PSE Design Report

Hydrology and Hydraulics Report

Goose River Bridge #2319, Over Goose River in Belfast

WIN 21874

By *Northstar Hydro, Inc.*

For Stantec and Maine Dept. of Transportation

July 1, 2019

NORTHSTAR
HYDRO

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STATE OF MAINE
ELLEN KNIGHT O'BRIEN
No. 7945
LICENSED PROFESSIONAL ENGINEER

Ellen K. O'Brien
7/1/2019

Goose River Bridge #2319, Belfast

PSE Hydrology/Hydraulics Report

June 28, 2019

Executive Summary: Bridge #2319 conveys flow from the Goose River under Route 1 in Belfast Maine. The Goose River is a tidal stream connected to Penobscot Bay. Water levels at the Bridge site are significantly influenced by a partially breached downstream dam between the bridge and Penobscot Bay. The existing bridge is a 24' single span concrete slab on concrete abutments which is skewed to flow. Analysis of hydrology and hydraulics shows the existing structure does not meet current ME DOT design requirements. After an analysis of several alternatives, the proposed structure is a 24'x10' concrete culvert aligned to flow. It is recommended that inlet control design guidance for culverts be used for design for several reasons. The future of the dam is not known and dam changes could have significant impacts on site. The existing channel is irregular in and near the bridge and may change over time. Finally, upland flows are significant in relation to existing bridge size. The proposed structure meets the inlet controlled culvert design criteria with an HW/D < 0.9. In addition several storm surge and sea level rise analyses were performed and show that the proposed structure is capable of acceptably conveying significant tidal events.

The following summaries are provided for inclusion as needed in the Final Design Package.

Hydrology Summary: This bridge conveys flow from the upstream drainage basin of the Goose River under Route 1. During high storm events on Penobscot Bay, storm surge can overtop the downstream partially breached dam and inundate the bridge with tidal flow passing upstream through the bridge. Flows were computed by MaineDOT using the USGS Regression Formulas and were checked using StreamStats.

Tidal Hydrology Summary: Design values for the project site shown below were selected at NAVD datum for the NOAA Belfast tide station, #8415191. Predicted storm tide surge levels were based on the FEMA Flood Study of Belfast, and were checked against Army Corps of Engineers predictions.

For this study, several tide levels were selected as the tailwater condition for modeling, including the 2017 highest annual tide (or HAT) at elevation 7.3', 0.0' NAVD and the 100-year storm surge with and without wave setup (11.8' and 9.7' NAVD, respectively). HAT was used for modeling due to the unusual configuration of this site. MHW, below the top of partially breached dam, had little impact on the site.

Drainage Area, square miles	21.1
Design Discharge (Q50), cfs	996
Check Discharge (Q100), cfs	1138
Scour Check Discharge (Q500), cfs	1477
Ordinary High Water (Q1.1), cfs	201
Flood of Record, cfs	unknown
Tide Elevations Downstream of Dam	
Mean Lower Low Water, ft NAVD	-5.8
Mean Low Water, ft, NAVD	-5.4
Mean Tide Level, ft, NAVD	-0.3
Mean High Water, ft NAVD	4.8
Mean High Water plus 4’ SLR, ft, NAVD	8.8
Mean Higher High Water, ft, NAVD	5.2
2017 Highest Annual Tide, ft NAVD	7.3
10-year tidal surge, NAVD	8.1
10-year tidal surge with 4’ of sea level rise. NAVD	12.1
100-year tidal surge, NAVD, US/DS	9.7

Hydrology Summary for Plans

Hydraulics Summary: Given significant upland flows, uncertainty about future downstream conditions including the dam and tides, and channel irregularities at the site, it is recommended that culvert inlet control design guidance be used at this site.

The existing structure was analyzed to account for:

- Upland flow under steady flow conditions,
- Tidal fluctuations via unsteady flow modeling, including normal tides and storm tides,
- Potential changes in the future condition of the dam.

The existing structure was found to not meet MaineDOT’s HW/D <0.9 criteria for inlet control even at the 10-year flow level. Stream bottom varies from 1.7’ left to 4.0’ at the center and 7.0’ on the right. With a low chord of 10.2’, maximum D is 8.5’ on the left. For the 50-year flood, HW varies from 9.4 center to 11.7 left, making HW/D = 1.4 minimum. The 10-year storm HW is 10, making HW/D = 1.2 for Q10.

