

Maximum +Shear in Top Slab

Truck	1	0.153	5.43	30.72
	2	0.611	5.43	16.72
	3	0.611	5.43	2.72

Maximum +Shear : 3.55 k
Corresponding Shear at Mid : 0.22 k

Maximum -Shear in Top Slab

Truck	1	0.153	5.43	32.12
	2	0.611	5.43	18.12
	3	0.611	5.43	4.12

Maximum -Shear : -3.55 k
Corresponding Shear at Mid : -0.22 k

Maximum Deflection in Top Slab = 0.010 in

Vehicle	Axle No.	Weight (k)	Dist. From Left End (ft)
Truck	1	0.00	45.08
	2	0.00	31.08
	3	0.00	17.08

Maximum +Moment in Top Slab

Tandem	1	0.550	9.43	11.46

Maximum +Moment : 16.87 k-ft
Corresponding Moment at End : -3.74 k-ft

Maximum -Moment in Top Slab

Tandem	1	0.550	9.43	7.84

Maximum -Moment : -4.70 k-ft
Corresponding Moment at Mid : 14.39 k-ft

Maximum +Shear in Top Slab

Tandem	1	0.550	9.43	4.72

Maximum +Shear : 4.02 k
Corresponding Shear at Mid : -1.18 k

Maximum -Shear in Top Slab

Tandem	1	0.550	9.43	16.12

Maximum -Shear : -4.02 k
Corresponding Shear at Mid : 1.18 k

Maximum Deflection in Top Slab = 0.019 in

Vehicle	Axle No.	Weight (k)	Dist. From Left End (ft)
Tandem	1	0.00	17.22

Unfactored Moments and Shears due to Truck Loads: (k-ft, k)

	Truck				Tandem				Lane			
M-PT	Mll+	Mll-	Vll+	Vll-	Mll+	Mll-	Vll+	Vll-	Mll+	Mll-	Vll+	Vll-
Member 1: (Exterior Wall)												
Bottom												
1- 0	0.00	0.00	0.00	-0.75	0.00	0.00	0.00	-0.87	0.00	0.00	0.00	-0.09
1- 1	0.00	-0.41	0.00	-0.75	0.00	-0.47	0.00	-0.87	0.00	-0.05	0.00	-0.09
1- 2	0.00	-0.81	0.00	-0.75	0.00	-0.94	0.00	-0.87	0.00	-0.10	0.00	-0.09
1- 3	0.00	-1.22	0.00	-0.75	0.00	-1.41	0.00	-0.87	0.00	-0.15	0.00	-0.09
1- 4	0.00	-1.62	0.00	-0.75	0.00	-1.88	0.00	-0.87	0.00	-0.20	0.00	-0.09
1- 5	0.00	-2.03	0.00	-0.75	0.00	-2.35	0.00	-0.87	0.00	-0.25	0.00	-0.09
1- 6	0.00	-2.43	0.00	-0.75	0.00	-2.82	0.00	-0.87	0.00	-0.30	0.00	-0.09
1- 7	0.00	-2.84	0.00	-0.75	0.00	-3.29	0.00	-0.87	0.00	-0.35	0.00	-0.09
1- 8	0.00	-3.24	0.00	-0.75	0.00	-3.76	0.00	-0.87	0.00	-0.40	0.00	-0.09
1- 9	0.00	-3.65	0.00	-0.75	0.00	-4.23	0.00	-0.87	0.00	-0.45	0.00	-0.09

1-10	0.00	-4.05	0.00	-0.75	0.00	-4.70	0.00	-0.87	0.00	-0.50	0.00	-0.09
Top												

Member 2: (Top Slab)

Left												
2- 0	0.00	-4.05	3.55	0.00	0.00	-4.70	4.02	0.00	0.00	-0.50	0.55	0.00
2- 1	5.15	0.00	2.89	-0.06	5.45	0.00	3.50	-0.06	0.52	0.00	0.44	-0.01
2- 2	9.16	0.00	2.33	-0.25	10.54	0.00	2.98	-0.23	1.32	0.00	0.35	-0.02
2- 3	10.79	0.00	1.90	-0.56	13.24	0.00	2.46	-0.52	1.89	0.00	0.27	-0.05
2- 4	11.05	0.00	1.56	-0.90	15.58	0.00	1.94	-0.92	2.24	0.00	0.20	-0.09
2- 5	12.70	0.00	1.23	-1.23	16.87	0.00	1.42	-1.42	2.35	0.00	0.14	-0.14
2- 6	13.15	0.00	0.90	-1.56	16.67	0.00	0.92	-1.94	2.24	0.00	0.09	-0.20
2- 7	12.48	0.00	0.56	-1.90	14.92	0.00	0.52	-2.46	1.89	0.00	0.05	-0.27
2- 8	9.92	0.00	0.25	-2.33	12.00	0.00	0.23	-2.98	1.32	0.00	0.02	-0.35
2- 9	5.96	-1.49	0.06	-2.89	7.54	-0.91	0.06	-3.50	0.65	-0.13	0.01	-0.44
2-10	0.00	-4.05	0.00	-3.55	0.00	-4.70	0.00	-4.02	0.00	-0.50	0.00	-0.55
Right												

Note: Unfactored live load results computed at 4.00 ft and 0 ft fill depths, per LRFD 3.6.1.2.6

Serviceability Check: Crack Control

Bar Mark	Location	Moment (k-ft)	Thrust (k)	Fss (ksi)	Spacing (in)	Allow (in)
A100	Top Slab (int)	44.4	4.96	30.33	6.00	12.36

Serviceability Check: Live Load Deflection

Deflection Ratio of Top Slab = 1/20563 (Limit = 1/1000)

Strength Limit State at Critical Sections: Flexure

Member 1: (Exterior Wall), Thickness = 10.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings IR	Load Ratings OR
BOT	0.00	0.00	13.76	0.00	8.19	3.89	0.90	0.00c	10.73	NC	NC
MID	26.00	0.00	8.75	9.24	8.25	11.13	0.90	0.24c	10.73	NC	NC
MID-	32.50	-19.79	21.74	12.93	8.25	18.06*	0.90	0.34a	10.73	0.62	0.81
TOP	36.00	-1.81	21.74	12.83	8.19	17.98	0.90	0.34b	10.73	27.24	35.31

Member 2: (Top Slab), Thickness = 10.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings IR	Load Ratings OR
LT	36.00	-1.43	9.79	54.13	33.90	51.08	0.90	0.34b	10.73	NC	NC
MID	125.00	67.48	6.65	76.86	7.86	66.15*	0.82	2.54a	10.73	0.96	1.25
RT	36.00	-3.02	9.79	54.13	33.90	51.08	0.90	0.34b	10.73	27.70	35.91

As Controlled By: a - Flexure, b - Crack Control, c - Minimum Steel, d - Fatigue

Note: Mu - Resisting moment under pure flexure, Ma - Allowable moment under applied axial load

Strength Limit State at Critical Sections: Vertical Shear

Member 1: (Exterior Wall), Thickness = 10.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	Load Ratings OR
BOT	0.00	-1.48	1.1	13.76	8.19	12.50	2.000	45.00	13.88b	0.00	0.00	0.00	NC	NC
MID	32.50	4.01	0.0	8.75	8.11	12.38	2.000	45.00	13.75b	0.00	0.00	0.00	NC	NC
MID-	32.50	4.01	-19.8	21.74	8.05	12.29	2.000	45.00	13.65b	0.00	0.00	0.00	3.72	4.82
TOP	12.20	-9.15	-1.8	21.74	7.99	12.19	2.000	45.00	13.55b	0.00	0.00	0.00	2.47	3.20

Member 2: (Top Slab), Thickness = 10.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	Load Ratings OR
LT	27.89	16.92	-1.4	9.79	33.70	51.43	2.000	45.00	57.15b	0.00	0.00	0.00	6.10	7.90
MID	125.00	2.72	67.5	6.65	7.20	10.99	2.000	45.00	12.21b	0.00	0.00	0.00	4.03	5.23
RT	27.89	16.92	-3.0	9.79	33.70	51.43	2.000	45.00	57.15b	0.00	0.00	0.00	6.10	7.90

Vc Calculation By: a - Iterative Beta, b - Constant Beta, c - Box Culvert, d - Standard/Arema
>>>Warning: Overstress due to fixed thickness

Load Combination Results at Tenth Points: (k-ft, k)(Fill Depth = 4.00 ft)

M-PT	+Moment	-Moment	+Axial	-Axial	+Shear	-Shear
Member 1: (Exterior Wall)						
Bottom						
1- 0	0.000	0.000	13.759	21.745	-1.483	-6.839
1- 1	-0.954	-3.759	8.753	21.745	-2.038	-7.039
1- 2	-2.201	-7.623	8.753	21.745	-2.567	-7.228
1- 3	-3.728	-11.586	8.753	21.745	-3.071	-7.405
1- 4	-5.521	-15.642	8.753	21.745	-3.551	-7.571
1- 5	-7.567	-19.784	8.753	21.745	-4.005	-7.888
1- 6	-9.853	-24.008	8.753	21.745	-4.435	-8.317
1- 7	-12.365	-28.305	8.753	21.745	-4.839	-8.722
1- 8	-15.089	-32.671	8.753	21.745	-5.219	-9.102
1- 9	-18.012	-37.100	8.753	21.745	-5.573	-9.456
1-10	-21.120	-42.152	8.753	21.745	-5.903	-9.786
Top						
Member 2: (Top Slab)						
Left						
2- 0	-21.131	-42.163	5.903	9.786	21.745	8.753
2- 1	3.217	-7.807	6.647	9.786	17.394	6.636
2- 2	32.264	6.697	6.647	5.903	13.314	4.701
2- 3	50.733	14.668	6.647	5.903	9.511	2.951
2- 4	62.704	19.185	6.647	5.903	5.984	0.486
2- 5	67.481	20.615	6.647	5.903	2.725	-2.725
2- 6	64.607	19.185	6.647	5.903	-0.486	-5.984
2- 7	53.659	14.668	6.647	5.903	-2.951	-9.511
2- 8	34.825	6.697	6.647	5.903	-4.701	-13.314
2- 9	7.106	-10.647	6.647	9.786	-6.636	-17.394
2-10	-21.131	-42.163	5.903	9.786	-8.753	-21.745
Right						

SUMMARY OF RIGID FRAME REACTIONS

Pinned Reactions Applied to Structure: (service load values, k/unit width) (Fill Depth = 3.00 ft)

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                        A           A
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                        |           |
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	Vertical	Horizontal
~~DC~~	~~4.30~~	~~1.32~~
DW	1.04	0.49
EV	4.17	1.95
EH	0.00	-1.07
LS	0.00	-0.30
WA	0.00	0.00
LL	5.30	1.16
Without LL	9.52	2.37
With LL	14.82	3.54

Note: Reactions as shown - positive

Pinned Reactions Applied to Structure: (service load values, k/unit width) (Fill Depth = 4.00 ft)

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                        A           A
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	Vertical	Horizontal
~~DC~~	~~4.30~~	~~1.32~~
DW	1.04	0.49
EV	5.61	2.62
EH	0.00	-1.22
LS	0.00	-0.30
WA	0.00	0.00
LL	4.56	0.96
Without LL	10.96	2.89
With LL	15.52	3.85

Note: Reactions as shown - positive

OVERRIDE DC WEIGHT

DC = 24.86 SF x 1 FT x 150 PCF / 2 / 1000

DC = 1.86 KLF

DC_{HORIZ} = (1.86/4.30) x 1.32 = 0.57 KLF

Tighe&Bond Engineers | Environmental Specialists							
	JOB NO	M1476-011		SHEET	1	OF	24
	CLIENT	TOWN OF MANCHESTER-BY-THE-SEA, MA					
	SUBJECT	CENTRAL STREET BRIDGE - FOOTING CALCULATIONS					
	PREPARED BY	EAO	DATE	JUL. '19	CHECKED BY		DATE

CONCEPTUAL FOOTING CALCULATIONS

INDEX OF SHEETS

APPENDIX

A PAGES FROM HATZINIKOLAS MASONRY DESIGN TEXTBOOK

REFERENCES

1 2017 AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS, 8th EDITION, WITH INTERIM REVISIONS

2 2013 MASSDOT BRIDGE DESIGN MANUAL

3 CIVIL ENGINEERING REFERENCE MANUAL (LINDEBURG) 15TH EDITION

4 2005 HATZINIKOLAS & KORANY MASONRY DESIGN TEXTBOOK

5 CONCEPTUAL ARCH RIGID FRAME CALCULATIONS (EAO JAN. '19)

6 GEOTECHNICAL EVALUATION REPORT (SEPTEMBER 26, 2018)

7 HYDRAULIC REPORT (OCTOBER 2018)

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JOB NO	M1476-011			SHEET	2	OF	24
CLIENT	TOWN OF MANCHESTER-BY-THE-SEA, MA						
SUBJECT	CENTRAL STREET BRIDGE - FOOTING CALCULATIONS						
PREPARED BY	EAO	DATE	JUL. '19	CHECKED BY		DATE	

ASSUMPTIONS

1 ASSUME 20' SPAN PRECAST CONCRETE ARCH RIGID FRAME

2 ASSUME CAST-IN-PLACE CONCRETE PEDESTAL FOOTINGS

METHODOLOGY

1 DESIGN IN ACCORDANCE WITH AASHTO LRFD REFERENCE 1

MATERIALS

CONCRETE:	FOOTING STRENGTH, f'c @ 28 DAYS	4000	PSI
	STEM STRENGTH, f'c @ 28 DAYS	4000	PSI
	UNIT WEIGHT, γ_c	0.150	KCF
REINFORCING:	YIELD STRENGTH, Fy	60	KSI
	MODULUS OF ELASTICITY, Es	29000	KSI
	CLEAR COVER (DIRECT EXPOSURE TO SALT WATER, AASHTO TABLE 5.10.1-1)	4.00	IN
BACKFILL:	GRAVEL BORROW FOR BRIDGE FOUNDATION (MASSDOT M1.03.0, TYPE B)		
	SOIL UNIT WEIGHT, γ_S (REF 2, 3.1.6)	0.120	KCF
	INTERNAL FRICTION ANGLE, ϕ_f (REF 6)	32	deg.
	AT-REST EARTH PRESSURE COEFFICIENT, K_0 (GEOTECH. RECOMMENDATIONS)	0.470	
	BACKFILL ANGLE, β	0	deg.
	MIN. DEPTH OF COVER FOR FROST PROTECTION - N/A ON LEDGE	0.00	FT
	MIN. DEPTH OF COVER FOR SCOUR PROTECTION (REF 7) - N/A ON LEDGE	0.00	FT
SUBGRADE:	ASSUME BEDROCK (REF 6)		
	NOMINAL BEARING RESISTANCE, q_n (REF 6)	200	KSF
	BEARING RESISTANCE FACTOR, ϕ_b (AASHTO TABLE 10.5.5.2.2-1 & REF. 6)	0.45	
	SLIDING RESISTANCE FACTOR, ϕ_t ~~(AASHTO TABLE 10.5.5.2.2-1)~~	0.80	

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	PREPARED BY	EAO	DATE	JUL. '19	CHECKED BY	DATE

ASSUMED FOOTING GEOMETRY

H_{FOOT}	FOOTING THICKNESS		2.00	FT
H_{STEM}	STEM HEIGHT (TO TOP OF KEYWAY)		4.50	FT
H_{BW}	BACKWALL HEIGHT		0.00	FT
H	TOTAL FOOTING HEIGHT	ELEV. 1.17 - ELEV. -5.33	6.50	FT
H_{BRG}	HEIGHT OF BEARING (3" KEYWAY-1" OF GROUT)		-0.17	FT
B_{TOE}	TOE WIDTH		0.67	FT
B_{HEEL}	HEEL WIDTH		4.00	FT
B_{STEM}	STEM WIDTH		2.33	FT
B_{FOOT}	TOTAL FOOTING WIDTH		7.00	FT
L_{FOOT}	TOTAL FOOTING LENGTH		48.00	FT
e_{BRG}	DIST. CL BEARING TO FACE OF STEM		1.17	FT
B_{BW}	BACKWALL WIDTH		0.00	FT

SUPERSTRUCTURE FORCES

CONTROLLING FORCES FROM RIGID FRAME REACTION CALCULATIONS (REFERENCE 5):

	VERT	HORIZ*
DC	1.86	-0.57
DW	1.04	-0.49
EV	5.61	-2.62
EH	0	1.22
LS	0	0.30
LL	5.30	-1.16

*POSITIVE FORCES ACT IN DIRECTION FROM STREAM TOWARDS BACKFILL WITH RESISTING EFFECTS

DEAD LOADS (DC) (3.5.1)

DETERMINE LOADS PER 1-FOOT LENGTH OF FOOTING

MOMENT ARMS DETERMINED FROM THE BOTTOM, TOE, OF THE FOOTING

SUPERSTRUCTURE DEAD LOADS

$DC_{SUPER,\ VERT}$	1.86	K/FT
MOMENT ARM = $B_{TOE} + e_{BRG}$	**1.83**	**FT**
$DC_{SUPER,\ HORIZ.}$	-0.57	K/FT
MOMENT ARM = $H_{FOOT} + H_{STEM} + H_{BRG}$	**6.33**	**FT**

SUBSTRUCTURE DEAD LOADS

FOOTING

$DC_{FOOT} = (B_{FOOT})(H_{FOOT})(\gamma c)$	**2.10**	**K/FT**
MOMENT ARM = $(0.5)B_{FOOT}$	**3.50**	**FT**

STEM

$DC_{STEM} = (B_{STEM})(H_{STEM})(\gamma c)$	**1.58**	**K/FT**
MOMENT ARM = $B_{TOE} + (0.5)B_{STEM}$	**1.83**	**FT**

BACKWALL

$DC_{BW} = (B_{BW})(H_{BW})(\gamma c)$	**0.00**	**K/FT**
MOMENT ARM = $B_{TOE} + B_{STEM} - (0.5)B_{BW}$	**3.00**	**FT**

WEARING SURFACE AND UTILITIES (DW) (3.5.1)

$DW_{SUPER, VERT}$	1.04	K/FT
MOMENT ARM = $B_{TOE} + e_{BRG}$	**1.83**	**FT**
$DW_{SUPER, HORIZ.}$	-0.49	K/FT
MOMENT ARM = $H_{FOOT} + H_{STEM} + H_{BRG}$	**6.33**	**FT**

VEHICULAR LIVE LOADS (LL) (3.6.1.1)

DESIGN FOR FULL HL-93

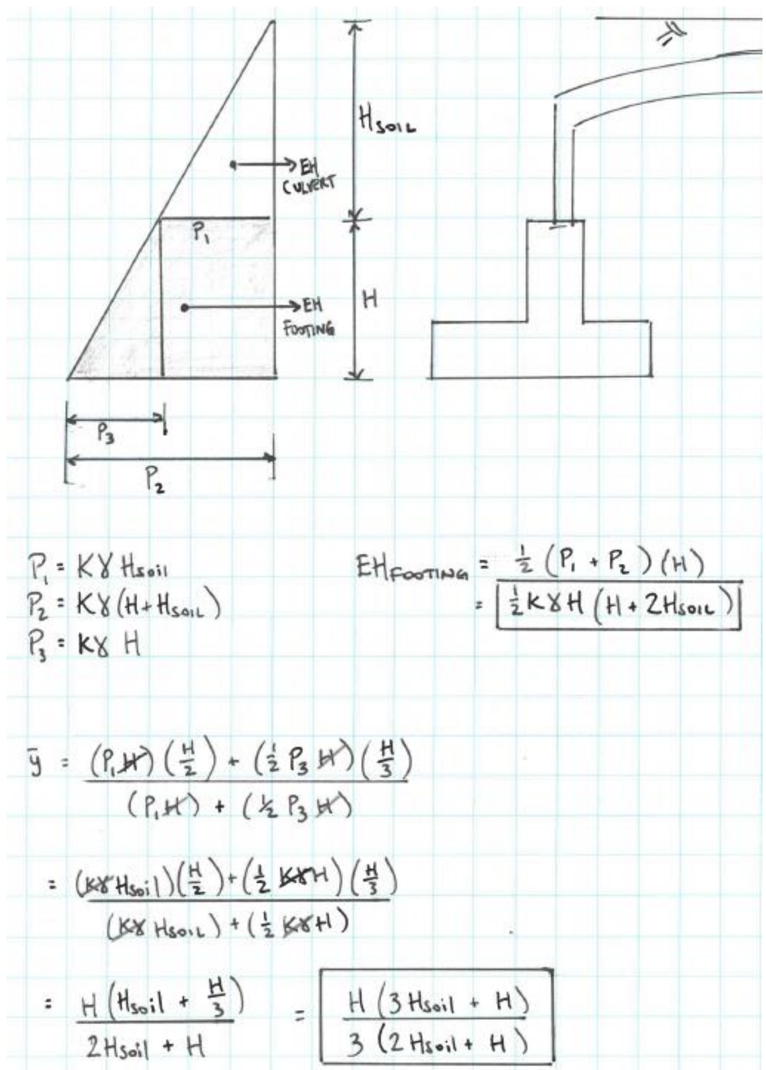
$LL_{SUPER, VERT}$	5.30	K/FT
MOMENT ARM = $B_{TOE} + e_{BRG}$	**1.83**	**FT**
$LL_{SUPER, HORIZ.}$	-1.16	K/FT
MOMENT ARM = $H_{FOOT} + H_{STEM} + H_{BRG}$	**6.33**	**FT**

EARTH PRESSURE (EH) (3.11.5)

AT-REST EARTH PRESSURE COEFFICIENT, K_0	0.470	
SOIL UNIT WEIGHT, γ_S	0.120	KCF
$H_{soilStem}$ DEPTH OF SOIL ABOVE TOP OF PEDESTAL STEM	9.51	FT

SUBSTRUCTURE

CONSIDER EARTH PRESSURE EFFECTS BETWEEN BOTTOM OF FOOTING AND TOP OF PEDESTAL STEM



HORIZONTAL EARTH PRESSURE RESULTANT, EH =0.5 $K_0 \gamma_s$ H (H + 2 $H_{soilStem}$)	**4.68**	**K/FT**
MOMENT ARM = H (3 $H_{soilStem}$+ H) / 3 (2 $H_{soilStem}$ + H)	**2.97**	**FT**

CULVERT

$EH_{CULVERT}$	**1.22**	**K/FT**
MOMENT ARM = H_{FOOT} + H_{STEM} + H_{BRG}	**6.33**	**FT**

VERTICAL PRESSURE FROM DEAD LOAD OF EARTH FILL (EV) (3.5.1)

$H_{soilStem}$	DEPTH OF SOIL ABOVE TOP OF PEDESTAL STEM	9.51	FT
$H_{soilheel}$	SOIL HEIGHT ABOVE FOOTING HEEL = $H + H_{soilStem} - H_{FOOT}$	14.01	FT
$H_{soiltoe}$	SOIL HEIGHT ABOVE FOOTING TOE	0.00	FT
EV_{HEEL}	SELF WEIGHT OF SOIL ABOVE FOOTING HEEL = $H_{soilheel}\ B_{HEEL}\ \gamma_S$	**6.72**	**K/FT**
MOMENT ARM = $B_{TOE} + B_{STEM} + (0.5)B_{HEEL}$		**5.00**	**FT**
EV_{TOE}	SELF WEIGHT OF SOIL ABOVE FOOTING TOE = $H_{soiltoe}\ B_{TOE}\ \gamma_S$	**0.00**	**K/FT**
MOMENT ARM = $(0.5)B_{TOE}$		**0.33**	**FT**

CULVERT

$EV_{CULVERT,\ VERT}$		**5.61**	K/FT
MOMENT ARM = $B_{TOE} + e_{BRG}$		**1.83**	**FT**
$EV_{CULVERT,\ HORIZ}$		-2.62	K/FT
MOMENT ARM = $H_{FOOT} + H_{STEM} + H_{BRG}$		**6.33**	**FT**

LIVE LOAD SURCHARGE (LS) (3.11.6.4)

$H + H_{soilStem}$	TOTAL ABUTMENT + FRAME HEIGHT	16.01	FT
h_{eq}	EQUIVALENT HEIGHT OF SOIL (TABLE 3.11.6.4.1)	2.40	FT

Abutment Height (ft)	h_{eq} (ft)
5.0	4.0
10.0	3.0
≥20.0	2.0

Δ_p	CONSTANT HORIZONTAL LS EARTH PRESSURE = $k\ \gamma_s\ h_{eq}$ (3.11.6.4-1)	0.135	KSF
LS	LIVE LOAD SURCHARGE = $(\Delta_p)\ (H + H_{soilStem})$	**2.17**	**k/ft**
MOMENT ARM = $1/2\ (H + H_{soilStem})$		**8.01**	**FT**