Some evidence of on-going contraction scour was noted in site topography although inspections have not noted specific scour issues.

StreamStats computes a Bank Full Width of 37' for a watershed of this size. The channel area near this bridge did not allow measurement of bank full width at the site. The site is not considered Priority or High Value for fish passage.

For these reasons, structures larger than existing and that meet or exceed MaineDOT's criteria of HW/D < 0.9 for upland 50-year flow were evaluated and a selected option was recommended.

As noted above, an old dam is located downstream of the bridge, between the tidal waters of Belfast Bay and the bridge. The dam is currently partially breached. Based on limited survey data at the dam, the lowest elevation in the partial breach is estimated at 7.3' NAVD. The future impact of the dam on this culvert is uncertain due to unknown future condition of dam and limited survey for this project.

Although this culvert primarily conveys upland flows it may also occasionally be inundated by tidal surge at times when Penobscot Bay is raised by storm surge or future sea level rise above the existing dam elevation of 7.3' (NAVD).

Preliminary design work included investigating at least 7 culvert options. Selected replacement option is 24' X 10' box culvert without embedment. Inverts for this option were set based on apparent natural stream bottom profile. 50-year HW/D for the 24' X 10' culvert with the existing dam is calculated as follows: LC= 13.93, D=10, HW= 8.57. HW/D = 0.86. Dam removal or modifications could impact the HW/D but actual impacts are dependent on dam geometries. This sized culvert provides approximately 1.4' of freeboard for the 50-year flood and 0.9' freeboard from low chord for the 100-year flood. Freeboard to the roadway is more than 10'. Freeboard above Q10 with MHW plus 4' of sea level rise (elevation 11.4' upstream of bridge) is more than 2'.

	Existing with dam	Proposed 24 X 10 box
Low Chord/Top of Box	10.2	13.93
Headwater El. @ Q50, ft NAVD	13.4	12.5
HW/D @ Q50	HW/D=1.4	HWD=0.86
Headwater El. @ Q100, ft NAVD	14.2	13
Discharge Velocity @ Q50, fps	7.8	5.3
Discharge Velocity @ Q100, fps	8.9	5.8
Ordinary High Water (Q1.1), ft NAVD	9.2	9.2
Discharge Velocity @ Q1.1, cfs	1.9	1.6
Clearance @ Q50, ft	-3.2	1.4
50-year storm tide, ft NAVD	9.1	9.1
100-year storm tide ft, NAVD	9.7	9.7

Hydraulic Summary for Plans

Goose River Bridge #2319, Belfast

PSE Hydrology/Hydraulics Report

June 4, 2019

1.0 Introduction and Site Description: This Hydrology and Hydraulics report for Bridge #2319 over Goose River in Belfast was prepared by Northstar Hydro, Inc. (NHI) for Stantec. Stantec is providing consulting services to MaineDOT for design of a replacement culvert. The project location is shown in Figure 1.