SUMMARY OF LOADS

LOAD		FORCE (K/FT)	ARM (FT)	MOMENT EFFECT (K-FT/FT)		
DC	(CUL. V)	1.86	1.83	3.41	RESISTING (+)	
DC	(CUL. H)	0.57	6.33	3.61	RESISTING (+)	
DC	(FOOT)	2.10	3.50	7.35	RESISTING (+)	
DC	(STEM)	1.58	1.83	2.89	RESISTING (+)	
DW	(CUL. V)	1.04	1.83	1.91	RESISTING (+)	
DW	(CUL. H)	0.49	6.33	3.10	RESISTING (+)	
EV	(HEEL)	6.72	5.00	33.62	RESISTING (+)	
EV	(TOE)	0.00	0.33	0.00	RESISTING (+)	(ZERO FOR MINIMUM)
EV	(CUL. V)	5.61	1.83	10.28	RESISTING (+)	
EV	(CUL. H)	2.62	6.33	16.59	RESISTING (+)	
LL	(CUL. V)	5.30	1.83	9.72	RESISTING (+)	(ZERO FOR MINIMUM)
LL	(CUL. H)	1.16	6.33	7.35	RESISTING (+)	(ZERO FOR MINIMUM)
EH	(SUB)	4.68	2.97	13.91	OVERTURNING (-)	
EH	(CUL.)	1.22	6.33	7.73	OVERTURNING (-)	
LS	(CUL.)	2.17	8.01	17.34	OVERTURNING (-)	(ZERO FOR MINIMUM)

LOAD COMBINATIONS AND LOAD FACTORS (TABLES 3.4.1-1 & 3.4.1-2)

LIMIT STATES	DC		DW		EH		EV		LL BR LS	WS	WL
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN			
STR. I	1.25	0.90	1.50	0.65	1.50	0.90	1.35	1.00	1.75	-	-
STR. II	1.25	0.90	1.50	0.65	1.50	0.90	1.35	1.00	1.35	-	-
STR. III	1.25	0.90	1.50	0.65	1.50	0.90	1.35	1.00	-	1.00	-
STR. IV	1.50	0.90	1.50	0.65	1.50	0.90	1.35	1.00	-	-	-
STR. V	1.25	0.90	1.50	0.65	1.50	0.90	1.35	1.00	1.35	1.00	1.00
EXTR. I	1.25	0.90	1.50	0.65	1.50	0.90	1.35	1.00	1.35	-	-
EXTR. II	1.25	0.90	1.50	0.65	1.50	0.90	1.35	1.00	0.50	-	-
SER. I	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SER. II	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.30	-	-
SER. III	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	-	-
SER. IV	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	-	1.00	-

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FACTORED MOMENTS AND FORCES

LIMIT STATES	{a} MAX. DRIVING MOMENT (K-FT/FT)	{b} MIN. DRIVING MOMENT (K-FT/FT)	{c} MAX. RESISTING MOMENT (K-FT/FT)	{d} MIN. RESISTING MOMENT (K-FT/FT)	{e} MAX. VERTICAL FORCE (K/FT)	{f} MIN. VERTICAL FORCE (K/FT)	{g} MAX. HORIZONTAL FORCE (K/FT)	{h} MIN. HORIZONTAL FORCE (K/FT)
STR. I	62.8	19.5	140.6	79.3	34.4	18.0	9.2	-1.7
STR. II	N/A - NO OWNER-SPECIFIED SPECIAL DESIGN VEHICLES (3.4.1)							
STR. III	32.5	19.5	110.8	79.3	25.1	18.0	5.4	0.3
STR. IV	32.5	19.5	115.1	79.3	26.5	18.0	5.4	0.2
STR. V	55.9	19.5	133.8	79.3	32.3	18.0	8.3	-1.2
EXTR. I	N/A FOR SINGLE SPAN BRIDGES (4.7.4.2)							
EXTR. II								
SER. I	39.0	21.6	99.8	82.8	24.2	18.9	4.4	1.1
SER. II	N/A - NOT A STEEL SUBSTRUCTURE (3.4.1)							
SER. III	N/A - NOT A PRESTRESSED CONCRETE SUBSTRUCTURE (3.4.1)							
SER. IV								

STRENGTH LIMIT STATE (11.5.3)

OVERTURNING & ECCENTRICITY LIMITS (11.6.3.3)

X_i RESULTANT VERT. FORCE LOCATION FROM TOE

FOUNDATON ON **ROCK**

MIN. X_i = (B_{FOOT} / 20)	0.35	FT
MAX. X_i = (B_{FOOT} - (B_{FOOT} / 20))	6.65	FT

11.6.3.3—Eccentricity Limits

For foundations on soil, the location of the resultant of the reaction forces shall be within the middle two-thirds of the base width.

For foundations on rock, the location of the resultant of the reaction forces shall be within the middle nine-tenths of the base width.

CASE 1 - MIN. VERT & MAX. HORIZ.
$$X_1 = \frac{\{MIN.\ RESIST.\ MOM\} - \{MAX.\ DRIV.\ MOM.\}}{\{MIN.\ VERT\ FORCE\}} = \frac{\{d\} - \{a\}}{\{f\}}$$

CASE 2 - MAX. VERT & MAX. HORIZ.
$$X_2 = \frac{\{MAX.\ RESIST.\ MOM\} - \{MAX.\ DRIV.\ MOM.\}}{\{MAX.\ VERT\ FORCE\}} = \frac{\{c\} - \{a\}}{\{e\}}$$

CASE 3 - MAX. VERT & MIN. HORIZ.
$$X_3 = \frac{\{MAX.\ RESIST.\ MOM\} - \{MIN.\ DRIV.\ MOM.\}}{\{MAX.\ VERT\ FORCE\}} = \frac{\{c\} - \{b\}}{\{e\}}$$

CASE 4 - MIN. VERT & MIN. HORIZ.
$$X_4 = \frac{\{MIN.\ RESIST.\ MOM\} - \{MIN.\ DRIV.\ MOM.\}}{\{MIN.\ VERT\ FORCE\}} = \frac{\{d\} - \{b\}}{\{f\}}$$

REFER TO TABLE BELOW FOR X_i ANALYSIS

LATERAL SLIDING (11.6.3.6)

ϕR_n FACTORED SLIDING RESISTANCE = ϕ_t V tan δ (10.6.3.4-1)

ϕ_t SLIDING RESISTANCE FACTOR 0.80

V TOTAL MIN. VERTICAL FORCE = COLUMN {f}

tan δ COEFFICIENT OF FRICTION (SLIDING) = (REF 6) 0.70

FS, SLIDING FACTOR OF SAFETY = $\dfrac{(\phi_t)\ (\tan\delta)\ \{\text{MIN. VERT. FORCE}\}}{|\{\text{MAX. HORIZ. FORCE}\}|^*}$ = $\dfrac{(\phi_t)\ (\tan\delta)\ \{f\}}{|\{g\}|\ \text{or}\ |\{h\}|}$

FOR LRFD ANALYSIS, VERIFY $FS_{SLIDING} \geq 1.0$

**NOTE - DESIGNER MAY CONSIDER PASSIVE PRESSURE TO RESIST THRUST OF FRAME*

REFER TO TABLE BELOW FOR $FS_{SLIDING}$ ANALYSIS

	OVERTURNING				SLIDING
LIMIT STATES	**X_1 (FT.)**	**X_2 (FT.)**	**X_3 (FT.)**	**X_4 (FT.)**	**FS**
STR. I	***0.92***	2.26	3.52	3.32	***1.10***
STR. II	N/A				
STR. III	2.60	3.12	***3.63***	3.32	1.87
STR. IV	2.60	3.12	3.61	3.32	1.87
STR. V	1.30	2.41	3.54	3.32	1.21
EXTR. I	N/A				
EXTR. II					
SER. I	2.32	2.51	3.23	3.23	2.42
SER. II	N/A				
SER. III	N/A				
SER. IV					
ALLOW MIN.	0.35				1.00
ALLOW MAX.	6.65				-
OK?	**OK**				**OK**

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PREPARED BY	EAO	DATE JUL. '19	CHECKED BY / DATE

BEARING RESISTANCE (11.6.3.2) FOUNDATON ON **ROCK**

IF RESULTANT IS WITHIN THE MIDDLE 1/3 OF THE BASE:

$\sigma_{v,max}$ LINEARLY DISTRIBUTED, MAX APPLIED VERTICAL STRESS = (∑V / B) (1 + 6e/B) (11.6.3.2-2)

$\sigma_{v,min}$ LINEARLY DISTRIBUTED, MIN APPLIED VERTICAL STRESS = (∑V / B) (1 - 6e/B) (11.6.3.2-3)

IF RESULTANT IS OUTSIDE THE MIDDLE 1/3 OF THE BASE:

$\sigma_{v,max}$ LINEARLY DISTRIBUTED, MAX APPLIED VERTICAL STRESS = 2∑V / 3[(B/2)-e] (11.6.3.2-4)

$\sigma_{v,min}$ LINEARLY DISTRIBUTED, MIN APPLIED VERTICAL STRESS = 0 (11.6.3.2-5)

V APPLIED VERTICAL FORCE = COLUMN {e} OR {f}

X_i RESULTANT VERT. FORCE LOCATION FROM TOE.

e_i RESULTANT VERT. FORCE LOCATION FROM CENTER OF FOOTING = |(0.5) (B_{FOOT}) - (X_i)|

RESULTANT IS OUTSIDE MIDDLE 1/3 OF BASE IF e ≤ B/6 = 1.167 FT

RESULTANT IS WITHIN MIDDLE 1/3 OF BASE IF e > B/6 = 1.167 FT

$\phi_b q_n$ NET BEARING RESISTANCE (REFER TO SHEET 2) = 0.45 x 200.00 KSF = 90.00 KSF

REFER TO TABLE BELOW FOR σ_v ANALYSIS

LIMIT STATES	BEARING											
	e_1 (FT.)	e_2 (FT.)	e_3 (FT.)	e_4 (FT.)	$\sigma_{vmax,1}$ (KSF)	$\sigma_{vmin,1}$ (KSF)	$\sigma_{vmax,2}$ (KSF)	$\sigma_{vmin,2}$ (KSF)	$\sigma_{vmax,3}$ (KSF)	$\sigma_{vmin,3}$ (KSF)	$\sigma_{vmax,4}$ (KSF)	$\sigma_{vmin,4}$ (KSF)
STR. I	2.58	1.24	0.02	0.18	***25.03***	0.00	10.14	0.00	5.00	4.83	5.65	4.18
STR. II	N/A											
STR. III	0.90	0.38	0.13	0.18	6.35	0.83	4.77	2.41	4.00	3.18	4.13	3.05
STR. IV	0.90	0.38	0.11	0.18	6.70	0.88	5.03	2.54	4.13	3.44	4.36	3.22
STR. V	2.20	1.09	0.04	0.18	16.53	0.00	8.91	0.32	4.77	4.45	5.31	3.92
EXTR. I	N/A											
EXTR. II												
SER. I	1.18	0.99	0.27	0.27	6.97	0.00	6.38	0.53	4.26	2.66	4.25	2.67
SER. II	N/A											
SER. III	N/A											
SER. IV												
ALLOW MIN.	-				-							
ALLOW MAX.	-				90.00							
OK?	-				**OK**							

LOSS OF BASE CONTACT DUE TO ECCENTRIC LOADING

11.6.3.4—Subsurface Erosion

For walls constructed along rivers and streams, scour of foundation materials shall be evaluated during design, as specified in Article 2.6.4.4.2. Where potential problem conditions are anticipated, adequate protective measures shall be incorporated in the design.

10.6.1.2—Bearing Depth

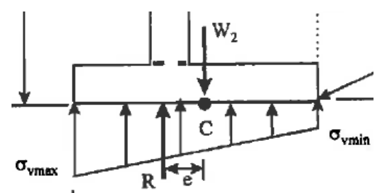
Where the potential for scour, erosion or undermining exists, spread footings shall be located to bear below the maximum anticipated depth of scour, erosion, or undermining as specified in Article 2.6.4.4.

DEPTH OF SCOUR POTENTIAL:	0.00	FT
MIN. DEPTH OF EARTH COVER (D_E)	0.00	FT
CHECK: D_E > SCOUR DEPTH?	**OK**	

SAFETY AGAINST STRUCTURAL FAILURE (11.6.4)

DESIGN REINFORCING STEEL OF INDIVIDUAL WALL ELEMENTS TO PREVENT STRUCTURAL FAILURE FOR MAXIMUM DESIGN EFFECTS

FOR FOOTING DESIGN, DETERMINE WORST-CASE CONTACT PRESSURE.



INTERPOLATE BETWEEN σ_{vmax} AT TOE AND σ_{vmin} AT HEEL:

$\sigma_{v,FF}$	VERTICAL STRESS AT BACK FACE OF STEM	σ_{vmax} - [B_{TOE} (σ_{vmax} - σ_{vmin}) / B_{FOOT}]
$\sigma_{v,BF}$	VERTICAL STRESS AT FRONT FACE OF STEM	σ_{vmin} + [B_{HEEL} (σ_{vmax} - σ_{vmin}) / B_{FOOT}]

CENTROID FOR RIGHT-ANGLED TRAPEZOID: $$\bar{y} = \frac{b+2a}{3(a+b)}h.$$

CALCULATE MAX RESULTANT SHEAR AND MOMENT ON TOE AND HEEL:

$V_{U, TOE}$ FACTORED DESIGN SHEAR APPLIED TO TOE = $0.5(\sigma_{vmax} + \sigma_{v,FF}) (B_{TOE})$

$M_{U, TOE}$ FACTORED DESIGN MOMENT APPLIED TO TOE = $(V_{u,TOE}) (\sigma_{v,FF} + 2\,\sigma_{vmax}) (B_{TOE}) / (3\,(\sigma_{v,FF} + \sigma_{vmax}))$

$V_{U, HEEL}$ FACTORED DESIGN SHEAR APPLIED TO HEEL = $0.5(\sigma_{vmin} + \sigma_{v,BF}) (B_{HEEL})$

$M_{U, HEEL}$ FACTORED DESIGN MOMENT APPLIED TO HEEL = $(V_{u,HEEL}) (\sigma_{vmin} + 2\,\sigma_{v,BF})$ (BHEEL) / $(3\,(\sigma_{v,BF} + \sigma_{vmin}))$

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LIMIT STATES	$\sigma_{vmax,1}$ (KSF)	$\sigma_{vFF,1}$ (KSF)	$\sigma_{vBF,1}$ (KSF)	$\sigma_{vmin,1}$ (KSF)	$V_{U,TOE,1}$ (K/FT)	$M_{U,TOE,1}$ (K-FT/FT)	$V_{U,HEEL,1}$ (K/FT)	$M_{U,HEEL,1}$ (K-FT/FT)
STR. I	25.03	22.65	14.31	0.00	***15.89***	***5.39***	***28.61***	38.15
STR. II	N/A							
STR. III	6.35	5.83	3.98	0.83	4.06	1.37	9.63	15.05
STR. IV	6.70	6.15	4.20	0.88	4.28	1.45	10.16	15.88
STR. V	16.53	14.96	9.45	0.00	10.50	3.56	18.90	25.20
EXTR. I	N/A							
EXTR. II								
SER. I	6.97	6.31	3.98	0.00	***4.42***	***1.50***	7.97	10.62
SER. II	N/A							
SER. III								
SER. IV								

LIMIT STATES	$\sigma_{vmax,2}$ (KSF)	$\sigma_{vFF,2}$ (KSF)	$\sigma_{vBF,2}$ (KSF)	$\sigma_{vmin,2}$ (KSF)	$V_{U,TOE,2}$ (K/FT)	$M_{U,TOE,2}$ (K-FT/FT)	$V_{U,HEEL,2}$ (K/FT)	$M_{U,HEEL,2}$ (K-FT/FT)
STR. I	10.14	9.18	5.79	0.00	6.44	2.18	11.59	15.45
STR. II	N/A							
STR. III	4.77	4.55	3.76	2.41	3.11	1.04	12.33	22.87
STR. IV	5.03	4.80	3.97	2.54	3.28	1.10	13.01	24.13
STR. V	8.91	8.09	5.23	0.32	5.66	1.92	11.09	15.63
EXTR. I	N/A							
EXTR. II								
SER. I	6.38	5.83	3.88	0.53	4.07	1.38	8.82	13.19
SER. II	N/A							
SER. III								
SER. IV								

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LIMIT STATES	$\sigma_{vmax,3}$ (KSF)	$\sigma_{vFF,3}$ (KSF)	$\sigma_{vBF,3}$ (KSF)	$\sigma_{vmin,3}$ (KSF)	$V_{U,TOE,3}$ (K/FT)	$M_{U,TOE,3}$ (K-FT/FT)	$V_{U,HEEL,3}$ (K/FT)	$M_{U,HEEL,3}$ (K-FT/FT)
STR. I	5.00	4.99	4.93	4.83	3.33	1.11	19.51	***38.88***
STR. II	N/A							
STR. III	4.00	3.92	3.65	3.18	2.64	0.88	13.66	26.70
STR. IV	4.13	4.07	3.84	3.44	2.73	0.91	14.56	28.60
STR. V	4.77	4.74	4.64	4.45	3.17	1.06	18.17	36.10
EXTR. I	N/A							
EXTR. II								
SER. I	4.26	4.11	3.57	2.66	2.79	0.94	12.46	23.70
SER. II	N/A							
SER. III								
SER. IV								

LIMIT STATES	$\sigma_{vmax,4}$ (KSF)	$\sigma_{vFF,4}$ (KSF)	$\sigma_{vBF,4}$ (KSF)	$\sigma_{vmin,4}$ (KSF)	$V_{U,TOE,4}$ (K/FT)	$M_{U,TOE,4}$ (K-FT/FT)	$V_{U,HEEL,4}$ (K/FT)	$M_{U,HEEL,4}$ (K-FT/FT)
STR. I	5.65	5.51	5.02	4.18	3.72	1.25	18.39	35.66
STR. II	N/A							
STR. III	4.13	4.03	3.67	3.05	2.72	0.91	13.43	26.05
STR. IV	4.36	4.25	3.87	3.22	2.87	0.96	14.17	27.48
STR. V	5.31	5.17	4.71	3.92	3.49	1.17	17.26	33.46
EXTR. I	N/A							
EXTR. II								
SER. I	4.25	4.10	3.57	2.67	2.78	0.93	***12.48***	***23.74***
SER. II	N/A							
SER. III								
SER. IV								

MAXIMUM DESIGN EFFECTS

$M_{U, TOE, STR.}$	FACTORED STRENGTH DESIGN MOMENT APPLIED TO TOE =	5.39	K-FT / FT
$M_{U, TOE, SER.}$	FACTORED SERVICE DESIGN MOMENT APPLIED TO TOE =	1.50	K-FT / FT
$V_{U, TOE}$	FACTORED DESIGN SHEAR APPLIED TO TOE =	15.89	K / FT
$M_{U, HEEL, STR.}$	FACTORED STRENGTH DESIGN MOMENT APPLIED TO HEEL =	38.88	K-FT / FT
$M_{U, HEEL, SER.}$	FACTORED SERVICE DESIGN MOMENT APPLIED TO HEEL =	23.74	K-FT / FT
$V_{U, HEEL}$	FACTORED DESIGN SHEAR APPLIED TO HEEL =	28.61	K /FT

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$M_{U, STEM,STR.}$	FACTORED STRENGTH DESIGN MOMENT APPLIED TO STEM = MAX({a})	62.8	K-FT / FT
$M_{U, STEM, SER.}$	FACTORED SERVICE DESIGN MOMENT APPLIED TO STEM = MAX({a})	39.0	K-FT / FT
	CONSERVATIVE, COULD SUBTRACT FOOTING DEPTH FROM MOMENT ARM		
$V_{U, STEM}$	FACTORED DESIGN SHEAR APPLIED TO STEM = MAX({g})	9.19	K /FT

SERVICE LIMIT STATES (11.5.2)

SETTLEMENT ANALYSES (10.6.2.4)

SEE GEOTECHNICAL REPORT

OVERALL STABILITY (11.6.2.3) SEE GEOTECHNICAL RECOMMENDATIONS

11.6.2.3—Overall Stability

The overall stability of the retaining wall, retained slope and foundation soil or rock shall be evaluated for all walls using limiting equilibrium methods of analysis. The overall stability of temporary cut slopes to facilitate construction shall also be evaluated. Special exploration, testing and analyses may be required for bridge abutments or retaining walls constructed over soft deposits.

The evaluation of overall stability of earth slopes with or without a foundation unit should be investigated at the Service I Load Combination and an appropriate resistance factor. In lieu of better information, the resistance factor, ϕ, may be taken as:

- Where the geotechnical parameters are well defined, and the slope does not support or contain a structural element 0.75
- Where the geotechnical parameters are based on limited information, or the slope contains or supports a structural element 0.65

C11.6.2.3

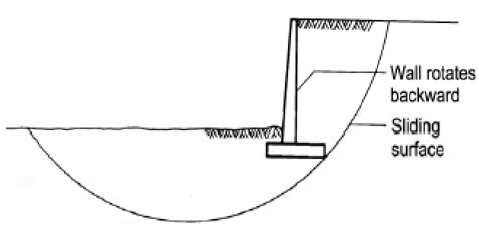

Figure C11.6.2.3-1—Retaining Wall Overall Stability Failure

Figure C11.6.2.3-1 shows a retaining wall overall stability failure. Overall stability is a slope stability issue, and, therefore, is considered a service limit state check.

The Modified Bishop, simplified Janbu or Spencer methods of analysis may be used.

Soft soil deposits may be subject to consolidation and/or lateral flow which could result in unacceptable long-term settlements or horizontal movements.

With regard to selection of a resistance factor for evaluation of overall stability of walls, examples of

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PRIMARY REINFORCING DESIGN - TOE OF FOOTING

BOTTOM MAT PRIMARY REINFORCING DUE TO BEARING PRESSURE

STRENGTH DESIGN

CRITERIA 1: TENSION = COMPRESSION

T = As * Fy   C = 0.85 * f'c * a * b   Fy = 60 KSI   As UNKOWN

EQ. 1 a = [Fy / (0.85 * f'c * b)] As   f'c = 4.0 KSI   a UNKOWN

b = 12 IN

CRITERIA 2: FACTORED MOMENT < FACTORED FLEXURAL RESISTANCE

Mu > ϕ * Mn = ϕ * As * Fy (d - 0.5 a)   ϕ = 0.90 (AASHTO 5.5.4.2)

EQ. 2 As = Mu / (ϕ * Fy * (d - 0.5 a))   CLR. CVR. = 4.00 IN

h = 24.00 IN

ASSUMED BAR DIAM. = 0.75 IN

SOLVE SYSTEM OF EQUATIONS TO SOLVE FOR As_required   d = 19.63 IN

$M_{U, TOE}$ = 5.39 K-FT/FT = 64.6 K-IN/FT

a	As_req
1.00	0.063
0.09	0.061
0.09	0.061
0.09	0.061
0.09	0.061

As_req = 0.061 IN^2/FT

As_prov = 0.440 IN^2/FT

CHECK: OK

PROVIDE: #6 @ 12 IN

LONGITUDINAL, BOTTOM, INT

BAR DIAM = 0.75 IN

d = 19.63 IN

a = 0.65 IN

Mr = ϕ * Mn = ϕ * As * Fy (d - 0.5 a) = 458.6 = 38.2 K-FT/FT

MINIMUM REINFORCEMENT (5.6.3.3)

Mr SHALL BE GREATER THAN THE LESSER OF (Mcr) AND (1.33 Mu)

M_{cr}	CRACKING MOMENT (5.6.3.3-1 NOTE PRESTRESSED & COMPOSITE N/A) = $\gamma_3\ \gamma_1\ f_r\ S_c$		
γ_3	RATIO OF MIN. YIELD STRENGTH TO ULTIMATE TENSILE STRENGTH (A615, GRADE 60)	0.67	
γ_1	FLEXURAL CRACKING VARIABILITY FACTOR: 1.2 FOR PRECAST OR 1.6 FOR OTHERS (C.I.P.)	1.6	
f_r	MODULUS OF RUPTURE (5.4.2.6) = 0.24 $\sqrt{f'_c}$	0.480	KSI
S_c	SECTION MODULUS = b H_{FOOT}^2/6 =	1152	IN^3

M_{cr} = 49.4 K-FT/FT

SMALLER VALUE, COMPARE TO Mr BELOW >>> 1.33 $M_{u,TOE}$ = **7.2** K-FT/FT

Mr = 38.2 K-FT/FT

OK

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PRIMARY REINFORCING DESIGN - HEEL OF FOOTING

TOP MAT PRIMARY REINFORCING DUE TO OVERBURDEN EARTH PRESSURE AND DEAD LOAD

STRENGTH DESIGN

CRITERIA 1: TENSION = COMPRESSION

T = As * Fy C = 0.85 * f'c * a * b

EQ. 1 a = [Fy / (0.85 * f'c * b)] As

Fy	=	60	KSI	As UNKOWN
f'c	=	4.0	KSI	a UNKOWN
b	=	12	IN	

CRITERIA 2: FACTORED MOMENT < FACTORED FLEXURAL RESISTANCE

Mu > ϕ * Mn = ϕ * As * Fy (d - 0.5 a)

EQ. 2 As = Mu / (ϕ * Fy * (d - 0.5 a))

SOLVE SYSTEM OF EQUATIONS TO SOLVE FOR As_required

ϕ	=	0.90	(AASHTO 5.5.4.2)	
CLR. CVR.	=	4.00	IN	
h	=	24.00	IN	
ASSUMED BAR DIAM.	=	0.75	IN	
d	=	19.63	IN	

$M_{U, HEEL}$ = 38.88 K-FT/FT = 466.5 K-IN/FT

a	As_req
1.00	0.452
0.66	0.448
0.66	0.448
0.66	0.448
0.66	0.448

As_req = 0.448 IN^2/FT

As_prov = 0.880 IN^2/FT

CHECK: OK

PROVIDE: #6 @ 6 IN

LONGITUDINAL, BOTTOM, INT

BAR DIAM = 0.75 IN

d = 19.63 IN

a = 1.29 IN

Mr = ϕ * Mn = ϕ * As * Fy (d - 0.5 a) = 901.8 = 75.2 K-FT/FT

MINIMUM REINFORCEMENT (5.6.3.3)

Mr SHALL BE GREATER THAN THE LESSER OF (Mcr) AND (1.33 Mu)

M_{cr}	CRACKING MOMENT (5.6.3.3-1 NOTE PRESTRESSED & COMPOSITE N/A) = $\gamma_3\ \gamma_1\ f_r\ S_c$		
γ_3	RATIO OF MIN. YIELD STRENGTH TO ULTIMATE TENSILE STRENGTH (A615, GRADE 60)	0.67	
γ_1	FLEXURAL CRACKING VARIABILITY FACTOR: 1.2 FOR PRECAST OR 1.6 FOR OTHERS (C.I.P.)	1.6	
f_r	MODULUS OF RUPTURE (5.4.2.6) = 0.24 $\sqrt{f'_c}$	0.480	KSI
S_c	SECTION MODULUS = b $H_{FOOT}^2/6$ =	1152	IN^3

SMALLER VALUE, COMPARE TO Mr BELOW >>>

M_{cr}	=	**49.4**	K-FT/FT
1.33 $M_{u,HEEL}$	=	51.7	K-FT/FT
Mr	=	75.2	K-FT/FT
		OK	

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PRIMARY REINFORCING DESIGN - VERTICAL STEM (AT BASE)

BACK FACE VERTICAL PRIMARY REINFORCING DUE TO HORIZONTAL LOADS AT BASE OF STEM

STRENGTH DESIGN

CRITERIA 1: TENSION = COMPRESSION

T = As * Fy C = 0.85 * f'c * a * b

EQ. 1 a = [Fy / (0.85 * f'c * b)] As

Fy	=	60	KSI	As UNKOWN
f'c	=	4.0	KSI	a UNKOWN
b	=	12	IN	

CRITERIA 2: FACTORED MOMENT < FACTORED FLEXURAL RESISTANCE

Mu > ϕ * Mn = ϕ * As * Fy (d - 0.5 a)

EQ. 2 As = Mu / (ϕ * Fy * (d - 0.5 a))

SOLVE SYSTEM OF EQUATIONS TO SOLVE FOR As_required

ϕ	=	0.90	(AASHTO 5.5.4.2)
CLR. CVR.	=	4.00	IN
h	=	28.00	IN
ASSUMED BAR DIAM.	=	0.75	IN
d	=	23.63	IN

$M_{U, STEM}$ = 62.80 K-FT/FT = 753.6 K-IN/FT

a	As_req
1.00	0.604
0.89	0.602
0.89	0.602
0.89	0.602
0.89	0.602

As_req = 0.602 IN^2/FT

As_prov = 0.880 IN^2/FT

CHECK: OK

PROVIDE: #6 @ 6 IN

LONGITUDINAL, BOTTOM, INT

BAR DIAM =	0.75	IN
d =	23.63	IN
a =	1.29	IN

Mr = ϕ * Mn = ϕ * As * Fy (d - 0.5 a) = 1091.9 = 91.0 K-FT/FT

MINIMUM REINFORCEMENT (5.6.3.3)

Mr SHALL BE GREATER THAN THE LESSER OF (Mcr) AND (1.33 Mu)

M_{cr}	CRACKING MOMENT (5.6.3.3-1 NOTE PRESTRESSED & COMPOSITE N/A) = $\gamma_3\ \gamma_1\ f_r\ S_c$		
γ_3	RATIO OF MIN. YIELD STRENGTH TO ULTIMATE TENSILE STRENGTH (A615, GRADE 60)	0.67	
γ_1	FLEXURAL CRACKING VARIABILITY FACTOR: 1.2 FOR PRECAST OR 1.6 FOR OTHERS (C.I.P.)	1.6	
f_r	MODULUS OF RUPTURE (5.4.2.6) = 0.24 $\sqrt{f'_c}$	0.480	KSI
S_c	SECTION MODULUS = b $H_{FOOT}^2/6$ =	1568	IN^3

SMALLER VALUE, COMPARE TO Mr BELOW >>>

M_{cr}	=	**67.2**	K-FT/FT
1.33 $M_{u,STEM}$	=	83.5	K-FT/FT
Mr	=	91.0	K-FT/FT
		OK	

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CONTROL OF CRACKING BY DISTRIBUTION OF REINFORCEMENT (5.6.7)

The spacing, s, of nonprestressed reinforcement in the layer closest to the tension face shall satisfy the following:

$$s \le \frac{700\gamma_e}{\beta_s f_{ss}} - 2d_c \qquad (5.6.7\text{-}1)$$

in which:

$$\beta_s = 1 + \frac{d_c}{0.7(h - d_c)} \qquad (5.6.7\text{-}2)$$

where:

β_s = ratio of flexural strain at the extreme tension face to the strain at the centroid of the reinforcement layer nearest the tension face

γ_e = exposure factor
= 1.00 for Class 1 exposure condition
= 0.75 for Class 2 exposure condition

d_c = thickness of concrete cover measured from extreme tension fiber to center of the flexural reinforcement located closest thereto (in.)

f_{ss} = calculated tensile stress in nonprestressed reinforcement at the service limit state not to exceed 0.60 f_y (ksi)

h = overall thickness or depth of the component (in.)

Class 1 exposure condition applies when cracks can be tolerated due to reduced concerns of appearance, corrosion, or both. Class 2 exposure condition applies to transverse design of segmental concrete box girders for any loads applied prior to attaining full design concrete compressive strength or when there is increased concern of appearance, corrosion, or both.

	TOE	HEEL	$STEM_{BOT}$
γ_e (IN.)	1.00	1.00	1.00
d_c (IN.)	4.38	4.38	4.38
d (IN.)	19.63	19.63	23.63
h (IN.)	24.00	24.00	28.00
b (IN.)		12.00	
$A_{s,\,PROV}$ (IN^2)	0.44	0.88	0.88
$M_{u,\,SER}$ (K-FT/FT)	1.50	23.74	38.98
Es (KSI)		29000	
Ec (KSI)	3640	3640	3640

Ec = 1820 √f'c (AASHTO C5.4.2.4-3)

REFER TO REFERENCE 4 FOR CALCULATING TENSILE STRESS IN STEEL REINFORCEMENT AT THE SERVICE LEVEL

ρ = As_prov / bd k = √[(nρ)^2 + 2nρ] - nρ fs = Mserv / (As_prov * j *d)

n = Es / Ec j = 1 - k/3

60% Fy = 36.00 KSI

TOE OF FOOTING

ρ =	0.001868	n =	7.97	k =	0.158	j =	0.947	fs =	2.20	KSI	β_1 =	1.318
	s ≤	**232.60**	**IN**	**s_prov =**	**12**	**IN**			**OK**		**CHECK =**	**OK**

HEEL OF FOOTING

ρ =	0.003737	n =	7.97	k =	0.216	j =	0.928	fs =	17.78	KSI	β_1 =	1.318
	s ≤	**21.11**	**IN**	**s_prov =**	**6**	**IN**			**OK**		**CHECK =**	**OK**

STEM (BASE)

ρ =	0.003104	n =	7.97	k =	0.199	j =	0.934	fs =	24.10	KSI	β_1 =	1.265
	s ≤	**14.22**	**IN**	**s_prov =**	**6**	**IN**			**OK**		**CHECK =**	**OK**

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SHRINKAGE AND TEMPERATURE REINFORCEMENT

5.10.6—Shrinkage and Temperature Reinforcement

Reinforcement for shrinkage and temperature stresses shall be provided near surfaces of concrete exposed to daily temperature changes and in structural mass concrete. Temperature and shrinkage reinforcement to ensure that the total reinforcement on exposed surfaces is not less than that specified herein.

Reinforcement for shrinkage and temperature may be in the form of bars, welded wire reinforcement, or prestressing tendons.

For bars or welded wire reinforcement, the area of reinforcement per foot, on each face and in each direction, shall satisfy the following:

$$A_s \geq \frac{1.30bh}{2(b+h)f_y} \quad (5.10.6\text{-}1)$$

except that:

$$0.11 \leq A_s \leq 0.60 \quad (5.10.6\text{-}2)$$

where:

A_s = area of reinforcement in each direction and each face (in.^{2}/ft)
b = least width of component section (in.)
h = least thickness of component section (in.)
f_y = specified minimum yield strength of reinforcement ≤75.0 ksi

Where the least dimension varies along the length of wall, footing, or other component, multiple sections should be examined to represent the average condition at each section. Spacing shall not exceed the following:

- 12.0 in. for walls and footings greater than 18.0 in. thick
- 12.0 in. for other components greater than 36.0 in. thick
- For all other situations, 3.0 times the component thickness but not less than 18.0 in.

Fy = 60 KSI

FOOTING - LONGITUDINAL

$b = B_{FOOT}$ =	84	IN	$h = H_{FOOT}$ =	24.00	IN	
$As_{,REQ.}$ ≥	0.202	IN^2/FT	MAX SPACING REQ. =	12.0	IN	PROVIDE: #5 @ 12 IN
$As_{,PROV.}$ =	0.310	IN^2/FT	SPACING PROVIDED =	12.0	IN	**CHECK = OK**

STEM - LONGITUDINAL

b = b =	12	IN	$h = B_{STEM}$ =	28.00	IN	
$As_{,REQ.}$ ≥	0.110	IN^2/FT	MAX SPACING REQ. =	18.0	IN	PROVIDE: #5 @ 12 IN
$As_{,PROV.}$ =	0.310	IN^2/FT	SPACING PROVIDED =	12.0	IN	**CHECK = OK**

STEM - VERTICAL (FRONT FACE)

b = b =	12	IN	$h = B_{STEM}$ =	28.00	IN	
$As_{,REQ.}$ ≥	0.110	IN^2/FT	MAX SPACING REQ. =	18.0	IN	PROVIDE: #5 @ 12 IN
$As_{,PROV.}$ =	0.310	IN^2/FT	SPACING PROVIDED =	12.0	IN	**CHECK = OK**

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SHEAR CHECK

SHEAR REINFORCEMENT REQUIRED IF $Vu \geq \phi V_{n,CONCRETE}$

ϕ_v	RESISTANCE FACTOR FOR SHEAR, 0.9 FOR NORMAL WEIGHT CONCRETE (5.5.4.2)	0.9	
$V_{n,CONCRETE}$	NOMINAL CONCRETE SHEAR RESISTANCE(5.7.3.3) = MIN[$0.0316\ \beta\ \sqrt{f'_c}\ b_v\ d_v$, $0.25\ f'_c\ b_v\ d_v$]		
β	SHEAR CAPACITY FACTOR, CONSERVATIVELY TAKEN AS 2.0 (5.7.3.4.1)	2.0	
b_v	EFFECTIVE (MINIMUM) WEB WIDTH (5.7.2.8), USE 12" DESIGN WIDTH	12	IN
d_v	EFFECTIVE SHEAR DEPTH, EQUAL TO INTERNAL MOMENT ARM BETWEEN TENSION & COMPRESSION RESULTANT		
	= MAX (I.M.A. , 0.9d , 0.72h) (5.7.2.8)		

TOE OF FOOTING

d_v	I.M.A.	**19.30**	IN	<<< CONTROLS	19.30	IN
	0.9d	17.66	IN			
	0.72h	17.28	IN			
$V_{n,CONCRETE}$	$0.0316\ \beta\ \sqrt{f'_c}\ b_v\ d_v$	**29.3**	K/FT	<<< CONTROLS	29.3	K/FT
	$0.25\ f'_c\ b_v\ d_v$	231.6	K/FT			
$\phi V_{n,CONCRETE}$					26.3	K/FT
$V_{u,TOE}$					15.9	K/FT
CHECK:				**NO SHEAR REINFORCEMENT REQUIRED FOR TOE**		

HEEL OF FOOTING

d_v	I.M.A.	**18.98**	IN		18.98	IN
	0.9d	17.66	IN			
	0.72h	17.28	IN			
$V_{n,CONCRETE}$	$0.0316\ \beta\ \sqrt{f'_c}\ b_v\ d_v$	**28.8**	K/FT		28.8	K/FT
	$0.25\ f'_c\ b_v\ d_v$	227.7	K/FT			
$\phi V_{n,CONCRETE}$					25.9	K/FT
$V_{u,HEEL}$					28.6	K/FT
CHECK:				**SHEAR REINFORCEMENT REQUIRED**		

STEM

d_v	I.M.A.	**22.98**	IN		22.98	IN
	0.9d	21.26	IN			
	0.72h	20.16	IN			
$V_{n,CONCRETE}$	$0.0316\ \beta\ \sqrt{f'_c}\ b_v\ d_v$	**34.9**	K/FT		34.9	K/FT
	$0.25\ f'_c\ b_v\ d_v$	275.7	K/FT			
$\phi V_{n,CONCRETE}$					31.4	K/FT
$V_{u,STEM}$					9.2	K/FT
CHECK:				**NO SHEAR REINFORCEMENT REQUIRED FOR STEM**		

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INTERFACE SHEAR TRANSFER - SHEAR FRICTION (5.7.4)

CHECK AT INTERFACE OF STEM AND FOOTING

b_{vi}	INTERFACE WIDTH ENGAGED IN SHEAR TRANSFER = B_{STEM}	28	IN
L_{vi}	INTERFACE LENGTH ENGAGED IN SHEAR TRANSFER = 12" DESIGN LENGTH	12	IN/FT
A_{cv}	AREA OF CONCRETE ENGAGED IN INTERFACE SHEAR TRANSFER = b_{vi} L_{vi}	336	IN^2/FT
c	COHESION FACTOR (5.7.4.4)	0.24	
μ	FRICTION FACTOR (5.7.4.4)	1.0	
K_1	CONCRETE STRENGTH FRACTION (5.7.4.4)	0.25	
K_2	LIMITING INTERFACE SHEAR RESISTANCE (5.7.4.4)	1.5	
A_{vf}	AREA OF INTERFACE SHEAR REINFORCEMENT CROSSING THE SHEAR PLANE	0.88	IN^2/FT
f_y	YIELD STRENGTH OF REINFORCEMENT	60	KSI
f'_c	CONCRETE COMPRESSIVE STRENGTH = MIN ($F'c_{STEM}$, $F'c_{FOOT}$)	4	KSI
P_c	PERMANENT NET COMPRESSIVE FORCE NORMAL TO SHEAR PLANE = $DC_{STEM + SUPER + BW}$	3.4	K/FT
V_{ni}	NOMINAL INTERFACE SHEAR RESISTANCE(5.7.4.3-3) = c A_{cv} + μ(A_{vf} f_y + P_c)	**136.9**	K/FT
	$V_{ni} \leq K_1 f'_c A_{cv}$ (5.7.4.3-4)	336.0	K/FT
	$V_{ni} \leq K_2 A_{cv}$ (5.7.4.3-5)	504.0	K/FT
ϕ_v	RESISTANCE FACTOR FOR SHEAR, 0.9 FOR NORMAL WEIGHT CONCRETE (5.5.4.2)	0.90	
ϕV_{ni}	FACTORED INTERFACE SHEAR RESISTANCE	123.2	K/FT
V_{ui}	FACTORED INTERFACE SHEAR FORCE	9.19	K/FT

CHECK: **SHEAR INTERFACE TRANSFER ADEQUATE**

5.7.4.2—Minimum Area of Interface Shear Reinforcement

Except as provided herein, the cross-sectional area of the interface shear reinforcement, A_{vf}, crossing the interface area, A_{cv}, shall satisfy:

$$A_{vf} \geq \frac{0.05 A_{cv}}{f_y} \quad (5.7.4.2\text{-}1)$$

where:

A_{cv} = area of concrete considered to be engaged in interface shear transfer (in.^{2})

A_{vf} = area of interface shear reinforcement crossing the shear plane within the area A_{cv} (in.^{2})

f_y = yield stress of reinforcement but design value not to exceed 60.0 (ksi)

$A_{vf\,(MIN)}$	≥	0.280	IN^2/FT
A_{vf}	=	0.880	IN^2/FT

SHEAR INTERFACE AREA ADEQUATE

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DEVELOPMENT OF REINFORCEMENT (5.10.8.2)

l_d TENSION DEVELOPMENT LENGTH (5.10.8.2.1) = MAX($l_{db}\ \lambda_{rl}\ \lambda_{er}$, 12")

l_{db} BASIC TENSION DEVELOPMENT LENGTH (5.10.8.2.1a-2) = 2.4 $d_b\ f_y / \sqrt{f'_c}$

λ_{rl} TOP BARS OR NEARLY HORIZONTAL REINFORCEMENT (5.10.8.2.1b) 1.3

λ_{er} FULL YIELD STRENGTH NOT MET (5.10.8.2.1c-4) = $A_{s,\ REQ.} / A_{s,\ PROV.}$

LONGITUDINAL FOOTING

l_{db}	2.4 $d_b\ f_y / \sqrt{f'_c}$	45.00	IN			45.00	IN
λ_{rl}						1.30	
λ_{er}						0.65	
l_d	l_{db} λrl λer	38.16	IN	<<< CONTROLS		38.16	IN
	12"	12.00	IN				
					USE:	39.00	IN

PROVIDE 39 IN. MIN LAP

LONGITUDINAL STEM

l_{db}	2.4 $d_b\ f_y / \sqrt{f'_c}$	45.00	IN		45.00	IN
λ_{rl}					1.30	
λ_{er}					0.35	
l_d	l_{db} λrl λer	20.76	IN		20.76	IN
	12"	12.00	IN			
				USE:	21.00	IN

PROVIDE 21 IN. MIN LAP

VERTICAL STEM

l_{db}	2.4 $d_b\ f_y / \sqrt{f'_c}$	54.00	IN		54.00	IN
λ_{er}					0.68	
l_d	l_{db} λer	36.94	IN		36.94	IN
	12"	12.00	IN			
				USE:	37.00	IN

PROVIDE 37 IN. MIN LAP

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SUMMARY OF CHECKS

OVERTURNING		OK
SLIDING	**NOTE - DESIGNER MAY CONSIDER PASSIVE PRESSURE TO RESIST OUTWARD THRUST OF FRAME*	OK
BEARING	*OR CONSIDER DOWELS INTO BEDROCK*	OK
SCOUR		OK
SETTLEMENT		PER GEOTECH
OVERALL STABILITY		PER GEOTECH
REINFORCING: TOE OF FOOTING STRENGTH		OK
REINFORCING: TOE OF FOOTING MINIMUM		OK
REINFORCING: TOE OF FOOTING CRACKING		OK
REINFORCING: HEEL OF FOOTING STRENGTH		OK
REINFORCING: HEEL OF FOOTING MINIMUM		OK
REINFORCING: HEEL OF FOOTING CRACKING		OK
REINFORCING: BASE OF STEM STRENGTH		OK
REINFORCING: BASE OF STEM MINIMUM		OK
REINFORCING: BASE OF STEM CRACKING		OK
REINFORCING: SHRINKAGE AND TEMERATURE FOOTING LONGITUDINAL		OK
REINFORCING: SHRINKAGE AND TEMERATURE STEM LONGITUDINAL		OK
REINFORCING: SHRINKAGE AND TEMERATURE STEM VERTICAL		OK
SHEAR: TOE		OK
SHEAR: HEEL	*NOTE - PROVIDE SHEAR REINFORCEMENT DURING FINAL DESIGN IF NEEDED	NO GOOD
SHEAR: STEM		OK
SHEAR INTERFACE TRANSFER: STEM TO FOOTING		OK

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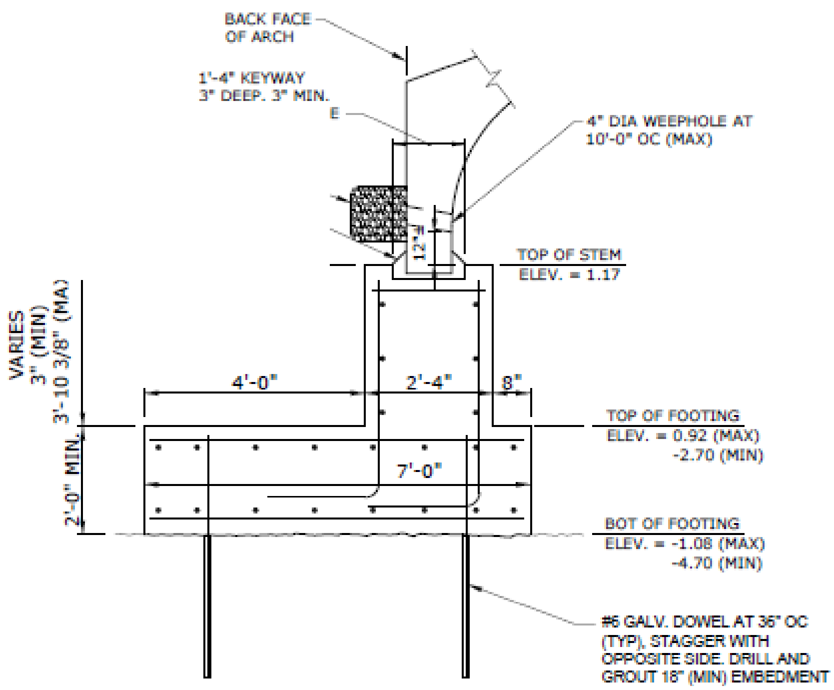
SKETCH



TYPICAL PRECAST ABUTMENT SECTION

1/2" = 1'-0"

$$V_m = \phi_m 0.07\lambda\sqrt{f'_m}b_w d$$
$$= (0.6)0.07(1.0)\sqrt{10}(190)(1500) = 38.0 \text{ kN}$$

Since $0.5V_m = 0.5(38.0) = 19.0$ kN < 150.0 kN $= V_f$, shear reinforcement is required at a spacing $s \le d/2 = 750$ mm, or 600 mm.

Try 10M single-legged stirrups, f_y *=400* MPa

The shear reinforcement must provide a resistance of at least
$V_s = V_f - V_m = 150.0 - 38.0 = 112.0$ kN

Recalling that
$V_s = \phi_s A_v f_y d / s = 0.85(100)(400)(1500) / s = 51(10)^6 / s$ N
That is, $V_s = 112(10)^3 = 51.0(10)^6/s$
$s = 51(10)^6/112(10)^3 = 455 \text{ mm} < 600 \text{ mm} = s_{max}$ OK

Therefore, use 10M single-legged stirrups @ 400 mm Ans.

Further from the support the spacing can be increased to the maximum of 600 mm at $V_s = 51(10)^6/600 = 85.0$ kN
That is, $V_r = V_s + V_m = 85.0 + 38.0 = 123.0$ kN

The minimum area of steel for this arrangement must be checked
$A_v = 0.35 b_w s / f_y = 0.35(190)(600)/400 = 99.75 < 100 \text{ mm}^2$ OK

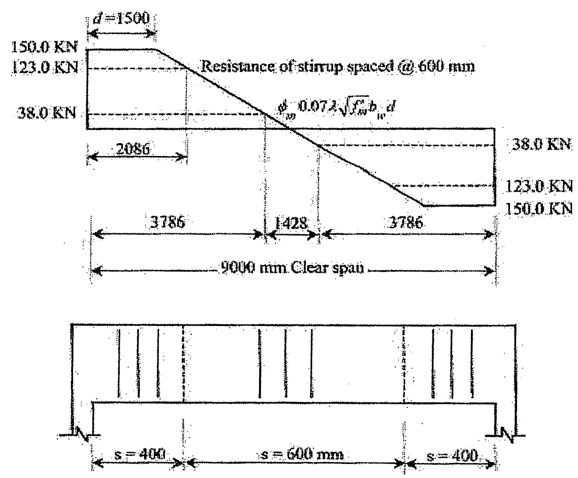


Figure 3-18 Shear Design of the Beam of Example 3-10

Shear reinforcement is theoretically no longer required at the point where $V_f = V_m = 38.0$ kN. However, it should be provided for a distance of at least d beyond that point.

Figure 3-18 shows a plot of the design shear force diagram that indicates the maximum shear force of 150.0 kN extending from the point of calculation to the support. Also shown are the values of V_r =123.0 kN corresponding to stirrups at 600 mm, and V_r = 38.0 kN corresponding to masonry shear resistance below which stirrups are not theoretically required. These values intersect the shear force diagram at distances that are easily calculated, or may be scaled if the diagram is accurately drawn to scale.