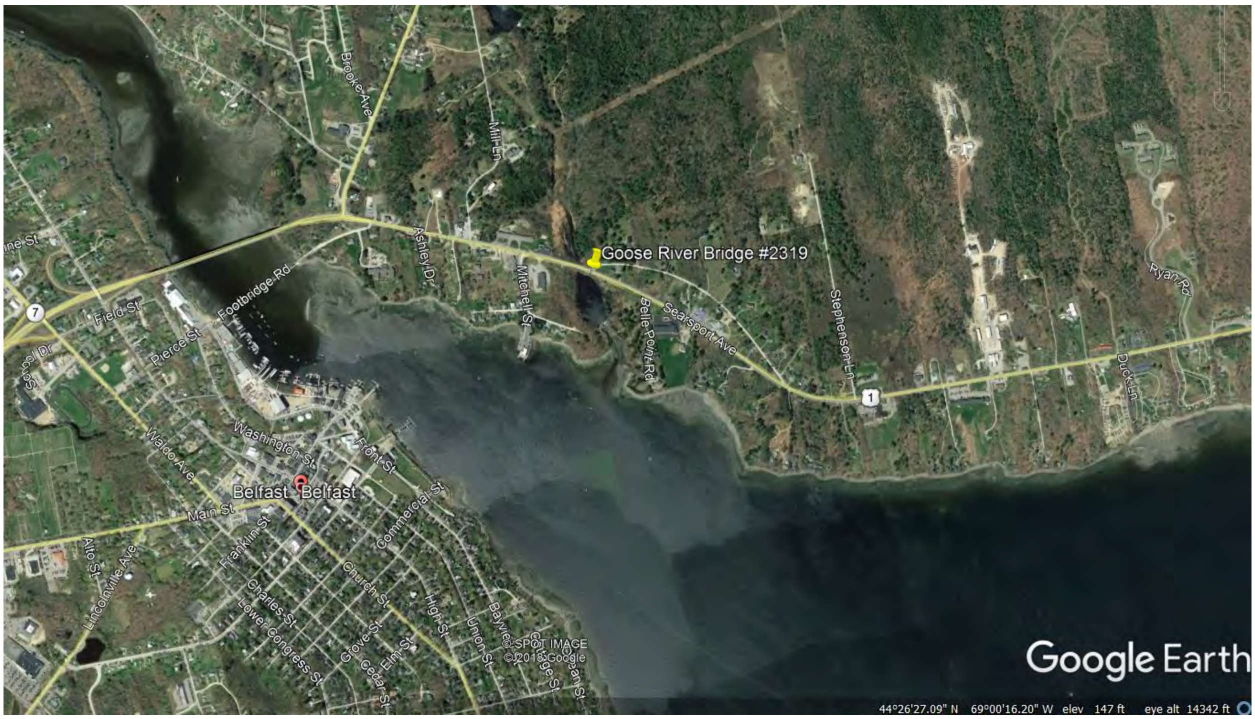

Figure 1. Site location, Bridge # 2319

The existing culvert is a single span concrete slab set on concrete abutments with wingwalls. The span is 24' but the bridge is set at about a 30 degree skew to flow resulting in a net span of 20' perpendicular to flow. The bridge has minimal freeboard for daily flows and is nearly filled with water due to the dam downstream (Figure 2).

Figure 2. Bridge from downstream. MDOT inspection photo. Note low freeboard.

The bridge is located upstream of an old dam which then empties into a tidal stream that connects to Penobscot Bay. Figure 3 shows the project site in close view.

Figure 3. Bridge # 2319 - site close-up

2.0 Existing Data Review

Note that all elevations are reported in NAVD datum unless specifically noted otherwise.

MaineDOT offers the following guidelines in Chapter 2 of the Bridge Design Guide for bridge design clearance and freeboard, noting that this bridge is treated as a culvert by MaineDOT:

Riverine:

- All bridges should be designed to safely convey Q50
- Culverts with inlet control: HW/D (Ratio of Headwater depth vs culvert diameter or height) for Q50 less than or equal to 0.9.
- Culverts with outlet control: Q100 or flood of record should be more than 1' below edge of pavement.

Tidal Structures:

- Culverts HW/D less than or equal to 0.9 at "Q50 with flow at MHW (Mean High Water)".
- Bridges – Design to protect the structure
- Minimum Design Freeboard "2 feet above Q10 (based on MHW) including wave heights".
- Consideration of 4' of future sea level rise (SLR), or MHW plus 4' coupled with upland Q10.

Existing data related to this bridge was compiled and reviewed. Existing information is detailed below.

- FEMA Flood Insurance Study: FEMA prepared the FIS for Belfast in July of 2015. An excerpt from map 23027CO461E is shown in figure 4. The following notes apply to the Effective FIRM: Upstream of the bridge, FEMA mapped the 100-year flood as "Zone A" and did not include a flood elevation designation. Downstream of the bridge, above the dam is listed as Zone AE Elevation 15' and downstream of the dam is Zone VE Elevation 15'. 100-year storm surge is 9.7' and wave action is about 5' above the surge level. (Note that the designation AE typically does not include damaging wave action, which FEMA defines as waves larger than 3'. However, the AE 15 designation seems to imply 5' of wave related flood level above the surge level of 9.7', a somewhat contradictory designation. This does not affect this design work, but is noted here in review of existing information). Based on site reconnaissance and review of maps, wave action at this site should be minimal.

Figure 4. Excerpt from FEMA FIS map of Waldo County.

- Historical Flood data including reports from the USGS on historical floods. This data is summarized in section 3.2 below.
- U.S. Army Corps of Engineers Tidal Profiles – see section 3.2.
- NOAA tide data for stations at Belfast (Subordinate Station 8415191), Bar Harbor (Recording Station 8413320) and Portland (Recording Station 8418150). Tide data is summarized in section 3.2 below.
- Bridge plans and inspection reports from MaineDOT. Inspection reports were reviewed for evidence of scour or channel instability. Scour data is described in section 6.0 below.