The arrangement of 10M single-legged stirrups shown in Figure 3-18 satisfies the shear requirements for the beam, and all that remains for the designer is to check that the stirrups are effectively anchored, as will be discussed in a later section.

3.5 SERVICEABILITY DESIGN

As noted in Section 1.5, the intent of the limit states design is to ensure that various limiting states are not exceeded during the reasonable life of the structure. These limiting states are *safety* (strength and stability) under specific overload, and *serviceability* (durability, stress level, cracking, deflections and vibration) under service loading. Now that safety has been covered through flexure and shear design, this section deals with serviceability requirements.

Durability is assured through selecting the appropriate materials to withstand the aggressiveness of the environment, sufficient cover on materials that can corrode, the appropriate selection and anchorage of connectors, proper construction and subsequent maintenance, all of which do not lend themselves to the type of analysis familiar to structural designers. Stress level, cracking, deflection and vibration are more quantifiable and, since they are being evaluated at service loads (linear elastic range), the analysis follows the principles of the theory of elasticity. The serviceability limit states of prime concern are deflection and crack control. Stresses at service load, where required, are readily calculated from the *transformed section analysis* discussed in the following sub-section, and vibration, as required, can be evaluated from the flexural stiffness derived from that analysis.

3.5.1 Deflection

Deflections under service load are normally calculated assuming that the materials are being stressed within the linear elastic range, and that the theory of elasticity may be applied. The deflection so calculated is of the general form

$$\delta = k\frac{wL^3}{EI} \qquad \text{Eq. 3-26}$$

where, w is the total uniform load on the span, L is the beam span, EI is the effective stiffness of the cross-section, and k is a factor that depends on the distribution of the load and on the support conditions. S304.1 Clause 11.4.1

requires the beam deflection to be checked if the span length exceeds 10 d in which case the immediate deflection due to service live load plus long-term deflection due to sustained load should not exceed $L/480$.

A characteristic of reinforced masonry, as of reinforced concrete, is that members in flexure generally crack in tension (an essential factor in assuring that the reinforcing steel works effectively), so there is the stiffness at the cracked sections to consider as well as the stiffness at the uncracked sections between cracks. The value of the modulus of elasticity of masonry is taken as $E_m = 850 f'_m \leq 20\,000$ MPa or is obtained by testing; and the effective moment of inertia, I_{eff}, is obtained from that of the cracked and uncracked sections, I_{cr} and I_o respectively.

Where the loading is of short duration, elastic analysis gives a reasonable estimate of deflection, but an estimate of deflection under sustained load should take the effects of creep and shrinkage into account. Compressive reinforcement is known to reduce both types of deformation and thus long-term deflection. The procedure adopted by S304.1 (Clause 11.4.4) to account for the additional deflection due to creep and shrinkage and the effect of the presence of compressive steel is to multiply the immediate deflection caused by the sustained load by the factor

$$\frac{S_1}{1+50\rho'} \qquad \text{Eq. 3-27}$$

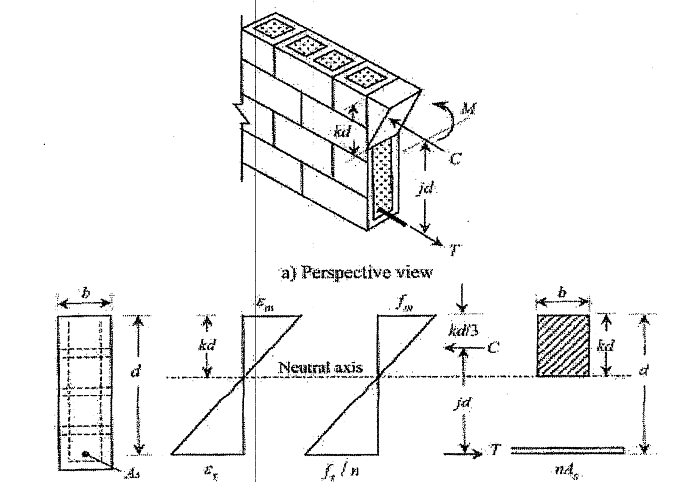
where, $\rho' = A'_s / bd$, as before, calculated at midspan for simple and continuous spans and at the support for cantilevers.

S_1 = time dependent factor that varies from 0.5 for loads of up to three months duration to 1.0 for loads applied for five years or more.

As was noted earlier, for tension reinforcement to be effective, tensile cracking must take place in the masonry and, once a crack starts, it is reasonable to assume that it extends to the neutral axis of the cross-section. Furthermore, if linear elastic behaviour is assumed at service loads, the situation shown in Figure 3-19 results.

Figure 3-19 shows a perspective view of a singly-reinforced multi-course masonry beam, its cross-section, the strain diagram, the stress diagram and the transformed section. Since plane sections remain plane during bending, the strain diagram is linear. It is reasonable to assume that the stress-strain relationships are linear at service loads, which leads to a linear stress diagram in which f_m is the maximum compressive stress in the masonry, f_s is the tensile stress in the steel and no tensile stress exists in the masonry.

The ratio $n = E_s / E_m$ is defined as the modular ratio, indicating that steel is n times as stiff as masonry. It is now convenient to consider the transformed section where the effective cracked section is converted to equivalent areas of masonry. In this case, the steel area is converted to an equivalent masonry area of nA_s which is stressed at f_s / n. Here, it can be verified that *area • stress = force* gives the force $f_s A_s$ at the level of steel.



a) Perspective view

b) Beam section c) Strain diagram d) Stress diagram e) Transformed section

Figure 3-19 Singly-Reinforced Beam

To determine the depth to the neutral axis, kd, moments of the areas can be taken about the neutral axis:

$$bkd(kd)/2 = nA_s(d-kd)$$

Then, dividing by bd^2 and substituting ρ for A_s / bd

$$0.5k^2 = n\rho(1-k)$$

The solution to this quadratic is

$$k = \sqrt{(n\rho)^2 + 2n\rho} - n\rho \qquad \text{Eq. 3-28}$$

Then $\quad I_{cr} = b(kd)^3/3 + nA_s(d-kd)^2 \qquad$ Eq. 3-29

If the designer wishes to calculate the stresses at service loads, this can be done as follows. Since the stress block is triangular, the resultant compressive force C is located at $kd/3$ and the moment arm jd is

$$jd = d - kd/3$$

The resultant compressive force is

$$C = 0.5 f_m bkd$$

and the tensile force

$$T = A_s f_s = \rho f_s bd$$

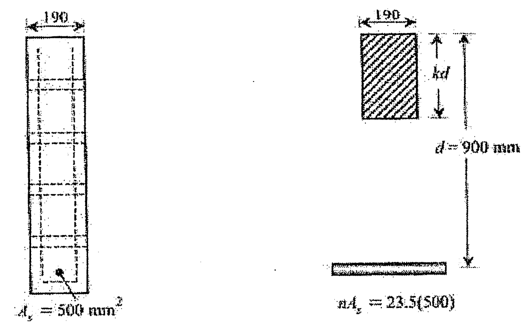
The moment M becomes

$$M = C\,jd = 0.5 f_m bkjd^2 = T\,jd = \rho f_s bjd^2$$

and the stresses in the masonry and the steel at service load are

$$f_m = \frac{2M}{bkjd^2} \qquad \text{Eq. 3-30}$$

$$f_s = \frac{M}{\rho bjd^2} \qquad \text{Eq. 3-31}$$



a) Beam section b) Transformed section

Figure 3-20 Masonry Beam of Example 3-11

EXAMPLE 3-11 *A 5-course 200 mm masonry beam is reinforced with one 25M bar at an effective depth of 900 mm. If f'_m = 10 MPa, what is the moment of inertia of the cracked section?*

Since E_m may be taken as $850 f'_m$

$$E_m = 850(10) = 8500 \text{ MPa} < 20{,}000 \text{ MPa} \qquad \underline{\text{OK}}$$

and $E_s = 200(10)^3$ MPa

Thus, the modular ratio

$$n = \frac{E_s}{E_m} = \frac{200(10)^3}{8.5(10)^3} = 23.5$$

Since A_s of one 25M bar is 500 mm², the transformed area of steel is

$$n\,A_s = 23.5(500) = 11{,}750 \text{ mm}^2$$

and taking moments of areas about the neutral axis (see Figure 3-20)

$$190kd(kd)/2 = 11{,}750(900-kd)$$

that is, $(kd)^2 + 123.7kd - 111.3(10)^3 = 0$

the solution to which is kd = 277 mm, and

$$I_{cr} = 190(277)^3/3 + 11{,}750(900-277)^2 = 5907(10)^6 \text{ mm}^4 \qquad \underline{\text{Ans.}}$$

Alternatively, Eq. 3-28 previously derived for k may be used.

$$\rho = A_s / bd = 500/[190(900)] = 0.00292$$

$$k = \sqrt{(n\rho)^2 + 2n\rho} - n\rho$$

$$= \sqrt{(23.5\text{x}0.00292) + 2(23.5)(0.00292)} - 23.5(0.00292) = 0.308$$

$$I_{cr} = b(kd)^3/3 + nA_s(d-kd)^2$$

$$= 190(0.308\times900)^3/3 + 23.5(500)[900-0.308(900)]^2$$

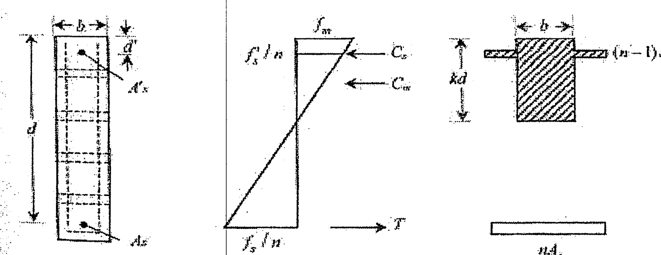
$$= 5907(10)^6 \text{ mm}^4 \qquad \underline{\text{Ans.}}$$

The moment of inertia of the cracked section of a doubly-reinforced beam such as that shown in Figure 3-21 may be obtained by a similar analysis to yield:

$$k = \sqrt{(n\rho + (n-1)\rho')^2 + 2[n\rho + (n-1)\rho' d'/d]} - [n\rho + (n-1)\rho'] \qquad \text{Eq. 3-32}$$

and,

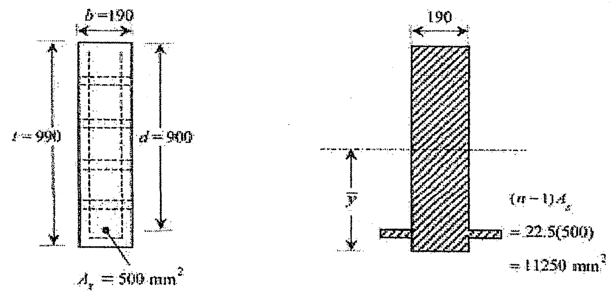
$$I_{cr} = b(kd)^3/3 + (n-1)A'_s(kd-d')^2 + nA_s(d-kd)^2 \qquad \text{Eq. 3-33}$$



a) Beam section b) Stress diagram c) Transformed section

Figure 3-21 Doubly-Reinforced Beam Section

The calculation of the uncracked moment of inertia, I_o, of reinforced sections can follow an analysis similar to that for cracked sections. However, for hand calculation, such an analysis can be unnecessarily tedious and reasonably simplifying assumptions may be made. One assumption is to use the moment of inertia of the gross-section, $I_g = bt^3/12$, in lieu of I_o, the uncracked moment of inertia of the transformed section including reinforcement. Since for I_g the presence of steel is not taken into account, $I_g < I_o$ and deflections will be slightly overestimated. A more reasonable assumption to make is that the centroid of the section lies at the mid-depth of the cross-section, and to calculate I_o from that point. These assumptions are illustrated in the following example.



a) Beam section b) Transformation section

Figure 3-22 Cross-Section of the Beam of Example 3-12

EXAMPLE 3-12 *A 5-course 200 mm masonry beam is reinforced with one 25M bar at an effective depth of 900 mm. If f'_m=10 MPa, find the moment of inertia of the gross-section, I_g, and the uncracked moment of inertia I_o.*

Gross moment of inertia, I_g,

$I_g = bt^3/12 = 190(990)^3/12 = 15.4(10)^9$ mm^4 <u>Ans.</u>

Uncracked moment of inertia, I_o

Referring to Figure 3-22 and taking moments of areas about the base, the centroid of the section is located at

$$\bar{y} = \frac{bt^2/2 + (n-1)A_s(t-d)}{bt + (n-1)A_s}$$

$$= \frac{190(990)^2/2 + (23.5-1)(500)(990-900)}{190(990) + (23.5-1)(500)} = 472 \text{ mm}$$

$I_o = bt^3/12 + bt(t/2 - \bar{y})^2 + (n-1)A_s[\bar{y} - (t-d)]^2$
$= 190(990)^3/12 + 190(990)(990/2 - 472)^2 +$
$(23.5 - 1)(500)[472 - (990 - 900)]^2$

$I_o = 17.1(10)^9$ mm^4 <u>Ans.</u>

As noted earlier, if the assumption is made that the centroid lies at the mid-depth of the section, that is, $\bar{y}$ = 990/2 = 495 mm, the calculation simplifies to

$I_o \approx bt^3/12 + (n-1)A_s(d - t/2)^2$
$\approx 190(990)^3/12 + (23.5-1)(500)(900-990/2)^2$

$I_o = 17.2(10)^9$ mm^4 <u>Ans.</u>

In this example I_g underestimates I_o by about 10%, and the approximate value is less than 1% different from the "true" value. Since deflection calculations are approximate at best, the approximation is justified.

Based on research, primarily stemming from work in reinforced concrete, the effective moment of inertia to be used in the calculation of deflection of reinforced masonry beams is obtained by combining the moments of inertia of cracked and uncracked sections as follows (Clause 11.4.3.2):

$$I_{eff} = (M_{cr}/M_a)^3 I_o + [1 - (M_{cr}/M_a)^3] I_{cr} < I_o \quad \text{Eq. 3-34}$$

where, M_{cr} = cracking moment = $(\phi_m f_t + f_{cs}) I_o / y_t$
f_t = flexural tensile strength (Table 5 of S304.1)
f_{cs} = unfactored axial load P/A_e
y_t = distance from centroid to extreme fibre in tension
M_a = maximum moment due to unfactored loads

and, if axial compression is also present in the beam, the bending moment resulting from the position of the axial load P relative to the centroid of the cracked section is included in the determination of I_{cr}. For the most part, of course, beams are not subjected to calculable or intentional axial load.

EXAMPLE 3-13 *A 5-course 200 mm hollow block beam is reinforced with one 25M bar at an effective depth of 900 mm and is fully grouted. The beam is simply-supported at its ends over a span of 6.0 m, and carries a service dead load (including self weight) of 10 kN/m and a live load of 10 kN/m. If f_y=400 MPa, f'_m=10 MPa, and type S mortar is used, estimate the maximum deflection.*

The maximum deflection of a uniformly-loaded beam simply supported over a span L is $\delta = 5wL^4/(384EI)$

and, for this beam
$w = w_D + w_L = 10.0 + 10.0 = 20.0$ kN/m
L = 6.0 m
$E_m = 850 f'_m = 8\,500$ MPa $< 20\,000$ MPa
$I_{eff} = (M_{cr}/M_a)^3 I_o + [1 - (M_{cr}/M_a)^3] I_{cr}$

In this expression, I_o and I_{cr} are obtained from the previous examples

$I_o = 17.1(10)^9$ mm^4

$I_{cr} = 5.91(10)^9$ mm^4

and $M_{cr} = (\phi_{m} f_t + f_{cs}) I_o / y_t$

$f_t = 0.65$ MPa (Table 5, S304.1), $\phi_m = 0.6$, $y_t = 472$ mm

and since there is no axial load $f_{cs} = 0.0$

$$M_{cr} = [0.6(0.65) + 0.0](17.1)(10)^9/472 = 14.13 \text{ kN-m}$$

and $M_a = (w_D + w_L)L^2/8 = 20.0(6.0)^2/8 = 90.0$ kN-m

Then
$$I_{eff} = (M_{cr}/M_a)^3 I_o + [1-(M_{cr}/M_a)^3] I_{cr}$$
$$= (14.13/90.0)^3(17.1)(10)^9 + [1 - (14.13/90.0)^3](5.91)(10)^9$$
$$= 5.95(10)^9 \text{ mm}^4$$

Recalling from Eq. 3-27 that allowance must be made for creep and, since there is no compression steel, and using $S_{\parallel}=1.0$ for a period longer than 5 years, the maximum expected deflection due to live load and sustained load, taken here as the dead load plus 50% of the live load, now becomes

$$\delta_{max} = 5[1+(0.5)1.0]w_L L^4/(384EI) + 5(1+1)w_D L^4/(384EI)$$
$$= 5(1.5)(10.0)(6000)^4/[384(8500)(5.95)(10)^9] +$$
$$5(2.0)(10.0)(6000)^4/[384(8500)(5.95)(10)^9] = 11.7 \text{ mm}$$

Therefore, maximum deflection = 11.7 mm Ans.

It is important that the designer keeps close track of units. In the final calculation above, units involving N and mm were used exclusively (note that 20.0 kN/m is also 20.0 N/mm) so that the final deflection is obtained in mm. It should be noted that deflection calculations are generally not as critical for beams as they are for slender walls, which are considered in detail in Chapter 5. The 11.7 mm deflection in the previous example amounts to only span/513.

3.5.2 Crack Control

Like reinforced concrete structures, masonry structures crack. Cracking may be the result of volume changes (shrinkage, creep and thermal effects), support movement, and flexural stresses. This can lead to corrosion of reinforcing steel and connectors and to the disintegration of the mortar due to freeze-thaw activity. Once mortar deterioration starts, moisture can enter more freely and the problem accelerates. Since excessive cracking can compromise strength due to corrosion and/or affect the aesthetics of masonry, a measure of control on crack width must be exercised. Cracking due to volume changes (mainly shrinkage) and support movement is an entirely different problem from cracking due to flexural stresses, one that can be controlled through the

judicious use of *movement joints*, which is the subject of other discussions. This section deals with the control of cracking resulting from flexural tension.

Based on substantial research in reinforced concrete, cracking is controlled by ensuring that the quantity z does not exceed 30 kN/mm for interior exposure and 25 kN/mm for exterior exposure (Clause 11.2.6.2 of S304.1).

$$z = f_s \sqrt[3]{d_c A}(10)^{-3} < 30 \text{ kN/mm for interior exposure} \quad \text{Eq. 3-35}$$
$$< 25 \text{ kN/mm for exterior exposure}$$

In Eq. 3-35, f_s is the stress in the reinforcing steel, which can be computed directly from the analysis presented in Section 3.5.1 (see Eq. 3-31), or may be assumed as 60% f_y; d_c is the cover on the tension steel measured from the centroid of the outermost bar; and A is the area of masonry surrounding the tensile reinforcement, having the same centroid as the tensile reinforcement and divided by the number of bars. This is illustrated in Figure 3-23.

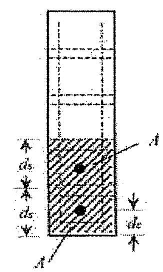


Figure 3-23 Parameters of the Crack Control Expression

These requirements have been taken directly from CSA Standard A23.3: *Design of Concrete Structures*, where the corresponding crack widths are in the order of 0.40 mm and 0.33 mm for interior and exterior exposures, respectively. S304.1 notes that in especially aggressive environments, such as in coastal regions subjected to high winds and rain, this requirement may not be sufficiently restrictive. Notwithstanding the requirements of S304.1, the reader is advised that reinforced masonry is not reinforced concrete. The maximum interior crack width limit of 0.40 mm (largely a cosmetic factor) could easily be 0.50 mm, whereas in particularly aggressive environments (wind, rain, freeze-thaw cycles) the 0.33 mm constraint should perhaps be reduced to 0.25 mm.

EXAMPLE 3-14 *Considering control of cracking, is the masonry beam of the previous example adequate for an interior use?*

Referring to Figure 3-24(a),

$d_c = 90$ mm

$A = 190(180) = 34.2(10)^3$ mm^2

$f_s = 0.6 f_y = 0.6(400) = 240$ MPa

$$z = f_s\sqrt[3]{d_c A}(10)^{-3} = 240\sqrt[3]{90(34.2)(10)^3}(10)^{-3}$$

$$z = 34.9 \text{ kN/mm} > 30.0 \text{ kN/mm}$$

NG

Therefore, the beam is not suitable for interior use. Ans.

To resolve this situation, the designer may choose to select two 20M bars (A_s= 2(300)= 600 mm^2), as shown in Figure 3-24(b), instead of one 25M (A_s=500 mm^2), in which case the steel stress may be reduced to 5/6 of its former value, and A is divided by the number of bars.

That is, $f_s = 5(240)/6 = 200$ MPa.
In that case

$$z = 200\sqrt[3]{90(34.2/2)(10)^3}(10)^{-3} = 23.1 \text{ kN/mm} < 30 \text{ kN/mm}$$

The beam now becomes suitable for interior use. Ans.

The more rigorous approach to determine the tensile stress in the steel could have been used by applying Eq. 3-31. From Example 3-11,

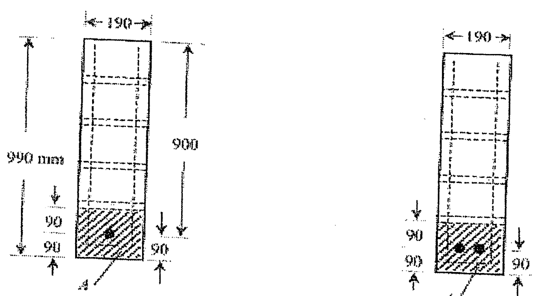
$$n = \frac{200{,}000}{8{,}500} = 23.5$$

$$\rho = \frac{A_s}{bd} = 0.00292 \text{ and } k = 0.308$$

$$j = (1 - k/3) = 0.9$$

and from Example 3-13,
$M = M_a = 90$ kN-m

$$f_s = \frac{M}{\rho b j d^2} = \frac{M}{A_s j d} = \frac{90(10)^6}{500(0.9)(900)} = 222 \text{ MPa}$$



a) One bar b) Two bars

Figure 3-24 Cross-Section of the Beam of Example 3-14

It is clear from the previous calculations that the 60% f_y = 240 MPa is a very reasonable and slightly conservative estimate of f_s. For hand calculation, the use of 60% f_y would be sufficiently accurate and the complexity of calculating f_s from Eq. 3-31 can generally be avoided.

One of the difficulties with applying the S304.1 requirements is that the basic principles supporting it are rather obscure. The following explanation of crack width development is intended to make the mechanism of crack formation in reinforced masonry more understandable.

The width of flexural cracks depends on the tensile stress in the reinforcement, on the location of the bars and on the crack spacing. In reinforced concrete, the concrete is continuous and cracks form at the weak spots, generally at 100 mm to 200 mm spacing. In masonry, on the other hand, crack spacing is normally controlled by the location of the mortar joints, these being the weakest tensile component. Figure 3-25, for example, shows two alternative arrangements for the bottom course of a masonry beam spanning an opening in a wall. On side (a) 200 mm high by 400 mm long bond beam units are used and cracking may be expected to start at 400 mm intervals, although at higher loads the influence of the second course may result in an eventual crack spacing of 200 mm. Side (b) illustrates the use of 400 mm high by 200 mm long lintel blocks which will lead to a 200 mm crack spacing. Flexural cracks in side (a) are likely to be about twice as wide as cracks in side (b). Generally, for outdoor exposures the use of 200 mm long lintel blocks is preferred.

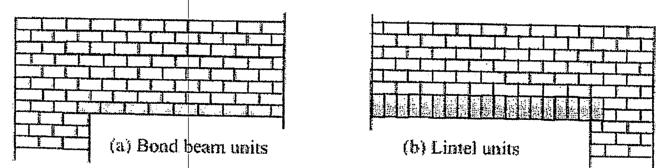


Figure 3-25 Masonry Beams Spanning an Opening

The masonry, being bonded to the steel bars, will undergo an average tensile strain equal to that in the reinforcement. As the masonry can sustain very little tensile strain, the crack width at the level of the reinforcement will be only slightly less than the steel strain multiplied by the crack spacing. Plane sections remaining plane, the maximum crack width is related to the location of the steel relative to the neutral axis, and to the amount of cover, as shown in Figure 3-26.

Crack width at the effective depth is

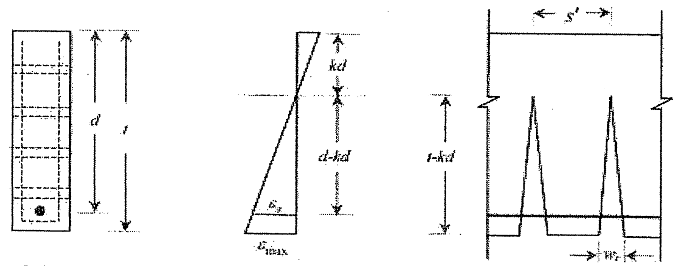
$$\varepsilon_s s' = f_s s' / E_s$$

where, s' = crack spacing.