Other data were collected and reviewed or added to the GIS database for the project including:

- Aerial photography
- USGS topographic data
- LIDAR data
- Project survey

Site photographs were collected from MaineDOT inspection files and were taken at the site visit.

Figure 5. Looking downstream from road towards dam.

Figure 6. Looking upstream from bridge.

Figure 7. Downstream face of bridge.

Figure 8. Dam downstream of bridge - downstream face of dam.

3.0 Hydrology

This bridge conveys flow from the upstream drainage basin of the Goose River under Route 1. During high storm events on Penobscot Bay, storm surge can overtop the downstream partially breached dam and inundate the bridge with tidal flow passing upstream through the bridge. Each type of flood event is described below.

3.1 **Upland Hydrology:** The Goose River drains 21.10 square miles and includes 3.8 square miles (18%) of wetlands. Flows were computed by MaineDOT using the USGS Regression Formulas and were checked using StreamStats. Table 1 summarizes upland flow data.

Flow Frequency		Flow, CFS
Drainage Area	21.1 square miles	
1-year	Ordinary High Water	201
2-year		378
10-year		692
25-year		864
50-year	Design Discharge	996
100-year	Check Discharge	1138
500-year	Scour Check Discharge	1477

Table 1. Hydrology, Goose River

3.2 **Tidal Hydrology**: Tide data was gathered to understand the range of potential tide elevations under typical tides, high annual tides, and storm conditions. Data includes NOAA tide gage, FEMA Flood Insurance Study information, USGS high water marks, and U.S. Army Corps of Engineers data.

<u>Sea Level Rise:</u>

The May 2018 update to Maine DOT's Bridge Design Guide includes the following:

"2.*3.7 Changes in Sea Level*
Historical data from NOAA shows that the sea level along the Maine coast over the past 80-100 years has risen between 0.5 and 0.75 feet per 100 years relative to local datums. More detailed information is available from the NOAA Tides and Currents website in the Sea Level Trends section. Based on this historical data and NOAA projections, the proposed design should assume 4 feet of sea level rise per 100 years."

<u>Tidal Bridge Guidance:</u>

MaineDOT's Bridge Design Guide recommends the following for tidal bridges:

"Bridges in tidal area - Bridges on tidal rivers/streams should be designed to protect the bridge structure itself. Most of the surrounding land and the approach roadways may be inundated by relatively frequent tidal storm surges. The minimum design freeboard in these areas is 2 feet above Q10 (based on MHW with sea level rise), including wave heights." (page 2-31)

Tides in Maine are recorded in Portland and Bar Harbor. Predicted tide data is published by NOAA for a series of subordinate tide stations, including station 8415191 at Belfast and 8415490 at Rockland. Available Daily tide data is summarized in Table 3. Design values for the project site are highlighted in bold and are listed at NAVD datum for the Belfast tide station.

Tide Level	**Belfast Station 8415191**	
	NAVD datum, ft	MLLW datum , ft
MHHW	**5.2**	11.03
MHW	**4.8**	10.63
MHW + 4' Sea Level Rise	**8.8**	14.23
NGVD	**0.76**	6.59
NAVD	**0**	5.83
MSL	**-0.27**	5.56
MTL	**-0.32**	5.51
MLW	**-5.43**	0.4
MLLW	**-5.83**	0
HAT predicted 12/4/17	**7.27**	13.1
LAT 12/4 17	**-7.93**	-2.1

Table 3. Daily and maximum tides at Belfast. Tide levels are standard NOAA designations. Abbreviations are spelled out in the appendix.

Table 4 summarizes historic flood elevations as reported by the USGS.

Storm Date		**2/2/1976**	**1/9/1978**	**2/7/1978**
Flood of Record in Belfast -USGS report- Marshall Wharf- #25	NGVD/NAVD	10.23/9.5	11.1/10.3	10.25/9.5
US face Passagassawaukeag River Upper Bridge Road, L Abut #24	NGVD/NAVD	8.93/8.2	9.73/9.0	9.03/8.3

Table 4. Summary of Historic Storm Data (USGS)

Table 5 summarizes predicted storm surge levels for the area near Belfast from different sources.