The maximum crack width, w_c, at the bottom of the beam becomes

$$w_c = \frac{f_s s'(t - kd)}{E_s(d - kd)}$$

and this equation leads to a reasonable, although somewhat overestimated, value of the crack width. The equation also indicates the influence of crack spacing (that is, the head joint spacing) on crack width.



a) Cross section b) Strain distribution c) Idealized cracks

Figure 3-26 Flexural Cracking of a Masonry Beam

Given the maximum allowable stresses in the reinforcement and the head joint spacing, the maximum expected crack width at the level of the reinforcement can be readily calculated.

For example, if $f_s = 0.6 f_y = 0.6(400) = 240$ MPa and head joints are spaced at 200 mm, the maximum expected crack width at the steel location is

$$f_s s' / E_s = \frac{240(200)}{200000} = 0.24 \text{ mm}$$

The crack control provided by satisfying the limits of the parameter z may not be sufficient to control cracking in masonry beams having a depth exceeding 600 mm. Therefore, Clause 11.2.6.3 requires that for such relatively deep beams, an intermediate reinforcement at 400 mm vertical spacing be used. A single bar 15M is required for beams less than 240 mm in width whereas two 15M bars are required for wider beams.

3.6 REINFORCEMENT REQUIREMENTS

Reinforced masonry is effective only if the reinforcement is bonded to the grout, and the grout to the masonry units. If grouting is properly carried out, the absorption by the masonry units and the large area of contact ensures an adequate grout-to-unit bond. On the other hand, the bond between reinforcement and grout is more critical, because the area of contact is comparatively small.

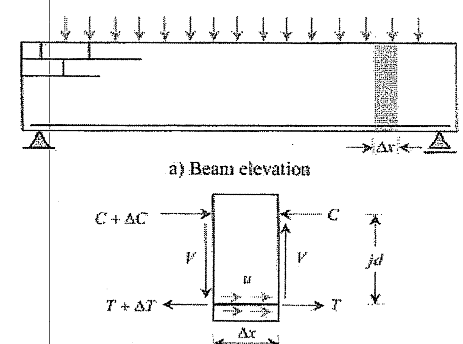
A shear-type *bond stress* acting along the surface of a reinforcing bar is the mechanism whereby force is transferred from grout to the bar. If the resistance to bond stress is exceeded, slip between bar and grout takes place and the reinforcing steel loses its effectiveness. Although standard deformations on the surface of normal reinforcement provide substantial resistance through the mechanical interlocking of bars with grout, the bond must be checked.

The question of bond in beam design is largely one of performing an analytical design check. In general, the reinforcement will have been selected during the design for bending or shear, then the bar sizes and anchorage lengths are checked to ensure that the required development lengths are available. Should they not be present, then a larger number of smaller diameter bars are selected, or greater anchorage lengths, or hooks, are provided. Section 12 of S304.1, *Reinforcement: Details, Development and Splices* covers bond and development requirements, which are, for the most part, self-explanatory practical rules. A detailed treatment of this section is beyond the scope of this book.

There are two basic ways to consider bond. One is to recognize that localized bond stress is directly related to the rate of increase of the tensile force in the reinforcement of a flexural member. This is referred to as *flexural bond stress*. The other is to assume that the bond stress is uniform along the bar and to ensure that the bar has sufficient embedment length to develop the required strength. This length is referred to as the *development length*, l_d. The anchorage of the bar can be further improved through the provision of hooks at the ends of the bars.

3.6.1 Flexural Bond Stress

Figure 3-27(a) shows a beam subjected to transverse loads, and therefore to bending moments and shear forces. The forces acting on a small element of length Δx are shown in Figure 3-27(b). The change in the reinforcing bar force from a value of T to $(T + \Delta T)$ must be transmitted by the bond stress, u, acting on the contact area between the bar and grout.



a) Beam elevation

b) Forces acting on element Δx

Figure 3-27 Mechanics of Bond Stress

A summation of forces along the bar gives

$$(T + \Delta T) - T = \Delta T = u \sum o \Delta x$$

Where $\sum o$ is the summation of bar perimeters. From a consideration of equilibrium of moments,

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PRELIMINARY RETAINING WALL CALCULATIONS

INDEX OF SHEETS

APPENDIX

REFERENCES

1 2012 AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS, 6th EDITION, WITH INTERIM REVISIONS

2 2013 MASSDOT BRIDGE DESIGN MANUAL

3 CIVIL ENGINEERING REFERENCE MANUAL (LINDEBURG) 15TH EDITION

4 2005 HATZINIKOLAS & KORANY MASONRY DESIGN TEXTBOOK

5 GEOTECHNICAL EVALUATION REPORT (SEPTEMBER 26, 2018)

6 HYDRAULIC REPORT (OCTOBER 2018)

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ASSUMPTIONS

1 ASSUME SOLID CONCRETE AND GRANITE GRAVITY WALL

METHODOLOGY

1 DESIGN IN ACCORDANCE WITH AASHTO LRFD REFERENCE 1

MATERIALS

CONCRETE:	FOOTING STRENGTH, f'c @ 28 DAYS	5000	PSI
	STEM STRENGTH, f'c @ 28 DAYS	5000	PSI
	UNIT WEIGHT, γ_c	0.150	KCF
REINFORCING:	YIELD STRENGTH, Fy	60	KSI
	MODULUS OF ELASTICITY, Es	29000	KSI
	CLEAR COVER (DIRECT EXPOSURE TO SALT WATER, AASHTO TABLE 5.10.1-1)	4.00	IN
BACKFILL:	ASSUME GRAVEL BORROW FOR BRIDGE FOUNDATION (MASSDOT M1.03.0, TYPE B) **OR** EXISTING GRANITE WALL		
	SOIL UNIT WEIGHT, γ_S (REF 2, 3.1.6)	0.120	KCF
	INTERNAL FRICTION ANGLE, ϕ_f (GEOTECH. RECOMMENDATIONS)	32	deg.
	AT-REST EARTH PRESSURE COEFFICIENT, K_0 (GEOTECH. RECOMMENDATIONS)	0.470	
	BACKFILL ANGLE, β	0	deg.
	MIN. DEPTH OF COVER FOR FROST PROTECTION - N/A ON LEDGE	0.00	FT
	MIN. DEPTH OF COVER FOR SCOUR PROTECTION - N/A ON LEDGE	0.00	FT
SUBGRADE:	ASSUME BEDROCK (GEOTECH. RECOMMENDATIONS)		
	NOMINAL BEARING RESISTANCE, q_n (GEOTECH. RECOMMENDATIONS)	200.00	KSF
	BEARING RESISTANCE FACTOR, ϕ_b (GEOTECH. RECOMMENDATIONS)	0.45	
	SLIDING RESISTANCE FACTOR, ϕ_t (AASHTO 11.5.5 & TABLE 11.5.7-1)	1.0	
FAÇADE:	FORMLINERS		
	UNIT WEIGHT, Ɣfacade (CONCRETE)	0.150	KCF
SEISMIC	ADJUSTED PEAK GROUND ACCELERATION (GEOTECH. RECOMMENDATIONS), A_s	0.103	g

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WALL GEOMETRY

H_{FOOT}	FOOTING THICKNESS		2.00	FT
H_{STEM}	STEM HEIGHT		13.00	FT
H_{BW}	BACKWALL HEIGHT		0.00	FT
H	TOTAL WALL HEIGHT	ELEV. 9.9 - ELEV. -4.9	15.00	FT
B_{TOE}	TOE WIDTH		2.00	FT
B_{HEEL}	HEEL WIDTH		6.00	FT
B_{STEM}	STEM WIDTH		2.00	FT
B_{FOOT}	TOTAL FOOTING WIDTH		10.00	FT
B_{FACADE}	FAÇADE WIDTH OVER TOE		0.167	FT
L_{WALL}	TOTAL WALL LENGTH		30.00	FT
e_{BRG}	DIST. CL APPLIED LOAD BEARING TO FACE OF STEM		0.00	FT
B_{BW}	BACKWALL WIDTH		0.00	FT

DEAD LOADS (DC) (3.5.1)

DETERMINE LOADS PER 1-FOOT LENGTH OF WALL

MOMENT ARMS DETERMINED FROM THE BOTTOM, TOE, OF THE FOOTING

APPLIED DEAD LOADS

NONE

NONE		0.00	K
$DC_{APPLIED}$	(TOTAL WEIGHT) / (L_{WALL})	0.00	K/FT

TOTAL DC FROM APPLIED LOADS, $DC_{APPLIED}$	**0.00**	**K/FT**
MOMENT ARM = $B_{TOE} + e_{BRG}$	**2.00**	**FT**

SELF-WEIGHT DEAD LOADS

FOOTING

$DC_{FOOT} = (B_{FOOT})(H_{FOOT})(\gamma c)$	**3.00**	**K/FT**
MOMENT ARM = $(0.5)B_{FOOT}$	**5.00**	**FT**

STEM

$DC_{STEM} = (B_{STEM})(H_{STEM})(\gamma c)$	**3.90**	**K/FT**
MOMENT ARM = $B_{TOE} + (0.5)B_{STEM}$	**3.00**	**FT**

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BACKWALL

$DC_{BW} = (B_{BW})(H_{BW})(\gamma c)$	**0.00**	**K/FT**
MOMENT ARM = $B_{TOE} + B_{STEM} - (0.5)B_{BW}$	**4.00**	**FT**

FAÇADE

$DC_{FAC} = (B_{FACADE})(H_{STEM})(\gamma_{FACADE})$	**0.33**	**K/FT**
MOMENT ARM = $B_{TOE} - (0.5)B_{FACADE}$	**1.92**	**FT**

WIND LOAD ON STRUCTURE (WS) (3.8.1.2)

FORCES APPLIED DIRECTLY TO WALL (3.8.1.2.3)

WIND PRESSURE (3.8.1.2.3)	0.040	KSF
D_E MINIMUM DEPTH OF EARTH COVER (AASHTO 3.6.2.2) (FROST/SCOUR)	0.00	FT
EXPOSED HEIGHT ($H_{STEM} + H_{FOOT} - D_E$)	15	FT
WS_{WALL} - WIND FORCE DIRECTLY APPLIED TO WALL	**0.6**	**K/FT**
MOMENT ARM = $H_{FOOT} + H_{STEM} - 0.5(H_{FOOT} + H_{STEM} - D_E)$	**7.50**	**FT**

EARTH PRESSURE (EH) (3.11.5)

AT-REST EARTH PRESSURE COEFFICIENT, K_0	0.470	
SOIL UNIT WEIGHT, γ_S	0.120	KCF
HORIZONTAL EARTH PRESSURE RESULTANT, $EH = 0.5K_a\gamma_S H^2$ (3.11.5.1-1)	**6.35**	K/FT
MOMENT ARM = (1/3)H	**5.00**	**FT**

LIVE LOAD SURCHARGE (LS) (3.11.6.4)

H TOTAL WALL HEIGHT	15.0	FT
h_{eq} EQUIVALENT HEIGHT OF SOIL (TABLE 3.11.6.4.1)	2.50	FT

Abutment Height (ft)	h_{eq} (ft)
5.0	4.0
10.0	3.0
≥20.0	2.0

Δ_p CONSTANT HORIZONTAL LS EARTH PRESSURE = $k\ \gamma_S\ h_{eq}$ (3.11.6.4-1)	0.14	KSF
LS LIVE LOAD SURCHARGE = (Δ_p) (H)	**2.12**	**k/ft**
MOMENT ARM = (1/2)H	**7.50**	**FT**

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EARTHQUAKE LOAD (EQ) (3.10)

11.5.4.2—Extreme Event I, No Analysis

A seismic design shall not be considered mandatory for walls located in Seismic Zones 1 through 3, or for walls at sites where the site adjusted peak ground acceleration, A_s, is less than or equal to 0.4g, unless one or more of the following is true:

- Liquefaction induced lateral spreading or slope failure, or seismically induced slope failure, due to the presence of sensitive clays that lose strength during the seismic shaking, may impact the stability of the wall for the design earthquake.
- The wall supports another structure that is required, based on the applicable design code or specification for the supported structure, to be designed for seismic loading and poor seismic performance of the wall could impact the seismic performance of that structure.

The no-seismic-analysis option should be limited to internal and external seismic stability design of the wall. If the wall is part of a bigger slope, overall seismic stability of the wall and slope combination should still be evaluated.

These no-seismic-analysis provisions shall not be considered applicable to walls functioning as support piers for bridges.

ADJUSTED PEAK GROUND ACCELERATION (GEOTECH. RECOMMENDATIONS), A_s	0.103	g
COMPARE TO MIN. NEEDED TO REQUIRE SEISMIC ANALYSIS	0.400	g

As BELOW THRESHOLD, NEGLECT EQ LOAD

VERTICAL PRESSURE FROM DEAD LOAD OF EARTH FILL (EV) (3.5.1)

$H_{soilheel}$	SOIL HEIGHT ABOVE FOOTING HEEL = $H - H_{FOOT}$	13.00	FT
$H_{soiltoe}$	SOIL HEIGHT ABOVE FOOTING TOE	0.00	FT
EV_{HEEL}	SELF WEIGHT OF SOIL ABOVE FOOTING HEEL = $H_{soilheel}\, B_{HEEL}\, \gamma_S$	**9.36**	**K/FT**
MOMENT ARM = $B_{TOE} + B_{STEM} + (0.5)B_{HEEL}$		**7.00**	**FT**
EV_{TOE}	SELF WEIGHT OF SOIL ABOVE FOOTING TOE = $H_{soiltoe}\, B_{TOE}\, \gamma_S$	**0.00**	**K/FT**
MOMENT ARM = $(0.5)B_{TOE}$		**1.00**	**FT**

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VEHICULAR COLLISION LOAD (CT) (3.6.5)

2 KIPS PER LINEAR FOOT, APPLIED AT A DISTANCE EQUAL TO THE HEIGHT OF THE RAILING/BARRIER (MASSDOT 3.3.2.4)

APPLIES TO EXTREME EVENT II LIMIT STATE

$H_{BARRIER}$	HEIGHT OF BARRIER	3.50	FT
CT	BEHICULAR COLLISION FORCE	**2.00**	**KLF**
MOMENT ARM = $H_{BARRIER}$ + H		**18.50**	**FT**

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SUMMARY OF LOADS

LOAD		FORCE (K/FT)	ARM (FT)	MOMENT EFFECT (K-FT/FT)		
DC	(APPLIED)	0.00	2.00	0.00	RESISTING (+)	
DC	(FOOT)	3.00	5.00	15.00	RESISTING (+)	
DC	(STEM)	3.90	3.00	11.70	RESISTING (+)	
DC	(BW)	0.00	1.92	0.00	RESISTING (+)	
DC	(FAÇADE)	0.33	1.92	0.62	RESISTING (+)	
EV	(HEEL)	9.36	7.00	65.52	RESISTING (+)	
EV	(TOE)	0.00	1.00	0.00	RESISTING (+)	(ZERO FOR MINIMUM)
EH	(HORIZ)	6.35	5.00	31.73	OVERTURNING (-)	
LS		2.12	7.50	15.86	OVERTURNING (-)	(ZERO FOR MINIMUM)
WS	(WALL)	0.60	7.50	4.50	OVERTURNING (-)	(ZERO FOR MINIMUM)
CT		2.00	18.50	37.00	OVERTURNING (-)	(ZERO FOR MINIMUM)

LOAD COMBINATIONS AND LOAD FACTORS (TABLES 3.4.1-1 & 3.4.1-2)

LIMIT STATES	DC		EH		EV		LS	WS	CT
	MAX	MIN	MAX	MIN	MAX	MIN			
STR. I	1.25	0.90	1.50	0.90	1.35	1.00	1.75	-	-
STR. II	1.25	0.90	1.50	0.90	1.35	1.00	1.35	-	-
STR. III	1.25	0.90	1.50	0.90	1.35	1.00	-	1.40	-
STR. IV	1.50	0.90	1.50	0.90	1.35	1.00	-	-	-
STR. V	1.25	0.90	1.50	0.90	1.35	1.00	1.35	0.40	-
EXTR. I	1.00	1.00	1.00	1.00	1.00	1.00	0.50	-	-
EXTR. II	1.00	1.00	1.00	1.00	1.00	1.00	0.50	-	1.00
SER. I	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.30	-
SER. II	1.00	1.00	1.00	1.00	1.00	1.00	1.30	-	-
SER. III	1.00	1.00	1.00	1.00	1.00	1.00	0.80	-	-
SER. IV	1.00	1.00	1.00	1.00	1.00	1.00	-	0.70	-

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FACTORED MOMENTS AND FORCES

	{a}	{b}	{c}	{d}	{e}	{f}	{g}	{h}
LIMIT STATES	**MAX. DRIVING MOMENT (K-FT/FT)**	**MIN. DRIVING MOMENT (K-FT/FT)**	**MAX. RESISTING MOMENT (K-FT/FT)**	**MIN. RESISTING MOMENT (K-FT/FT)**	**MAX. VERTICAL FORCE (K/FT)**	**MIN. VERTICAL FORCE (K/FT)**	**MAX. HORIZONTAL FORCE (K/FT)**	**MIN. HORIZONTAL FORCE (K/FT)**
STR. I	75.3	28.6	122.6	90.1	21.7	15.9	9.5	5.7
STR. II	N/A - NO OWNER-SPECIFIED SPECIAL DESIGN VEHICLES (3.4.1)							
STR. III	53.9	28.6	122.6	90.1	21.7	15.9	10.4	5.7
STR. IV	47.6	28.6	129.4	90.1	23.5	15.9	9.5	5.7
STR. V	70.8	28.6	122.6	90.1	21.7	15.9	12.6	5.7
EXTR. I	N/A (11.5.4.2)							
EXTR. II	76.7	31.7	92.8	92.8	16.6	16.6	9.4	6.3
SER. I	48.9	31.7	92.8	92.8	16.6	16.6	8.6	6.3
SER. II	N/A - NOT A STEEL STRUCTURE (3.4.1)							
SER. III	N/A - NOT A PRESTRESSED CONCRETE STRUCTURE (3.4.1)							
SER. IV								

STRENGTH LIMIT STATES (11.5.3)

OVERTURNING & ECCENTRICITY LIMITS (11.6.3.3)

X_i RESULTANT VERT. FORCE LOCATION FROM TOE

FOUNDATON ON **ROCK**

MIN. $X_i = (B_{FOOT} / 20)$ 0.50 FT

MAX. $X_i = (B_{FOOT} - (B_{FOOT} / 20))$ 9.50 FT

11.6.3.3—Eccentricity Limits

For foundations on soil, the location of the resultant of the reaction forces shall be within the middle two-thirds of the base width.

For foundations on rock, the location of the resultant of the reaction forces shall be within the middle nine-tenths of the base width.

CASE 1 - MIN. VERT & MAX. HORIZ. $X_1 = \dfrac{\{MIN.\ RESIST.\ MOM\} - \{MAX.\ DRIV.\ MOM.\}}{\{MIN.\ VERT\ FORCE\}}$ $\dfrac{\{d\} - \{a\}}{\{f\}}$

CASE 2 - MAX. VERT & MAX. HORIZ. $X_2 = \dfrac{\{MAX.\ RESIST.\ MOM\} - \{MAX.\ DRIV.\ MOM.\}}{\{MAX.\ VERT\ FORCE\}}$ $\dfrac{\{c\} - \{a\}}{\{e\}}$

CASE 3 - MAX. VERT & MIN. HORIZ. $X_3 = \dfrac{\{MAX.\ RESIST.\ MOM\} - \{MIN.\ DRIV.\ MOM.\}}{\{MAX.\ VERT\ FORCE\}}$ $\dfrac{\{c\} - \{b\}}{\{e\}}$

CASE 4 - MIN. VERT & MIN. HORIZ. $X_4 = \dfrac{\{MIN.\ RESIST.\ MOM\} - \{MIN.\ DRIV.\ MOM.\}}{\{MIN.\ VERT\ FORCE\}}$ $\dfrac{\{d\} - \{b\}}{\{f\}}$

REFER TO TABLE BELOW FOR X_i ANALYSIS

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LATERAL SLIDING (11.6.3.6)

NOTE: CONSIDER DOWELS INTO ROCK OR SOCKETING FOOTING FOR FINAL DESIGN

ϕR_n FACTORED SLIDING RESISTANCE = ϕ_t V tan δ (10.6.3.4-1)

ϕ_t SLIDING RESISTANCE FACTOR 1.00

V TOTAL MIN. VERTICAL FORCE = COLUMN {f}

tan δ COEFFICIENT OF FRICTION (SLIDING) (GEOTECH RECOMMENDATIONS) 0.70

FS, SLIDING FACTOR OF SAFETY = $\frac{(\phi_t)\ (\tan\delta)\ \{\text{MIN. VERT. FORCE}\}}{\{\text{MAX. HORIZ. FORCE}\}}$ = $\frac{(\phi t)\ (\tan\delta)\ \{f\}}{\{g\}}$

FOR LRFD ANALYSIS, VERIFY $FS_{SLIDING} \geq 1.0$

REFER TO TABLE BELOW FOR $FS_{SLIDING}$ ANALYSIS

	OVERTURNING				SLIDING
LIMIT STATES	**X_1 (FT.)**	**X_2 (FT.)**	**X_3 (FT.)**	**X_4 (FT.)**	**FS**
STR. I	***0.93***	2.18	***4.34***	3.88	1.17
STR. II	N/A				
STR. III	2.28	3.17	***4.34***	3.88	1.07
STR. IV	2.68	3.49	4.30	3.88	1.17
STR. V	1.22	2.39	***4.34***	3.88	***0.88***
EXTR. I	N/A				
EXTR. II	0.98	0.98	3.69	3.69	1.23
SER. I	2.65	2.65	3.69	3.69	1.34
SER. II	N/A				
SER. III	N/A				
SER. IV					
ALLOW MIN.	0.50				1.00
ALLOW MAX.	9.50				-
OK?	**OK**				**NO GOOD**

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BEARING RESISTANCE (11.6.3.2) FOUNDATON ON **ROCK**

IF RESULTANT IS WITHIN THE MIDDLE 1/3 OF THE BASE:

$\sigma_{v,max}$ LINEARLY DISTRIBUTED, MAX APPLIED VERTICAL STRESS = (∑V / B) (1 + 6e/B) (11.6.3.2-2)

$\sigma_{v,min}$ LINEARLY DISTRIBUTED, MIN APPLIED VERTICAL STRESS = (∑V / B) (1 - 6e/B) (11.6.3.2-3)

IF RESULTANT IS OUTSIDE THE MIDDLE 1/3 OF THE BASE:

$\sigma_{v,max}$ LINEARLY DISTRIBUTED, MAX APPLIED VERTICAL STRESS = 2∑V / 3[(B/2)-e] (11.6.3.2-4)

$\sigma_{v,min}$ LINEARLY DISTRIBUTED, MIN APPLIED VERTICAL STRESS = 0 (11.6.3.2-5)

V APPLIED VERTICAL FORCE = COLUMN {e} OR {f}

X_i RESULTANT VERT. FORCE LOCATION FROM TOE.

e_i RESULTANT VERT. FORCE LOCATION FROM CENTER OF FOOTING = |(0.5) (B_{FOOT}) - (X_i)|

RESULTANT IS OUTSIDE MIDDLE 1/3 OF BASE IF e ≤ B/6 = 1.667 FT

RESULTANT IS WITHIN MIDDLE 1/3 OF BASE IF e > B/6 = 1.667 FT

$\phi_b q_n$ NET ALLOWABLE BEARING PRESSURE (REFER TO SHEET 2) = 0.45 x 200.00 KSF = 90 KSF

REFER TO TABLE BELOW FOR σ_v ANALYSIS

LIMIT STATES	BEARING											
	e_1 (FT.)	e_2 (FT.)	e_3 (FT.)	e_4 (FT.)	$\sigma_{vmax,1}$ (KSF)	$\sigma_{vmin,1}$ (KSF)	$\sigma_{vmax,2}$ (KSF)	$\sigma_{vmin,2}$ (KSF)	$\sigma_{vmax,3}$ (KSF)	$\sigma_{vmin,3}$ (KSF)	$\sigma_{vmax,4}$ (KSF)	$\sigma_{vmin,4}$ (KSF)
STR. I	4.07	2.82	0.66	1.12	***15.52***	0.00	6.62	0.00	3.02	1.31	3.62	0.71
STR. II	N/A											
STR. III	2.72	1.83	0.66	1.12	6.33	0.00	4.55	0.00	3.02	1.31	3.62	0.71
STR. IV	2.32	1.51	0.70	1.12	5.84	0.00	4.48	0.22	3.34	1.36	3.92	0.77
STR. V	3.78	2.61	0.66	1.12	11.87	0.00	6.04	0.00	3.02	1.31	3.62	0.71
EXTR. I	N/A											
EXTR. II	4.02	4.02	1.31	1.31	11.33	0.00	11.33	0.00	2.97	0.35	2.97	0.35
SER. I	2.35	2.35	1.31	1.31	4.18	0.00	4.18	0.00	2.97	0.35	2.97	0.35
SER. II	N/A											
SER. III	N/A											
SER. IV												
ALLOW MIN.	-				-							
ALLOW MAX.	-				90.00							
OK?	-				**OK**							

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LOSS OF BASE CONTACT DUE TO ECCENTRIC LOADING

11.6.3.4—Subsurface Erosion

For walls constructed along rivers and streams, scour of foundation materials shall be evaluated during design, as specified in Article 2.6.4.4.2. Where potential problem conditions are anticipated, adequate protective measures shall be incorporated in the design.