Source of Data	1.1-year	10-year	50-year	100-year	100-year plus wave setup	500-year	Zone/Elev
US Army Corps of Engineers Tidal Flood Elevations, 2012	7.5	8.1	9.1	9.9		11	
COE at Rockland 2012	7.4	8.1	9.2	10		11.1	
FEMA Belfast Flood Study							VE 15
Transect 23 – Rte 1 BR		8.1	9.1	9.7	11.8	11.1	VE 15
Transect 24 - Patterson Pt				9.7	10.9		VE 15-16

Table 5. Available tidal storm surge data for Belfast including FEMA, US Army Corps of Engineers and USGS data. All readings are in Feet, NAVD.

For this study, several tide levels were selected as the tailwater condition for modeling, including the 2017 highest annual tide (or HAT) at elevation 7.3', 0.0' NAVD and the 100-year storm surge with and without wave setup (11.8' and 9.7' NAVD, respectively). In addition, one model run used a MHW tide hydrograph to improve model stability. HAT was used for modeling due to the unusual configuration of this site. MHW is below the top of partially breached dam and had little impact on the site.

The top of the partially breached dam is the same as the 2017 HAT, 7.3'. Thus, under existing conditions, typical tides rarely overtop the dam. With potential future sea level rise, tidal inundation at the bridge could become more frequent.

4.0 Project Survey and Import of Survey to GIS

Maine DOT provided survey of the bridge area and the dam. Survey was imported to the GIS database and meshed with local LIDAR data to create a topographic surface for the project area. Figure 4 illustrates the combined topographic dataset that was used to develop the geometric model for the study area. Note that no channel data was collected between just upstream of the dam and approximately 350 feet downstream of the bridge. The survey extends approximately 200 feet upstream of the bridge. Data was collected for the channel at the up- and down-stream faces of the bridge. The dam was also surveyed, primarily across the dam top. Limited channel data was collected near the dam.

Figure 9 shows both survey data and Lidar elevations for the project area.

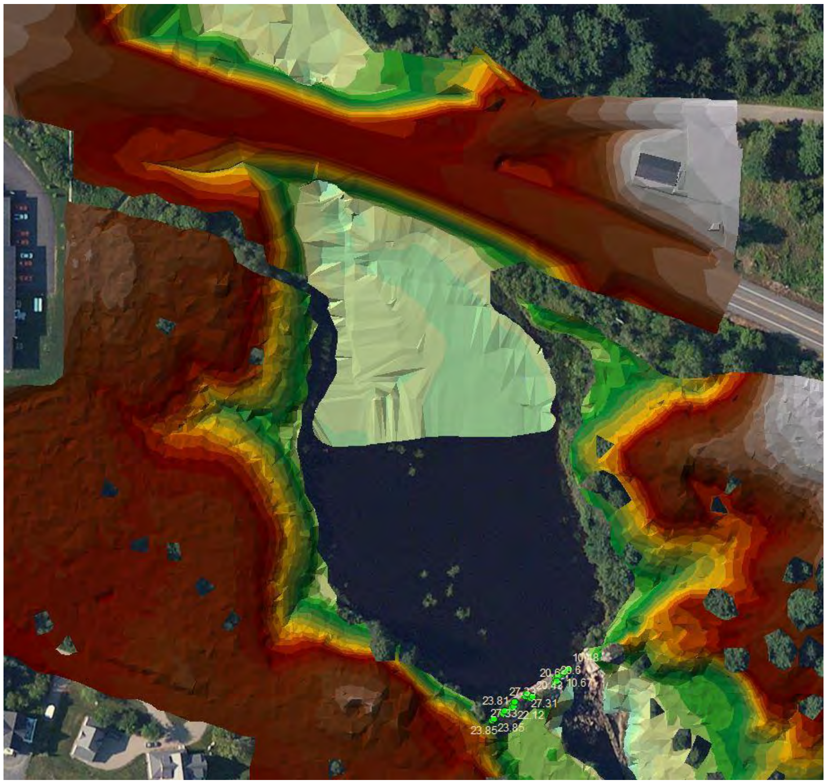

Figure 9. Lidar and Project Survey merged data for topographic coverage

5.0 Hydraulics – HECRAS model

5.1 Geometric Model: The topographic model and bridge plans were combined to form a geometric model of the project site. The model included simulations with the dam as it is now (partially breached), assuming fully breached, and options for an assumed reconstructed dam. Figure 10 shows the cross section layout for the model.

Figure 10. Survey (bright green and red) and LIDAR coverage (green contours) of project area. Geometric model cross sections are shown in black.