10.6.1.2—Bearing Depth

Where the potential for scour, erosion or undermining exists, spread footings shall be located to bear below the maximum anticipated depth of scour, erosion, or undermining as specified in Article 2.6.4.4.

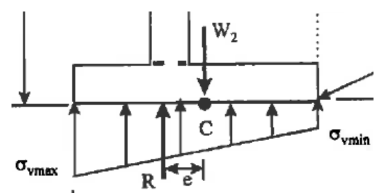
REFER TO SCOUR MEMORANDUM IN APPENDIX C.

DEPTH OF SCOUR POTENTIAL:	0	FT
MIN. DEPTH OF EARTH COVER (D_E)	0	FT
CHECK: D_E > SCOUR DEPTH?	**OK**	

SAFETY AGAINST STRUCTURAL FAILURE (11.6.4)

DESIGN REINFORCING STEEL OF INDIVIDUAL WALL ELEMENTS TO PREVENT STRUCTURAL FAILURE FOR MAXIMUM DESIGN EFFECTS

FOR FOOTING DESIGN, DETERMINE WORST-CASE CONTACT PRESSURE.



INTERPOLATE BETWEEN σ_{vmax} AT TOE AND σ_{vmin} AT HEEL:

$\sigma_{v,FF}$	VERTICAL STRESS AT BACK FACE OF STEM	$\sigma_{vmax} - [B_{TOE} (\sigma_{vmax} - \sigma_{vmin}) / B_{FOOT}]$
$\sigma_{v,BF}$	VERTICAL STRESS AT FRONT FACE OF STEM	$\sigma_{vmin} + [B_{HEEL} (\sigma_{vmax} - \sigma_{vmin}) / B_{FOOT}]$

CENTROID FOR RIGHT-ANGLED TRAPEZOID: $$\bar{y} = \frac{b+2a}{3(a+b)}h.$$

CALCULATE MAX RESULTANT SHEAR AND MOMENT ON TOE AND HEEL:

$V_{U, TOE}$	FACTORED DESIGN SHEAR APPLIED TO TOE = $0.5(\sigma_{vmax} + \sigma_{v,FF}) (B_{TOE})$
$M_{U, TOE}$	FACTORED DESIGN MOMENT APPLIED TO TOE = $(V_{u,TOE}) (\sigma_{v,FF} + 2\,\sigma_{vmax}) (B_{TOE}) / (3\,(\sigma_{v,FF} + \sigma_{vmax}))$
$V_{U, HEEL}$	FACTORED DESIGN SHEAR APPLIED TO HEEL = $0.5(\sigma_{vmin} + \sigma_{v,BF}) (B_{HEEL})$
$M_{U, HEEL}$	FACTORED DESIGN MOMENT APPLIED TO HEEL = $(V_{u,HEEL}) (\sigma_{vmin} + 2\,\sigma_{v,BF})$ (BHEEL) / (3 $(\sigma_{v,BF} + \sigma_{vmin})$)

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LIMIT STATES	$\sigma_{vmax,1}$ (KSF)	$\sigma_{vFF,1}$ (KSF)	$\sigma_{vBF,1}$ (KSF)	$\sigma_{vmin,1}$ (KSF)	$V_{U,TOE,1}$ (K/FT)	$M_{U,TOE,1}$ (K-FT/FT)	$V_{U,HEEL,1}$ (K/FT)	$M_{U,HEEL,1}$ (K-FT/FT)
STR. I	15.52	12.42	9.31	0.00	***27.94***	***28.97***	***27.94***	***55.87***
STR. II	N/A							
STR. III	6.33	5.06	3.80	0.00	11.39	11.81	11.39	22.77
STR. IV	5.84	4.67	3.50	0.00	10.51	10.90	10.51	21.02
STR. V	11.87	9.49	7.12	0.00	21.36	22.15	21.36	42.72
EXTR. I	N/A							
EXTR. II	11.33	9.06	6.80	0.00	20.39	21.15	20.39	40.78
SER. I	4.18	3.34	2.51	0.00	***7.52***	***7.80***	***7.52***	15.04
SER. II	N/A							
SER. III	N/A							
SER. IV	N/A							

LIMIT STATES	$\sigma_{vmax,2}$ (KSF)	$\sigma_{vFF,2}$ (KSF)	$\sigma_{vBF,2}$ (KSF)	$\sigma_{vmin,2}$ (KSF)	$V_{U,TOE,2}$ (K/FT)	$M_{U,TOE,2}$ (K-FT/FT)	$V_{U,HEEL,2}$ (K/FT)	$M_{U,HEEL,2}$ (K-FT/FT)
STR. I	6.62	5.30	3.97	0.00	11.92	12.36	11.92	23.84
STR. II	N/A							
STR. III	4.55	3.64	2.73	0.00	8.20	8.50	8.20	16.40
STR. IV	4.48	3.63	2.77	0.22	8.10	8.39	8.97	19.24
STR. V	6.04	4.83	3.62	0.00	10.87	11.28	10.87	21.75
EXTR. I	N/A							
EXTR. II	11.33	9.06	6.80	0.00	20.39	21.15	20.39	40.78
SER. I	4.18	3.34	2.51	0.00	***7.52***	***7.80***	***7.52***	15.04
SER. II	N/A							
SER. III	N/A							
SER. IV	N/A							

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LIMIT STATES	$\sigma_{vmax,3}$ (KSF)	$\sigma_{vFF,3}$ (KSF)	$\sigma_{vBF,3}$ (KSF)	$\sigma_{vmin,3}$ (KSF)	$V_{U,TOE,3}$ (K/FT)	$M_{U,TOE,3}$ (K-FT/FT)	$V_{U,HEEL,3}$ (K/FT)	$M_{U,HEEL,3}$ (K-FT/FT)
STR. I	3.02	2.68	2.34	1.31	5.70	5.82	10.94	29.75
STR. II	N/A							
STR. III	3.02	2.68	2.34	1.31	5.70	5.82	10.94	29.75
STR. IV	3.34	2.94	2.55	1.36	6.28	6.41	11.71	31.57
STR. V	3.02	2.68	2.34	1.31	5.70	5.82	10.94	29.75
EXTR. I	N/A							
EXTR. II	2.97	2.44	1.92	0.35	5.41	5.58	6.81	15.72
SER. I	2.97	2.44	1.92	0.35	5.41	5.58	6.81	***15.72***
SER. II	N/A							
SER. III								
SER. IV								

LIMIT STATES	$\sigma_{vmax,4}$ (KSF)	$\sigma_{vFF,4}$ (KSF)	$\sigma_{vBF,4}$ (KSF)	$\sigma_{vmin,4}$ (KSF)	$V_{U,TOE,4}$ (K/FT)	$M_{U,TOE,4}$ (K-FT/FT)	$V_{U,HEEL,4}$ (K/FT)	$M_{U,HEEL,4}$ (K-FT/FT)
STR. I	3.62	3.04	2.46	0.71	6.66	6.86	9.51	23.29
STR. II	N/A							
STR. III	3.62	3.04	2.46	0.71	6.66	6.86	9.51	23.29
STR. IV	3.92	3.29	2.66	0.77	7.22	7.43	10.30	25.23
STR. V	3.62	3.04	2.46	0.71	6.66	6.86	9.51	23.29
EXTR. I	N/A							
EXTR. II	2.97	2.44	1.92	0.35	5.41	5.58	6.81	15.72
SER. I	2.97	2.44	1.92	0.35	5.41	5.58	6.81	***15.72***
SER. II	N/A							
SER. III								
SER. IV								

MAXIMUM DESIGN EFFECTS

$M_{U, TOE, STR.}$	FACTORED STRENGTH DESIGN MOMENT APPLIED TO TOE =	28.97	K-FT / FT
$M_{U, TOE, SER.}$	FACTORED SERVICE DESIGN MOMENT APPLIED TO TOE =	7.80	K-FT / FT
$V_{U, TOE}$	FACTORED DESIGN SHEAR APPLIED TO TOE =	27.94	K / FT
$M_{U, HEEL, STR.}$	FACTORED STRENGTH DESIGN MOMENT APPLIED TO HEEL =	55.87	K-FT / FT
$M_{U, HEEL, SER.}$	FACTORED SERVICE DESIGN MOMENT APPLIED TO HEEL =	15.72	K-FT / FT
$V_{U, HEEL}$	FACTORED DESIGN SHEAR APPLIED TO HEEL =	27.94	K /FT

$M_{U, STEM,STR.}$	FACTORED STRENGTH DESIGN MOMENT APPLIED TO STEM = MAX({a})	75.3	K-FT / FT
$M_{U, STEM, SER.}$	FACTORED SERVICE DESIGN MOMENT APPLIED TO STEM = MAX({a})	48.9	K-FT / FT
	CONSERVATIVE, COULD SUBTRACT FOOTING DEPTH FROM MOMENT ARM		
$V_{U, STEM}$	FACTORED DESIGN SHEAR APPLIED TO STEM = MAX({g})	12.61	K /FT

STEP DOWN REINFORCING REQUIRED IN STEM AT SPECIFIED HEIGHT **CONSIDER FOR FINAL DESIGN**

$M_{U, STEM, STEP}$	FACTORED STRENGTH DESIGN MOMENT APPLIED TO STEM @ A STEPPED STEM HEIGHT		
H_{STEP}	HEIGHT FROM TOP OF FOOTING TO STEP DOWN THE REINFORCING IN THE STEM	4.0	FT
	TAKE MOMENTS ABOUT H_{STEP}		

LOAD	FORCE (K/FT)	ARM (FT)	UNFACTORED MOMENT (K-FT/FT)
EH (HORIZ)	2.28	3.00	6.85
BR	#REF!	#REF!	#REF!
LS	1.27	4.50	5.71
WS (SUPER)	#REF!	#REF!	#REF!
WS (WALL)	0.60	1.50	0.90
WL	#REF!	#REF!	#REF!

LIMIT STATES	MAX. DRIVING MOMENT (K-FT/FT)
STR. I	#REF!
STR. II	-
STR. III	#REF!
STR. IV	#REF!
STR. V	#REF!
EXTR. I	-
EXTR. II	-
SER. I	#REF!
SER. II	-
SER. III	-
SER. IV	-

$M_{U, STEM, STEP, STR}$	#REF!	K-FT / FT
$M_{U, STEM, STEP, SER}$	#REF!	K-FT / FT

SERVICE LIMIT STATES (11.5.2)

SETTLEMENT ANALYSES (10.6.2.4)

SEE GEOTECHNICAL REPORT

OVERALL STABILITY (11.6.2.3) SEE GEOTECHNICAL RECOMMENDATIONS

11.6.2.3—Overall Stability

The overall stability of the retaining wall, retained slope and foundation soil or rock shall be evaluated for all walls using limiting equilibrium methods of analysis. The overall stability of temporary cut slopes to facilitate construction shall also be evaluated. Special exploration, testing and analyses may be required for bridge abutments or retaining walls constructed over soft deposits.

The evaluation of overall stability of earth slopes with or without a foundation unit should be investigated at the Service I Load Combination and an appropriate resistance factor. In lieu of better information, the resistance factor, ϕ, may be taken as:

- Where the geotechnical parameters are well defined, and the slope does not support or contain a structural element.. 0.75
- Where the geotechnical parameters are based on limited information, or the slope contains or supports a structural element 0.65

C11.6.2.3

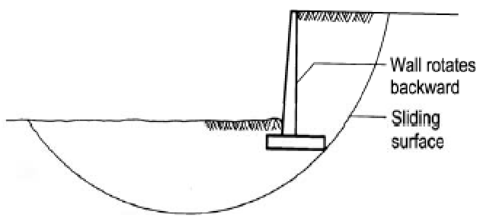

Figure C11.6.2.3-1—Retaining Wall Overall Stability Failure

Figure C11.6.2.3-1 shows a retaining wall overall stability failure. Overall stability is a slope stability issue, and, therefore, is considered a service limit state check.

The Modified Bishop, simplified Janbu or Spencer methods of analysis may be used.

Soft soil deposits may be subject to consolidation and/or lateral flow which could result in unacceptable long-term settlements or horizontal movements.

With regard to selection of a resistance factor for evaluation of overall stability of walls, examples of

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PRIMARY REINFORCING DESIGN - TOE OF FOOTING

BOTTOM MAT PRIMARY REINFORCING DUE TO BEARING PRESSURE

STRENGTH DESIGN

CRITERIA 1: TENSION = COMPRESSION

T = As * Fy   C = 0.85 * f'c * a * b   Fy = 60 KSI   As UNKOWN

EQ. 1 a = [Fy / (0.85 * f'c * b)] As   f'c = 5.0 KSI   a UNKOWN

b = 12 IN

CRITERIA 2: FACTORED MOMENT < FACTORED FLEXURAL RESISTANCE

Mu > ϕ * Mn = ϕ * As * Fy (d - 0.5 a)   ϕ = 0.90 (AASHTO 5.5.4.2.1)

EQ. 2 As = Mu / (ϕ * Fy * (d - 0.5 a))   CLR. CVR. = 4.00 IN

h = 24.00 IN

ASSUMED BAR DIAM. = 0.75 IN

SOLVE SYSTEM OF EQUATIONS TO SOLVE FOR As_required   d = 19.63 IN

$M_{U,\,TOE}$ = 28.97 K-FT/FT = 347.6 K-IN/FT

a	As_req
1.00	0.337
0.40	0.331
0.39	0.331
0.39	0.331
0.39	0.331

As_req = 0.331 IN^2/FT

As_prov = 0.440 IN^2/FT

CHECK: OK

PROVIDE: #6 @ 12 IN

LONGITUDINAL, BOTTOM, INT

BAR DIAM = 0.75 IN

d = 19.63 IN

a = 0.52 IN

Mr = ϕ * Mn = ϕ * As * Fy (d - 0.5 a) = 460.1 = 38.3 K-FT/FT

MINIMUM REINFORCEMENT CHECK (5.7.3.3.2)

Mr SHALL BE GREATER THAN THE LESSER OF (Mcr) AND (1.33 Mu)

M_{cr}	CRACKING MOMENT (5.7.3.3.2-1 NOTE PRESTRESSED & COMPOSITE N/A) = $\gamma_3\ \gamma_1\ f_r\ S_c$		
γ_3	RATIO OF MIN. YIELD STRENGTH TO ULTIMATE TENSILE STRENGTH (A615, GRADE 60)	0.67	
γ_1	FLEXURAL CRACKING VARIABILITY FACTOR: 1.2 FOR PRECAST OR 1.6 FOR OTHERS (C.I.P.)	1.2	
f_r	MODULUS OF RUPTURE (5.4.2.6) = 0.20 $\sqrt{f'_c}$	0.447	KSI
S_c	SECTION MODULUS = b H_{FOOT}^2/6 =	1152	IN^3

SMALLER VALUE, COMPARE TO Mr BELOW >>> M_{cr} = **34.5** K-FT/FT

1.33 $M_{u,TOE}$ = 38.5 K-FT/FT

Mr = 38.3 K-FT/FT

OK

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PRIMARY REINFORCING DESIGN - HEEL OF FOOTING

TOP MAT PRIMARY REINFORCING DUE TO OVERBURDEN EARTH PRESSURE AND DEAD LOAD

STRENGTH DESIGN

CRITERIA 1: TENSION = COMPRESSION

T = As * Fy   C = 0.85 * f'c * a * b   Fy = 60 KSI   As UNKOWN

EQ. 1 a = [Fy / (0.85 * f'c * b)] As   f'c = 5.0 KSI   a UNKOWN

b = 12 IN

CRITERIA 2: FACTORED MOMENT < FACTORED FLEXURAL RESISTANCE

Mu > ϕ * Mn = ϕ * As * Fy (d - 0.5 a)   ϕ = 0.90 (AASHTO 5.5.4.2.1)

EQ. 2 As = Mu / (ϕ * Fy * (d - 0.5 a))   CLR. CVR. = 4.00 IN

h = 24.00 IN

ASSUMED BAR DIAM. = 0.75 IN

SOLVE SYSTEM OF EQUATIONS TO SOLVE FOR As_required   d = 19.63 IN

$M_{U, HEEL}$ = 55.87 K-FT/FT = 670.5 K-IN/FT

a	As_req
1.00	0.649
0.76	0.645
0.76	0.645
0.76	0.645
0.76	0.645

As_req = 0.645 IN^2/FT

As_prov = 0.880 IN^2/FT

CHECK: **OK**

PROVIDE: #6 @ 6 IN

LONGITUDINAL, BOTTOM, INT

BAR DIAM = 0.75 IN

d = 19.63 IN

a = 1.04 IN

Mr = ϕ * Mn = ϕ * As * Fy (d - 0.5 a) = 908.0 = 75.7 K-FT/FT

MINIMUM REINFORCEMENT CHECK (5.7.3.3.2)

Mr SHALL BE GREATER THAN THE LESSER OF (Mcr) AND (1.33 Mu)

M_{cr}	CRACKING MOMENT (5.7.3.3.2-1 NOTE PRESTRESSED & COMPOSITE N/A) = $\gamma_3\ \gamma_1\ f_r\ S_c$		
γ_3	RATIO OF MIN. YIELD STRENGTH TO ULTIMATE TENSILE STRENGTH (A615, GRADE 60)	0.67	
γ_1	FLEXURAL CRACKING VARIABILITY FACTOR: 1.2 FOR PRECAST OR 1.6 FOR OTHERS (C.I.P.)	1.2	
f_r	MODULUS OF RUPTURE (5.4.2.6) = 0.20 $\sqrt{f'_c}$	0.447	KSI
S_c	SECTION MODULUS = b H_{FOOT}^2/6 =	1152	IN^3

SMALLER VALUE, COMPARE TO Mr BELOW >>> M_{cr} = **34.5** K-FT/FT

1.33 $M_{u,HEEL}$ = 74.3 K-FT/FT

Mr = 75.7 K-FT/FT

OK

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PRIMARY REINFORCING DESIGN - VERTICAL STEM (AT BASE)

BACK FACE VERTICAL PRIMARY REINFORCING DUE TO HORIZONTAL LOADS AT BASE OF STEM

STRENGTH DESIGN

CRITERIA 1: TENSION = COMPRESSION

T = As * Fy C = 0.85 * f'c * a * b Fy = 60 KSI As UNKOWN

EQ. 1 a = [Fy / (0.85 * f'c * b)] As f'c = 5.0 KSI a UNKOWN

b = 12 IN

CRITERIA 2: FACTORED MOMENT < FACTORED FLEXURAL RESISTANCE

Mu > ϕ * Mn = ϕ * As * Fy (d - 0.5 a) ϕ = 0.90 (AASHTO 5.5.4.2.1)

EQ. 2 As = Mu / (ϕ * Fy * (d - 0.5 a)) CLR. CVR. = 4.00 IN

h = 24.00 IN

ASSUMED BAR DIAM. = 0.75 IN

SOLVE SYSTEM OF EQUATIONS TO SOLVE FOR As_required d = 19.63 IN

$M_{U, STEM}$ = 75.35 K-FT/FT = 904.2 K-IN/FT

a	As_req
1.00	0.875
1.03	0.876
1.03	0.876
1.03	0.876
1.03	0.876

As_req = 0.876 IN^2/FT

As_prov = 1.200 IN^2/FT

CHECK: **OK**

PROVIDE: #7 @ 6 IN

LONGITUDINAL, BOTTOM, INT

BAR DIAM = 0.875 IN

d = 19.56 IN

a = 1.41 IN

Mr = ϕ * Mn = ϕ * As * Fy (d - 0.5 a) = 1221.9 = 101.8 K-FT/FT

MINIMUM REINFORCEMENT CHECK (5.7.3.3.2)

Mr SHALL BE GREATER THAN THE LESSER OF (Mcr) AND (1.33 Mu)

M_{cr}	CRACKING MOMENT (5.7.3.3.2-1 NOTE PRESTRESSED & COMPOSITE N/A) = $\gamma_3\ \gamma_1\ f_r\ S_c$		
γ_3	RATIO OF MIN. YIELD STRENGTH TO ULTIMATE TENSILE STRENGTH (A615, GRADE 60)	0.67	
γ_1	FLEXURAL CRACKING VARIABILITY FACTOR: 1.2 FOR PRECAST OR 1.6 FOR OTHERS (C.I.P.)	1.2	
f_r	MODULUS OF RUPTURE FOR CRACKING MOMENT (5.4.2.6) = 0.20 √f'$_c$	0.447	KSI
S_c	SECTION MODULUS = b B_{STEM}^2/6 =	1152	IN^3

SMALLER VALUE, COMPARE TO Mr BELOW >>>

M_{cr}	=	**34.5**	K-FT/FT
1.33 $M_{u,STEM}$	=	100.2	K-FT/FT
Mr	=	101.8	K-FT/FT
		OK	

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PRIMARY REINFORCING DESIGN - VERTICAL STEM (AT STEP POINT)

BACK FACE VERTICAL PRIMARY REINFORCING DUE TO HORIZONTAL LOADS AT STEP POINT H_{STEP} = 4.0 FT

STRENGTH DESIGN

CRITERIA 1: TENSION = COMPRESSION

T = As * Fy C = 0.85 * f'c * a * b

EQ. 1 a = [Fy / (0.85 * f'c * b)] As

Fy = 60 KSI As UNKOWN

f'c = 5.0 KSI a UNKOWN

b = 12 IN

CRITERIA 2: FACTORED MOMENT < FACTORED FLEXURAL RESISTANCE

Mu > ϕ * Mn = ϕ * As * Fy (d - 0.5 a)

EQ. 2 As = Mu / (ϕ * Fy * (d - 0.5 a))

ϕ = 0.90 (AASHTO 5.5.4.2.1)

CLR. CVR. = 4.00 IN

h = 24.00 IN

ASSUMED BAR DIAM. = 0.75 IN

SOLVE SYSTEM OF EQUATIONS TO SOLVE FOR As_required d = 19.63 IN

$M_{U, STEM}$ = #REF! K-FT/FT = #REF! K-IN/FT

a	As_req
1.00	#REF!
#REF!	#REF!
#REF!	#REF!
#REF!	#REF!
#REF!	#REF!

As_req = #REF! IN^2/FT

As_prov = 0.310 IN^2/FT

CHECK: #REF!

PROVIDE: #5 @ 12 IN

LONGITUDINAL, BOTTOM, INT

BAR DIAM = 0.625 IN

d = 19.69 IN

a = 0.36 IN

Mr = ϕ * Mn = ϕ * As * Fy (d - 0.5 a) = 326.5 = 27.2 K-FT/FT

MINIMUM REINFORCEMENT CHECK (5.7.3.3.2)

Mr SHALL BE GREATER THAN THE LESSER OF (Mcr) AND (1.33 Mu)

M_{cr}	CRACKING MOMENT (5.7.3.3.2-1 NOTE PRESTRESSED & COMPOSITE N/A) = $\gamma_3\ \gamma_1\ f_r\ S_c$		
γ_3	RATIO OF MIN. YIELD STRENGTH TO ULTIMATE TENSILE STRENGTH (A615, GRADE 60)	0.67	
γ_1	FLEXURAL CRACKING VARIABILITY FACTOR: 1.2 FOR PRECAST OR 1.6 FOR OTHERS (C.I.P.)	1.2	
f_r	MODULUS OF RUPTURE FOR CRACKING MOMENT (5.4.2.6) = 0.20 $\sqrt{f'_c}$	0.447	KSI
S_c	SECTION MODULUS = b $B_{STEM}^2/6$ =	1152	IN^3

###	M_{cr}	=	**34.5**	K-FT/FT
###	1.33 $M_{u,STEM}$	=	#REF!	K-FT/FT
	Mr	=	27.2	K-FT/FT
			#REF!	

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CONTROL OF CRACKING BY DISTRIBUTION OF REINFORCEMENT

AASHTO 5.7.3.4 - CONTROL OF CRACKING BY DISTRIBUTION OF REINFORCEMENT TO BE CHECKED SINCE ELEMENTS DESIGNED IN ACCORDANCE WITH THE APPROXIMATE METHOD, NOT THE EMPERICAL DESIGN METHOD (9.7.2)

The spacing s of mild steel reinforcement in the layer closest to the tension face shall satisfy the following:

$$s \le \frac{700\gamma_e}{\beta_s f_{ss}} - 2d_c \quad (5.7.3.4\text{-}1)$$

in which:

$$\beta_s = 1 + \frac{d_c}{0.7(h - d_c)}$$

γ_e = exposure factor
= 1.00 for Class 1 exposure condition
= 0.75 for Class 2 exposure condition

d_c = thickness of concrete cover measured from extreme tension fiber to center of the flexural reinforcement located closest thereto (in.)

f_{ss} = tensile stress in steel reinforcement at the service limit state (ksi)

h = overall thickness or depth of the component (in.)

d_ℓ = distance from the extreme compression fiber to the centroid of extreme tension steel element (in.)

Class 1 exposure condition applies when cracks can be tolerated due to reduced concerns of appearance and/or corrosion. Class 2 exposure condition applies to transverse design of segmental concrete box girders for any loads applied prior to attaining full nominal concrete strength and when there is increased concern of appearance and/or corrosion.

	TOE	HEEL	$STEM_{BOT}$	$STEM_{TOP}$
γ_e (IN.)	1.00	1.00	1.00	1.00
d_c (IN.)	4.38	4.38	4.44	4.31
d (IN.)	19.63	19.63	19.56	19.69
h (IN.)	24.00	24.00	24.00	24.00
b (IN.)		12.00		
$A_{s,\,PROV}$ (IN^2)	0.44	0.88	1.2	0.31
$M_{u,\,SER}$ (K-FT/FT)	7.80	15.72	48.94	#REF!
Es (KSI)		29000		
Ec (KSI)	4069.644	4069.644	4069.644	4069.644

Ec = 1820 √f'c (AASHTO C5.4.2.4-1)

REFER TO REFERENCE 4 FOR CALCULATING TENSILE STRESS IN STEEL REINFORCEMENT AT THE SERVICE LEVEL

ρ = As_prov / bd k = $\sqrt{(n\rho)^2 + 2n\rho} - n\rho$ fs = Mserv / (As_prov * j *d)

n = Es / Ec j = 1 - k/3

TOE OF FOOTING

ρ = 0.001868 n = 7.13 k = 0.150 j = 0.950 fs = 11.41 KSI β_1 = 1.318

s ≤ 37.80 IN s_prov = 12 IN CHECK = OK

HEEL OF FOOTING

ρ = 0.003737 n = 7.13 k = 0.206 j = 0.931 fs = 11.73 KSI β_1 = 1.318

s ≤ 36.52 IN s_prov = 6 IN CHECK = OK

STEM (BASE)

ρ = 0.005112 n = 7.13 k = 0.236 j = 0.921 fs = 27.15 KSI β_1 = 1.324

s ≤ 10.60 IN s_prov = 6 IN CHECK = OK

STEM (STEPPED)

ρ = 0.001312 n = 7.13 k = 0.128 j = 0.957 fs = #REF! KSI β_1 = 1.315

s ≤ #REF! IN s_prov = 12 IN CHECK = ###

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SHRINKAGE AND TEMPERATURE REINFORCEMENT

5.10.8—Shrinkage and Temperature Reinforcement

Reinforcement for shrinkage and temperature stresses shall be provided near surfaces of concrete exposed to daily temperature changes and in structural mass concrete. Temperature and shrinkage reinforcement to ensure that the total reinforcement on exposed surfaces is not less than that specified herein.

Reinforcement for shrinkage and temperature may be in the form of bars, welded wire fabric, or prestressing tendons.

For bars or welded wire fabric, the area of reinforcement per foot, on each face and in each direction, shall satisfy:

$$A_s \geq \frac{1.30bh}{2(b+h)f_y} \qquad (5.10.8\text{-}1)$$

$$0.11 \leq A_s \leq 0.60 \qquad (5.10.8\text{-}2)$$

where:

- A_s = area of reinforcement in each direction and each face (in.^{2}/ft)
- b = least width of component section (in.)
- h = least thickness of component section (in.)
- f_y = specified yield strength of reinforcing bars $\leq$75 ksi

Where the least dimension varies along the length of wall, footing, or other component, multiple sections should be examined to represent the average condition at each section. Spacing shall not exceed:

- 3.0 times the component thickness, or 18.0 in.

Fy = 60 KSI

FOOTING - LONGITUDINAL

$b = B_{FOOT}$ =	120	IN	$h = H_{FOOT}$ =	24.00	IN	
$As,_{REQ.} \geq$	0.217	IN^2/FT	MAX SPACING REQ. =	18.0	IN	PROVIDE: #5 @ 12 IN
$As,_{PROV.}$ =	0.310	IN^2/FT	SPACING PROVIDED =	12.0	IN	**CHECK = OK**

STEM - LONGITUDINAL

b = b =	12	IN	$h = B_{STEM}$ =	24.00	IN	
$As,_{REQ.} \geq$	0.110	IN^2/FT	MAX SPACING REQ. =	18.0	IN	PROVIDE: #5 @ 12 IN
$As,_{PROV.}$ =	0.310	IN^2/FT	SPACING PROVIDED =	12.0	IN	**CHECK = OK**

STEM - VERTICAL (FRONT FACE)

b = b =	12	IN	$h = B_{STEM}$ =	24.00	IN	
$As,_{REQ.} \geq$	0.110	IN^2/FT	MAX SPACING REQ. =	18.0	IN	PROVIDE: #5 @ 12 IN
$As,_{PROV.}$ =	0.310	IN^2/FT	SPACING PROVIDED =	12.0	IN	**CHECK = OK**

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SHEAR CHECK

SHEAR REINFORCEMENT REQUIRED IF Vu ≥ $\phi V_{n,CONCRETE}$

ϕ_v	RESISTANCE FACTOR FOR SHEAR, 0.9 FOR NORMAL WEIGHT CONCRETE (5.5.4.2.1)	0.9	
$V_{n,CONCRETE}$	NOMINAL CONCRETE SHEAR RESISTANCE(5.8.3.3-3) = MIN[0.0316 β √(f'$_c$) b_v d_v , 0.25 f'$_c$ b_v d_v]		
β	SHEAR CAPACITY FACTOR, CONSERVATIVELY TAKEN AS 2.0 (5.8.3.4.1)	2.0	
b_v	EFFECTIVE (MINIMUM) WEB WIDTH (5.8.2.9), USE 12" DESIGN WIDTH	12	IN
d_v	EFFECTIVE SHEAR DEPTH, EQUAL TO INTERNAL MOMENT ARM BETWEEN TENSION & COMPRESSION RESULTANT		
	= MAX (I.M.A. , 0.9d , 0.72h) (5.8.2.9)		

TOE OF FOOTING

d_v	I.M.A.	**19.37**	IN	<<< CONTROLS	19.37	IN
	0.9d	17.66	IN			
	0.72h	17.28	IN			
$V_{n,CONCRETE}$	0.0316 β √(f'$_c$) b_v d_v	**32.8**	K/FT	<<< CONTROLS	32.8	K/FT
	0.25 f'$_c$ b_v d_v	290.5	K/FT			
$\phi V_{n,CONCRETE}$					29.6	K/FT
$V_{u,TOE}$					27.9	K/FT

CHECK: **NO SHEAR REINFORCEMENT REQUIRED FOR TOE**

HEEL OF FOOTING

d_v	I.M.A.	**19.11**	IN	19.11	IN
	0.9d	17.66	IN		
	0.72h	17.28	IN		
$V_{n,CONCRETE}$	0.0316 β √(f'$_c$) b_v d_v	**32.4**	K/FT	32.4	K/FT
	0.25 f'$_c$ b_v d_v	286.6	K/FT		
$\phi V_{n,CONCRETE}$				29.2	K/FT
$V_{u,HEEL}$				27.9	K/FT

CHECK: **NO SHEAR REINFORCEMENT REQUIRED FOR HEEL**

STEM

d_v	I.M.A.	**18.86**	IN	18.86	IN
	0.9d	17.61	IN		
	0.72h	17.28	IN		
$V_{n,CONCRETE}$	0.0316 β √(f'$_c$) b_v d_v	**32.0**	K/FT	32.0	K/FT
	0.25 f'$_c$ b_v d_v	282.8	K/FT		
$\phi V_{n,CONCRETE}$				28.8	K/FT
$V_{u,STEM}$				12.6	K/FT

CHECK: **NO SHEAR REINFORCEMENT REQUIRED FOR STEM**

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INTERFACE SHEAR TRANSFER - SHEAR FRICTION (5.8.4)

CHECK AT INTERFACE OF STEM AND FOOTING

b_{vi}	INTERFACE WIDTH ENGAGED IN SHEAR TRANSFER = B_{STEM}	24	IN
L_{vi}	INTERFACE LENGTH ENGAGED IN SHEAR TRANSFER = 12" DESIGN LENGTH	12	IN/FT
A_{cv}	AREA OF CONCRETE ENGAGED IN INTERFACE SHEAR TRANSFER = b_{vi} L_{vi}	288	IN^2/FT
c	COHESION FACTOR (5.8.4.3)	0.24	
μ	FRICTION FACTOR (5.8.4.3)	1.0	
K_1	CONCRETE STRENGTH FRACTION (5.8.4.3)	0.25	
K_2	LIMITING INTERFACE SHEAR RESISTANCE (5.8.4.3)	1.5	
A_{vf}	AREA OF INTERFACE SHEAR REINFORCEMENT CROSSING THE SHEAR PLANE	1.2	IN^2/FT
f_y	YIELD STRENGTH OF REINFORCEMENT	60	KSI
f'_c	CONCRETE COMPRESSIVE STRENGTH = MIN ($F'c_{STEM}$, $F'c_{FOOT}$)	5	KSI
P_c	PERMANENT NET COMPRESSIVE FORCE NORMAL TO SHEAR PLANE = $DC_{STEM + SUPER + BW}$	3.9	K/FT
V_{ni}	NOMINAL INTERFACE SHEAR RESISTANCE(5.8.4.1-3) = $c\ A_{cv} + \mu(A_{vf}\ f_y + P_c)$	**145.0**	K/FT
	$V_{ni} \leq K_1\ f'_c\ A_{cv}$ (5.8.4.1-4)	360.0	K/FT
	$V_{ni} \leq K_2\ A_{cv}$ (5.8.4.1-5)	432.0	K/FT
ϕ_v	RESISTANCE FACTOR FOR SHEAR, 0.9 FOR NORMAL WEIGHT CONCRETE (5.5.4.2.1)	0.9	
ϕV_{ni}	FACTORED INTERFACE SHEAR RESISTANCE	130.5	K/FT
V_{ui}	FACTORED INTERFACE SHEAR FORCE	12.61	K/FT

CHECK: **SHEAR INTERFACE TRANSFER ADEQUATE**

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DEVELOPMENT OF REINFORCEMENT (5.11.2)

l_d	TENSION DEVELOPMENT LENGTH (5.11.2.1.1) = MAX(l_{db} MOD_1 MOD_2 , 12")						
l_{db}	BASIC TENSION DEVELOPMENT LENGTH (5.11.2.1.1, BAR < #11) = MAX(1.25 A_b f_y / √f'$_c$, 0.40 d_b f_y)						
MOD_1	TOP BARS OR NEARLY HORIZONTAL REINFORCEMENT (5.11.2.1.2)					1.4	
MOD_2	FULL YIELD STRENGTH NOT MET (5.11.2.1.3) = $A_{s, REQ.}$ / $A_{s, PROV.}$						

LONGITUDINAL FOOTING

l_{db}	1.25 A_b f_y / √f'$_c$	10.40	IN			15.00	IN
	0.40 d_b f_y	15.00	IN	<<< CONTROLS			
MOD_2						0.70	
l_d	l_{db} MOD_1 MOD_2	14.68	IN	<<< CONTROLS		14.68	IN
	12"	12.00	IN				
					USE:	15.00	IN

PROVIDE 15 IN. MIN LAP

LONGITUDINAL STEM

l_{db}	1.25 A_b f_y / √f'$_c$	10.40	IN			15.00	IN
	0.40 d_b f_y	15.00	IN	<<< CONTROLS			
MOD_2						0.35	
l_d	l_{db} MOD_1 MOD_2	7.45	IN			12.00	IN
	12"	12.00	IN				
					USE:	12.00	IN

PROVIDE 12 IN. MIN LAP

VERTICAL STEM

l_{db}	1.25 A_b f_y / √f'$_c$	20.12	IN			21.00	IN
	0.40 d_b f_y	21.00	IN				
MOD_2						0.73	
l_d	l_{db} MOD_2	15.33	IN			15.33	IN
	12"	12.00	IN				
					USE:	16.00	IN

PROVIDE 16 IN. MIN LAP

Tighe&Bond Engineers | Environmental Specialists	JOB NO	M1476-011	SHEET		OF	24
	CLIENT	TOWN OF MANCHESTER-BY-THE-SEA, MA				
	SUBJECT	SW WINGWALL (SEAWALL) DESIGN				
	PREPARED BY	EAO	DATE	JUL. '19	CHECKED BY	-

DATE -

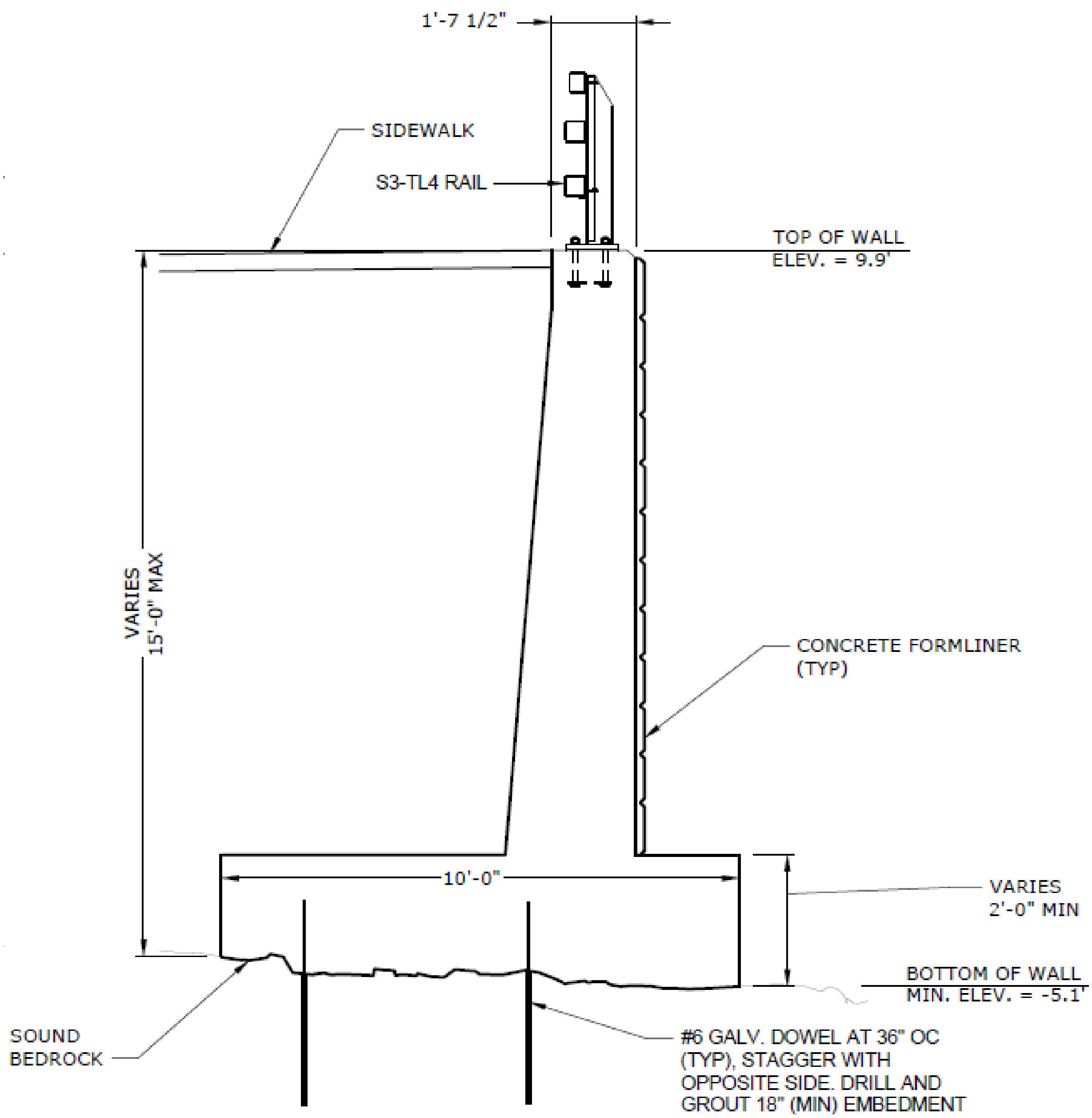
SUMMARY OF CHECKS

EARTHQUAKE ANALYSIS		OK
OVERTURNING		OK
SLIDING	**NOTE: CONSIDER DOWELS INTO ROCK FOR FINAL DESIGN**	NO GOOD
BEARING		OK
SCOUR		OK
SETTLEMENT		PER GEOTECH
OVERALL STABILITY		PER GEOTECH
REINFORCING: TOE OF FOOTING STRENGTH		OK
REINFORCING: TOE OF FOOTING MINIMUM		OK
REINFORCING: TOE OF FOOTING CRACKING		OK
REINFORCING: HEEL OF FOOTING STRENGTH		OK
REINFORCING: HEEL OF FOOTING MINIMUM		OK
REINFORCING: HEEL OF FOOTING CRACKING		OK
REINFORCING: BASE OF STEM STRENGTH		OK
REINFORCING: BASE OF STEM MINIMUM		OK
REINFORCING: BASE OF STEM CRACKING		OK
REINFORCING: TOP OF STEM STRENGTH		#REF!
REINFORCING: TOP OF STEM MINIMUM		#REF!
REINFORCING: TOP OF STEM CRACKING		#REF!
REINFORCING: SHRINKAGE AND TEMERATURE FOOTING LONGITUDINAL		OK
REINFORCING: SHRINKAGE AND TEMERATURE STEM LONGITUDINAL		OK
REINFORCING: SHRINKAGE AND TEMERATURE STEM VERTICAL		OK
SHEAR: TOE		OK
SHEAR: HEEL		OK
SHEAR: STEM		OK
SHEAR INTERFACE TRANSFER: STEM TO FOOTING		OK

NOTE: DESIGN REINFORCING FOR FINAL DESIGN

Tighe&Bond Engineers | Environmental Specialists							
JOB NO	M1476-011			SHEET		OF	24
CLIENT	TOWN OF MANCHESTER-BY-THE-SEA, MA						
SUBJECT	SW WINGWALL (SEAWALL) DESIGN						
PREPARED BY	EAO	DATE	JUL. '19	CHECKED BY	-	DATE	-

SKETCH



SOUTHWEST WINGWALL

$$V_m = \phi_m 0.07\lambda\sqrt{f'_m}b_w d$$
$$= (0.6)0.07(1.0)\sqrt{10}(190)(1500) = 38.0 \text{ kN}$$

Since $0.5V_m = 0.5(38.0) = 19.0$ kN < 150.0 kN = V_f, shear reinforcement is required at a spacing $s \leq d/2 = 750$ mm, or 600 mm.

Try 10M single-legged stirrups, $f_y = 400$ MPa

The shear reinforcement must provide a resistance of at least
$V_s = V_f - V_m = 150.0 - 38.0 = 112.0$ kN

Recalling that
$V_s = \phi_s A_v f_y d / s = 0.85(100)(400)(1500)/s = 51(10)^6/s$ N
That is, $V_s = 112(10)^3 = 51.0(10)^6/s$
$s = 51(10)^6/112(10)^3 = 455$ mm < 600 mm = s_{max} OK

Therefore, use 10M single-legged stirrups @ 400 mm Ans.

Further from the support the spacing can be increased to the maximum of 600 mm at $V_s = 51(10)^6/600 = 85.0$ kN
That is, $V_r = V_s + V_m = 85.0 + 38.0 = 123.0$ kN

The minimum area of steel for this arrangement must be checked
$A_v = 0.35 b_w s/f_y = 0.35(190)(600)/400 = 99.75 < 100 \text{ mm}^2$ OK

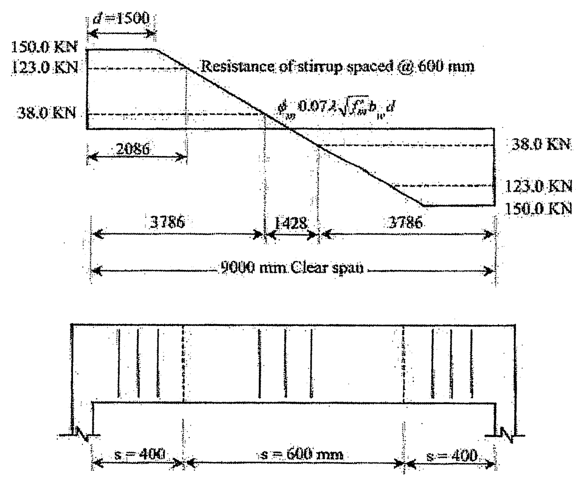


Figure 3-18 Shear Design of the Beam of Example 3-10

Shear reinforcement is theoretically no longer required at the point where $V_f = V_m = 38.0$ kN. However, it should be provided for a distance of at least d beyond that point.

Figure 3-18 shows a plot of the design shear force diagram that indicates the maximum shear force of 150.0 kN extending from the point of calculation to the support. Also shown are the values of $V_r = 123.0$ kN corresponding to stirrups at 600 mm, and $V_r = 38.0$ kN corresponding to masonry shear resistance below which stirrups are not theoretically required. These values intersect the shear force diagram at distances that are easily calculated, or may be scaled if the diagram is accurately drawn to scale.

The arrangement of 10M single-legged stirrups shown in Figure 3-18 satisfies the shear requirements for the beam, and all that remains for the designer is to check that the stirrups are effectively anchored, as will be discussed in a later section.

3.5 SERVICEABILITY DESIGN

As noted in Section 1.5, the intent of the limit states design is to ensure that various limiting states are not exceeded during the reasonable life of the structure. These limiting states are *safety* (strength and stability) under specific overload, and *serviceability* (durability, stress level, cracking, deflections and vibration) under service loading. Now that safety has been covered through flexure and shear design, this section deals with serviceability requirements.

Durability is assured through selecting the appropriate materials to withstand the aggressiveness of the environment, sufficient cover on materials that can corrode, the appropriate selection and anchorage of connectors, proper construction and subsequent maintenance, all of which do not lend themselves to the type of analysis familiar to structural designers. Stress level, cracking, deflection and vibration are more quantifiable and, since they are being evaluated at service loads (linear elastic range), the analysis follows the principles of the theory of elasticity. The serviceability limit states of prime concern are deflection and crack control. Stresses at service load, where required, are readily calculated from the *transformed section analysis* discussed in the following sub-section, and vibration, as required, can be evaluated from the flexural stiffness derived from that analysis.

3.5.1 Deflection

Deflections under service load are normally calculated assuming that the materials are being stressed within the linear elastic range, and that the theory of elasticity may be applied. The deflection so calculated is of the general form

$$\delta = k\frac{wL^3}{EI} \qquad \text{Eq. 3-26}$$

where, w is the total uniform load on the span, L is the beam span, EI is the effective stiffness of the cross-section, and k is a factor that depends on the distribution of the load and on the support conditions. S304.1 Clause 11.4.1

requires the beam deflection to be checked if the span length exceeds 10 d in which case the immediate deflection due to service live load plus long-term deflection due to sustained load should not exceed $L/480$.

A characteristic of reinforced masonry, as of reinforced concrete, is that members in flexure generally crack in tension (an essential factor in assuring that the reinforcing steel works effectively), so there is the stiffness at the cracked sections to consider as well as the stiffness at the uncracked sections between cracks. The value of the modulus of elasticity of masonry is taken as $E_m = 850 f'_m \leq 20\,000$ MPa or is obtained by testing; and the effective moment of inertia, I_{eff}, is obtained from that of the cracked and uncracked sections, I_{cr} and I_o respectively.

Where the loading is of short duration, elastic analysis gives a reasonable estimate of deflection, but an estimate of deflection under sustained load should take the effects of creep and shrinkage into account. Compressive reinforcement is known to reduce both types of deformation and thus long-term deflection. The procedure adopted by S304.1 (Clause 11.4.4) to account for the additional deflection due to creep and shrinkage and the effect of the presence of compressive steel is to multiply the immediate deflection caused by the sustained load by the factor

$$\frac{S_1}{1+50\rho'} \qquad \text{Eq. 3-27}$$

where, $\rho' = A'_s / bd$, as before, calculated at midspan for simple and continuous spans and at the support for cantilevers.

S_1 = time dependent factor that varies from 0.5 for loads of up to three months duration to 1.0 for loads applied for five years or more.

As was noted earlier, for tension reinforcement to be effective, tensile cracking must take place in the masonry and, once a crack starts, it is reasonable to assume that it extends to the neutral axis of the cross-section. Furthermore, if linear elastic behaviour is assumed at service loads, the situation shown in Figure 3-19 results.

Figure 3-19 shows a perspective view of a singly-reinforced multi-course masonry beam, its cross-section, the strain diagram, the stress diagram and the transformed section. Since plane sections remain plane during bending, the strain diagram is linear. It is reasonable to assume that the stress-strain relationships are linear at service loads, which leads to a linear stress diagram in which f_m is the maximum compressive stress in the masonry, f_s is the tensile stress in the steel and no tensile stress exists in the masonry.

The ratio $n = E_s / E_m$ is defined as the modular ratio, indicating that steel is n times as stiff as masonry. It is now convenient to consider the transformed section where the effective cracked section is converted to equivalent areas of masonry. In this case, the steel area is converted to an equivalent masonry area of $n A_s$ which is stressed at f_s / n. Here, it can be verified that *area • stress = force* gives the force $f_s A_s$ at the level of steel.

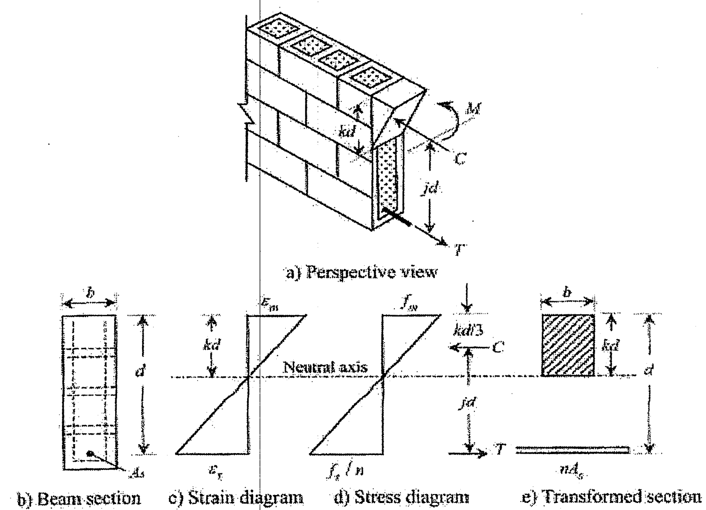


Figure 3-19 Singly-Reinforced Beam

To determine the depth to the neutral axis, kd, moments of the areas can be taken about the neutral axis:

$$bkd(kd)/2 = nA_s(d - kd)$$

Then, dividing by bd^2 and substituting ρ for A_s / bd

$$0.5k^2 = n\rho(1-k)$$

The solution to this quadratic is

$$k = \sqrt{(n\rho)^2 + 2n\rho} - n\rho \qquad \text{Eq. 3-28}$$

Then $$I_{cr} = b(kd)^3/3 + nA_s(d-kd)^2 \qquad \text{Eq. 3-29}$$

If the designer wishes to calculate the stresses at service loads, this can be done as follows. Since the stress block is triangular, the resultant compressive force C is located at $kd/3$ and the moment arm jd is

$$jd = d - kd/3$$

The resultant compressive force is

$$C = 0.5 f_m bkd$$

and the tensile force

$$T = A_s f_s = \rho f_s bd$$

The moment M becomes

$$M = C\,jd = 0.5 f_m bkjd^2 = T\,jd = \rho f_s bjd^2$$

and the stresses in the masonry and the steel at service load are

$$f_m = \frac{2M}{bkjd^2} \qquad \text{Eq. 3-30}$$

$$f_s = \frac{M}{\rho bjd^2} \qquad \text{Eq. 3-31}$$

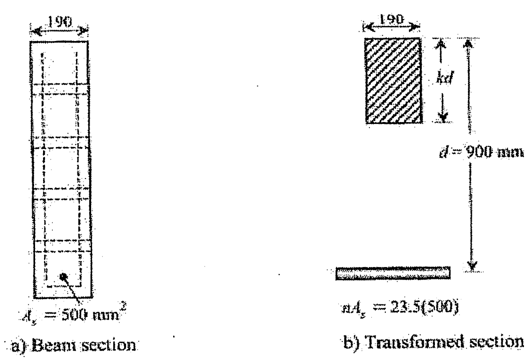


Figure 3-20 Masonry Beam of Example 3-11

EXAMPLE 3-11 *A 5-course 200 mm masonry beam is reinforced with one 25M bar at an effective depth of 900 mm. If $f'_m = 10$ MPa, what is the moment of inertia of the cracked section?*

Since E_m may be taken as $850 f'_m$

$$E_m = 850(10) = 8500 \text{ MPa} < 20{,}000 \text{ MPa} \qquad \underline{\text{OK}}$$

and $E_s = 200(10)^3$ MPa

Thus, the modular ratio

$$n = \frac{E_s}{E_m} = \frac{200(10)^3}{8.5(10)^3} = 23.5$$

Since A_s of one 25M bar is 500 mm², the transformed area of steel is

$$n\,A_s = 23.5(500) = 11{,}750 \text{ mm}^2$$

and taking moments of areas about the neutral axis (see Figure 3-20)

$$190kd(kd)/2 = 11{,}750(900-kd)$$

that is, $(kd)^2 + 123.7kd - 111.3(10)^3 = 0$

the solution to which is $kd = 277$ mm, and

$$I_{cr} = 190(277)^3/3 + 11{,}750(900-277)^2 = 5907(10)^6 \text{ mm}^4 \qquad \underline{\text{Ans.}}$$

Alternatively, Eq. 3-28 previously derived for k may be used.

$$\rho = A_s / bd = 500/[190(900)] = 0.00292$$

$$k = \sqrt{(n\rho)^2 + 2n\rho} - n\rho$$

$$= \sqrt{(23.5\text{x}0.00292) + 2(23.5)(0.00292)} - 23.5(0.00292) = 0.308$$

$$I_{cr} = b(kd)^3/3 + nA_s(d-kd)^2$$

$$= 190(0.308\times900)^3/3 + 23.5(500)[900-0.308(900)]^2$$

$$= 5907(10)^6 \text{ mm}^4 \qquad \underline{\text{Ans.}}$$

The moment of inertia of the cracked section of a doubly-reinforced beam such as that shown in Figure 3-21 may be obtained by a similar analysis to yield:

$$k = \sqrt{(n\rho + (n-1)\rho')^2 + 2[n\rho + (n-1)\rho' d'/d]} - [n\rho + (n-1)\rho'] \qquad \text{Eq. 3-32}$$

and,

$$I_{cr} = b(kd)^3/3 + (n-1)A'_s(kd-d')^2 + nA_s(d-kd)^2 \qquad \text{Eq. 3-33}$$

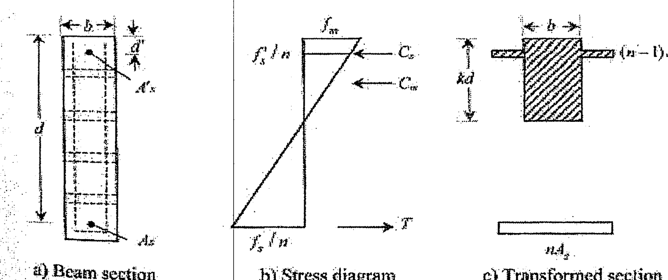
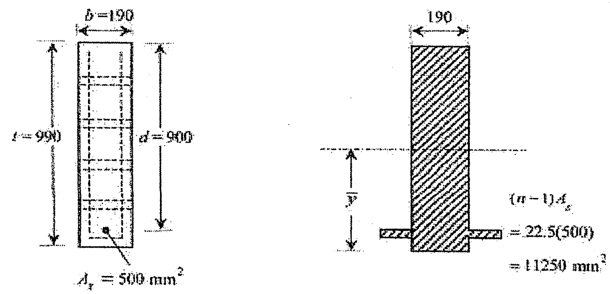


Figure 3-21 Doubly-Reinforced Beam Section

The calculation of the uncracked moment of inertia, I_o, of reinforced sections can follow an analysis similar to that for cracked sections. However, for hand calculation, such an analysis can be unnecessarily tedious and reasonably simplifying assumptions may be made. One assumption is to use the moment of inertia of the gross-section, $I_g = bt^3/12$, in lieu of I_o, the uncracked moment of inertia of the transformed section including reinforcement. Since for I_g the presence of steel is not taken into account, $I_g < I_o$ and deflections will be slightly overestimated. A more reasonable assumption to make is that the centroid of the section lies at the mid-depth of the cross-section, and to calculate I_o from that point. These assumptions are illustrated in the following example.



a) Beam section b) Transformation section

Figure 3-22 Cross-Section of the Beam of Example 3-12

EXAMPLE 3-12 *A 5-course 200 mm masonry beam is reinforced with one 25M bar at an effective depth of 900 mm. If f'_m=10 MPa, find the moment of inertia of the gross-section, I_g, and the uncracked moment of inertia I_o.*

Gross moment of inertia, I_g,

$I_g = bt^3/12 = 190(990)^3/12 = 15.4(10)^9$ mm^4 <u>Ans.</u>

Uncracked moment of inertia, I_o

Referring to Figure 3-22 and taking moments of areas about the base, the centroid of the section is located at

$$\bar{y} = \frac{bt^2/2 + (n-1)A_s(t-d)}{bt + (n-1)A_s}$$

$$= \frac{190(990)^2/2 + (23.5-1)(500)(990-900)}{190(990) + (23.5-1)(500)} = 472 \text{ mm}$$

$$I_o = bt^3/12 + bt(t/2 - \bar{y})^2 + (n-1)A_s[\bar{y} - (t-d)]^2$$
$$= 190(990)^3/12 + 190(990)(990/2 - 472)^2 + (23.5 - 1)(500)[472 - (990 - 900)]^2$$

I_o = 17.1(10)^9 mm^4 <u>Ans.</u>

As noted earlier, if the assumption is made that the centroid lies at the mid-depth of the section, that is, $\bar{y}$ = 990/2 = 495 mm, the calculation simplifies to

$I_o \approx bt^3/12 + (n-1)A_s(d - t/2)^2$

$\approx 190(990)^3/12 + (23.5-1)(500)(900-990/2)^2$

$I_o = 17.2(10)^9$ mm^4 <u>Ans.</u>

In this example I_g underestimates I_o by about 10%, and the approximate value is less than 1% different from the "true" value. Since deflection calculations are approximate at best, the approximation is justified.

Based on research, primarily stemming from work in reinforced concrete, the effective moment of inertia to be used in the calculation of deflection of reinforced masonry beams is obtained by combining the moments of inertia of cracked and uncracked sections as follows (Clause 11.4.3.2):

$$I_{eff} = (M_{cr}/M_a)^3 I_o + [1-(M_{cr}/M_a)^3] I_{cr} < I_o \qquad \text{Eq. 3-34}$$

where, M_{cr} = cracking moment = $(\phi_m f_t + f_{cs}) I_o / y_t$
f_t = flexural tensile strength (Table 5 of S304.1)
f_{cs} = unfactored axial load P/A_e
y_t = distance from centroid to extreme fibre in tension
M_a = maximum moment due to unfactored loads

and, if axial compression is also present in the beam, the bending moment resulting from the position of the axial load P relative to the centroid of the cracked section is included in the determination of I_{cr}. For the most part, of course, beams are not subjected to calculable or intentional axial load.

EXAMPLE 3-13 *A 5-course 200 mm hollow block beam is reinforced with one 25M bar at an effective depth of 900 mm and is fully grouted. The beam is simply-supported at its ends over a span of 6.0 m, and carries a service dead load (including self weight) of 10 kN/m and a live load of 10 kN/m. If f_y=400 MPa, f'_m=10 MPa, and type S mortar is used, estimate the maximum deflection.*

The maximum deflection of a uniformly-loaded beam simply supported over a span L is $\delta = 5wL^4/(384EI)$

and, for this beam

$w = w_D + w_L = 10.0 + 10.0 = 20.0$ kN/m
L = 6.0 m
$E_m = 850 f'_m$ = 8 500 MPa < 20 000 MPa
$I_{eff} = (M_{cr}/M_a)^3 I_o + [1-(M_{cr}/M_a)^3] I_{cr}$

In this expression, I_o and I_{cr} are obtained from the previous examples

$I_o = 17.1(10)^9$ mm^4

$I_{cr} = 5.91(10)^9$ mm^4

and $M_{cr} = (\phi_m f_t + f_{cs}) I_o / y_t$

$f_t = 0.65$ MPa (Table 5, S304.1), $\phi_m = 0.6$, $y_t = 472$ mm

and since there is no axial load $f_{cs} = 0.0$

$$M_{cr} = [0.6(0.65) + 0.0](17.1)(10)^9/472 = 14.13 \text{ kN-m}$$

and $M_a = (w_D + w_L)L^2/8 = 20.0(6.0)^2/8 = 90.0$ kN-m

$$\text{Then } I_{eff} = (M_{cr}/M_a)^3 I_o + [1-(M_{cr}/M_a)^3] I_{cr}$$
$$= (14.13/90.0)^3(17.1)(10)^9 + [1 - (14.13/90.0)^3](5.91)(10)^9$$
$$= 5.95(10)^9 \text{ mm}^4$$

Recalling from Eq. 3-27 that allowance must be made for creep and, since there is no compression steel, and using $S_t = 1.0$ for a period longer than 5 years, the maximum expected deflection due to live load and sustained load, taken here as the dead load plus 50% of the live load, now becomes

$$\delta_{max} = 5[1+(0.5)1.0]w_L L^4/(384EI) + 5(1+1)w_D L^4/(384EI)$$
$$= 5(1.5)(10.0)(6000)^4/[384(8500)(5.95)(10)^9] +$$
$$5(2.0)(10.0)(6000)^4/[384(8500)(5.95)(10)^9] = 11.7 \text{ mm}$$

Therefore, maximum deflection = 11.7 mm Ans.

It is important that the designer keeps close track of units. In the final calculation above, units involving N and mm were used exclusively (note that 20.0 kN/m is also 20.0 N/mm) so that the final deflection is obtained in mm. It should be noted that deflection calculations are generally not as critical for beams as they are for slender walls, which are considered in detail in Chapter 5. The 11.7 mm deflection in the previous example amounts to only span/513.

3.5.2 Crack Control

Like reinforced concrete structures, masonry structures crack. Cracking may be the result of volume changes (shrinkage, creep and thermal effects), support movement, and flexural stresses. This can lead to corrosion of reinforcing steel and connectors and to the disintegration of the mortar due to freeze-thaw activity. Once mortar deterioration starts, moisture can enter more freely and the problem accelerates. Since excessive cracking can compromise strength due to corrosion and/or affect the aesthetics of masonry, a measure of control on crack width must be exercised. Cracking due to volume changes (mainly shrinkage) and support movement is an entirely different problem from cracking due to flexural stresses, one that can be controlled through the

judicious use of *movement joints*, which is the subject of other discussions. This section deals with the control of cracking resulting from flexural tension.

Based on substantial research in reinforced concrete, cracking is controlled by ensuring that the quantity z does not exceed 30 kN/mm for interior exposure and 25 kN/mm for exterior exposure (Clause 11.2.6.2 of S304.1).

$$z = f_s \sqrt[3]{d_c A}(10)^{-3} \le 30 \text{ kN/mm for interior exposure} \qquad \text{Eq. 3-35}$$
$$\le 25 \text{ kN/mm for exterior exposure}$$

In Eq. 3-35, f_s is the stress in the reinforcing steel, which can be computed directly from the analysis presented in Section 3.5.1 (see Eq. 3-31), or may be assumed as 60% f_y; d_c is the cover on the tension steel measured from the centroid of the outermost bar; and A is the area of masonry surrounding the tensile reinforcement, having the same centroid as the tensile reinforcement and divided by the number of bars. This is illustrated in Figure 3-23.

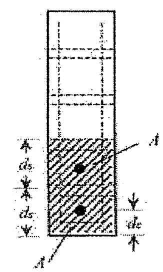


Figure 3-23 Parameters of the Crack Control Expression

These requirements have been taken directly from CSA Standard A23.3: *Design of Concrete Structures*, where the corresponding crack widths are in the order of 0.40 mm and 0.33 mm for interior and exterior exposures, respectively. S304.1 notes that in especially aggressive environments, such as in coastal regions subjected to high winds and rain, this requirement may not be sufficiently restrictive. Notwithstanding the requirements of S304.1, the reader is advised that reinforced masonry is not reinforced concrete. The maximum interior crack width limit of 0.40 mm (largely a cosmetic factor) could easily be 0.50 mm, whereas in particularly aggressive environments (wind, rain, freeze-thaw cycles) the 0.33 mm constraint should perhaps be reduced to 0.25 mm.

EXAMPLE 3-14 *Considering control of cracking, is the masonry beam of the previous example adequate for an interior use?*

Referring to Figure 3-24(a),

$d_c = 90$ mm

$A = 190(180) = 34.2(10)^3$ mm^2

$f_s = 0.6 f_y = 0.6(400) = 240$ MPa

$$z = f_s\sqrt[3]{d_c A}(10)^{-3} = 240\sqrt[3]{90(34.2)(10)^3}(10)^{-3}$$
$$z = 34.9 \text{ kN/mm} > 30.0 \text{ kN/mm}$$

<u>NG</u>

Therefore, the beam is not suitable for interior use. <u>Ans.</u>

To resolve this situation, the designer may choose to select two 20M bars (A_s= 2(300)= 600 mm^2), as shown in Figure 3-24(b), instead of one 25M (A_s= 500 mm^2), in which case the steel stress may be reduced to 5/6 of its former value, and A is divided by the number of bars.

That is, $f_s = 5(240)/6 = 200$ MPa.
In that case

$$z = 200\sqrt[3]{90(34.2/2)(10)^3}(10)^{-3} = 23.1 \text{ kN/mm} < 30 \text{ kN/mm}$$

The beam now becomes suitable for interior use. <u>Ans.</u>

The more rigorous approach to determine the tensile stress in the steel could have been used by applying Eq. 3-31. From Example 3-11,

$$n = \frac{200{,}000}{8{,}500} = 23.5$$

$$\rho = \frac{A_s}{bd} = 0.00292 \text{ and } k = 0.308$$

$$j = (1 - k/3) = 0.9$$

and from Example 3-13,
$M = M_a = 90$ kN-m

$$f_s = \frac{M}{\rho bjd^2} = \frac{M}{A_s jd} = \frac{90(10)^6}{500(0.9)(900)} = 222 \text{ MPa}$$

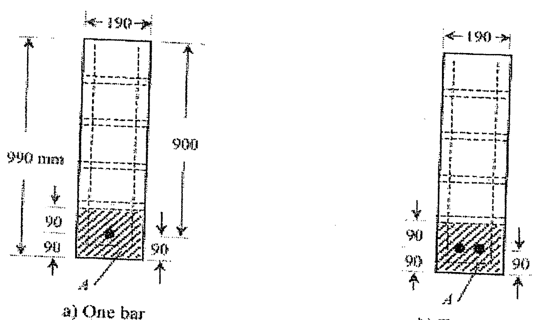


Figure 3-24 Cross-Section of the Beam of Example 3-14

It is clear from the previous calculations that the 60% f_y = 240 MPa is a very reasonable and slightly conservative estimate of f_s. For hand calculation, the use of 60% f_y would be sufficiently accurate and the complexity of calculating f_s from Eq. 3-31 can generally be avoided.

One of the difficulties with applying the S304.1 requirements is that the basic principles supporting it are rather obscure. The following explanation of crack width development is intended to make the mechanism of crack formation in reinforced masonry more understandable.

The width of flexural cracks depends on the tensile stress in the reinforcement, on the location of the bars and on the crack spacing. In reinforced concrete, the concrete is continuous and cracks form at the weak spots, generally at 100 mm to 200 mm spacing. In masonry, on the other hand, crack spacing is normally controlled by the location of the mortar joints, these being the weakest tensile component. Figure 3-25, for example, shows two alternative arrangements for the bottom course of a masonry beam spanning an opening in a wall. On side (a) 200 mm high by 400 mm long bond beam units are used and cracking may be expected to start at 400 mm intervals, although at higher loads the influence of the second course may result in an eventual crack spacing of 200 mm. Side (b) illustrates the use of 400 mm high by 200 mm long lintel blocks which will lead to a 200 mm crack spacing. Flexural cracks in side (a) are likely to be about twice as wide as cracks in side (b). Generally, for outdoor exposures the use of 200 mm long lintel blocks is preferred.

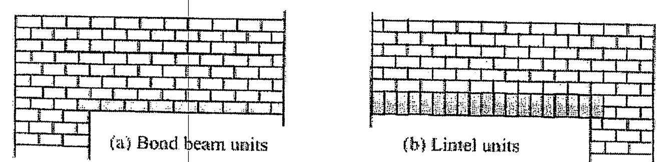


Figure 3-25 Masonry Beams Spanning an Opening

The masonry, being bonded to the steel bars, will undergo an average tensile strain equal to that in the reinforcement. As the masonry can sustain very little tensile strain, the crack width at the level of the reinforcement will be only slightly less than the steel strain multiplied by the crack spacing. Plane sections remaining plane, the maximum crack width is related to the location of the steel relative to the neutral axis, and to the amount of cover, as shown in Figure 3-26.

Crack width at the effective depth is

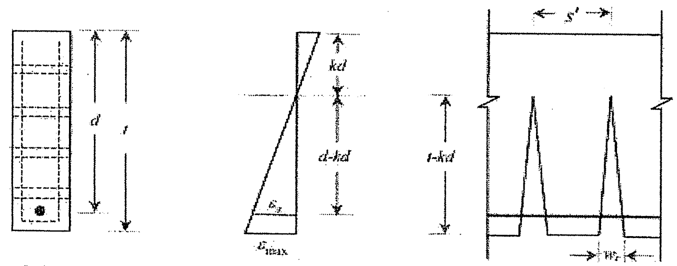
$$\varepsilon_s s' = f_s s' / E_s$$

where, s' = crack spacing.

The maximum crack width, w_c, at the bottom of the beam becomes

$$w_c = \frac{f_s s'(t - kd)}{E_s(d - kd)}$$

and this equation leads to a reasonable, although somewhat overestimated, value of the crack width. The equation also indicates the influence of crack spacing (that is, the head joint spacing) on crack width.



a) Cross section b) Strain distribution c) Idealized cracks

Figure 3-26 Flexural Cracking of a Masonry Beam

Given the maximum allowable stresses in the reinforcement and the head joint spacing, the maximum expected crack width at the level of the reinforcement can be readily calculated.

For example, if $f_s = 0.6 f_y = 0.6(400) = 240$ MPa and head joints are spaced at 200 mm, the maximum expected crack width at the steel location is

$$f_s s' / E_s = \frac{240(200)}{200000} = 0.24 \text{ mm}$$

The crack control provided by satisfying the limits of the parameter z may not be sufficient to control cracking in masonry beams having a depth exceeding 600 mm. Therefore, Clause 11.2.6.3 requires that for such relatively deep beams, an intermediate reinforcement at 400 mm vertical spacing be used. A single bar 15M is required for beams less than 240 mm in width whereas two 15M bars are required for wider beams.

3.6 REINFORCEMENT REQUIREMENTS

Reinforced masonry is effective only if the reinforcement is bonded to the grout, and the grout to the masonry units. If grouting is properly carried out, the absorption by the masonry units and the large area of contact ensures an adequate grout-to-unit bond. On the other hand, the bond between reinforcement and grout is more critical, because the area of contact is comparatively small.

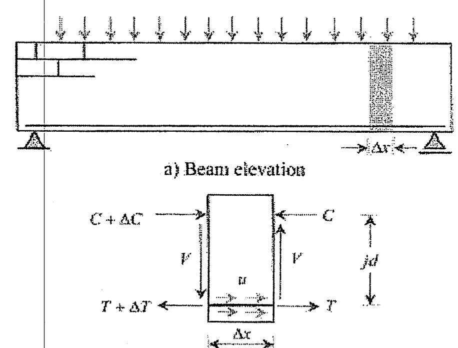
A shear-type *bond stress* acting along the surface of a reinforcing bar is the mechanism whereby force is transferred from grout to the bar. If the resistance to bond stress is exceeded, slip between bar and grout takes place and the reinforcing steel loses its effectiveness. Although standard deformations on the surface of normal reinforcement provide substantial resistance through the mechanical interlocking of bars with grout, the bond must be checked.

The question of bond in beam design is largely one of performing an analytical design check. In general, the reinforcement will have been selected during the design for bending or shear, then the bar sizes and anchorage lengths are checked to ensure that the required development lengths are available. Should they not be present, then a larger number of smaller diameter bars are selected, or greater anchorage lengths, or hooks, are provided. Section 12 of S304.1, *Reinforcement: Details, Development and Splices* covers bond and development requirements, which are, for the most part, self-explanatory practical rules. A detailed treatment of this section is beyond the scope of this book.

There are two basic ways to consider bond. One is to recognize that localized bond stress is directly related to the rate of increase of the tensile force in the reinforcement of a flexural member. This is referred to as *flexural bond stress*. The other is to assume that the bond stress is uniform along the bar and to ensure that the bar has sufficient embedment length to develop the required strength. This length is referred to as the *development length*, l_d. The anchorage of the bar can be further improved through the provision of hooks at the ends of the bars.

3.6.1 Flexural Bond Stress

Figure 3-27(a) shows a beam subjected to transverse loads, and therefore to bending moments and shear forces. The forces acting on a small element of length Δx are shown in Figure 3-27(b). The change in the reinforcing bar force from a value of T to $(T + \Delta T)$ must be transmitted by the bond stress, u, acting on the contact area between the bar and grout.



a) Beam elevation

b) Forces acting on element Δx

Figure 3-27 Mechanics of Bond Stress

A summation of forces along the bar gives

$$(T + \Delta T) - T = \Delta T = u \sum o \Delta x$$

Where $\sum o$ is the summation of bar perimeters. From a consideration of equilibrium of moments,