Figure 11 shows the existing bridge model simulated as a bridge in HECRAS. Note variable bottom elevations reflecting possible scour and deposition.

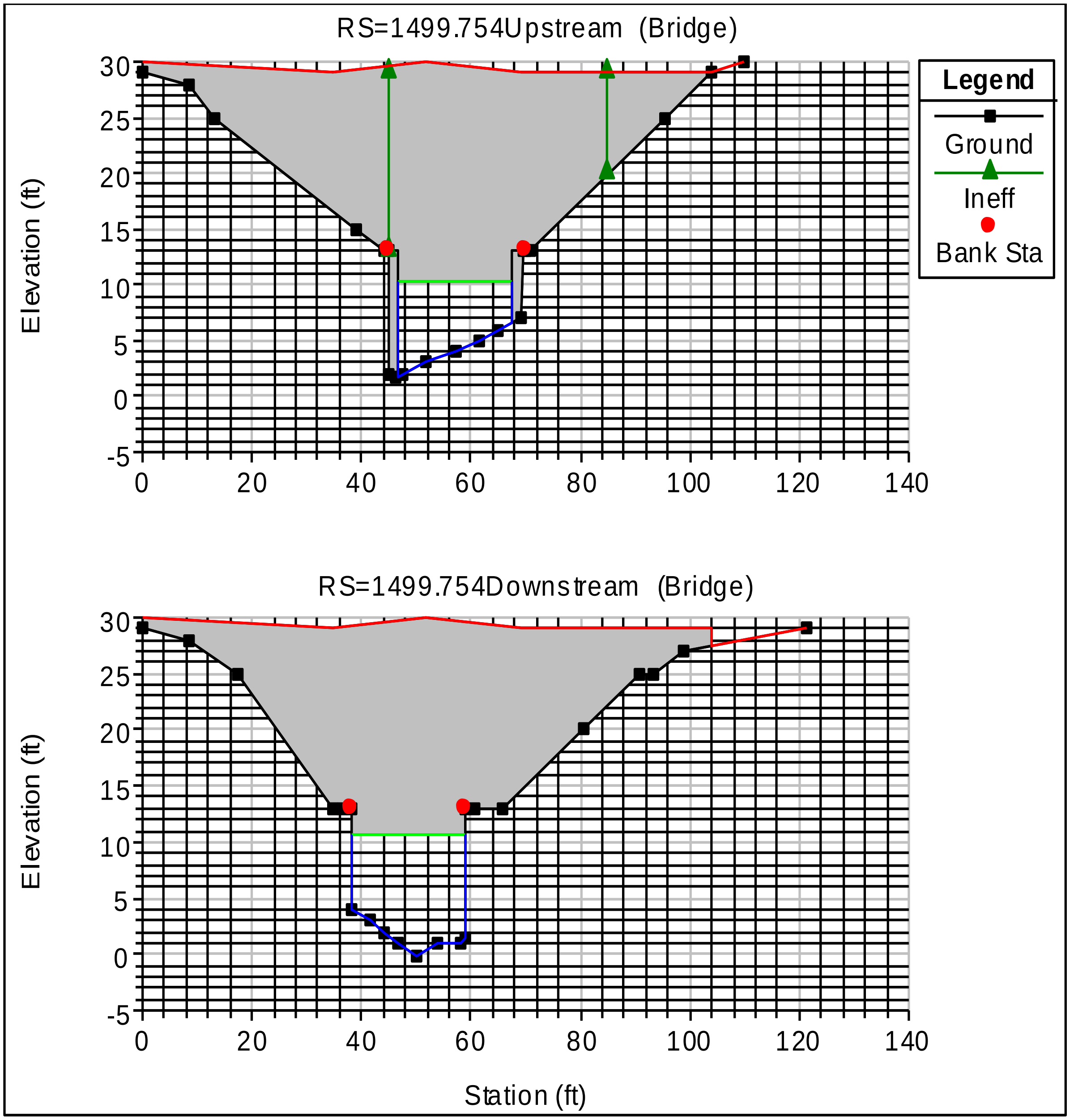

Figure 11. Bridge modeled as a bridge in HECRAS

Figure 12 shows the dam model as represented in HECRAS. For the "no dam" model, the grey area in the model depiction is assumed to be removed. Note that any assumptions of future dam conditions are estimates of possible future geometry and based on limited survey data at the dam and the channel up- and down-stream of the partially breached dam.

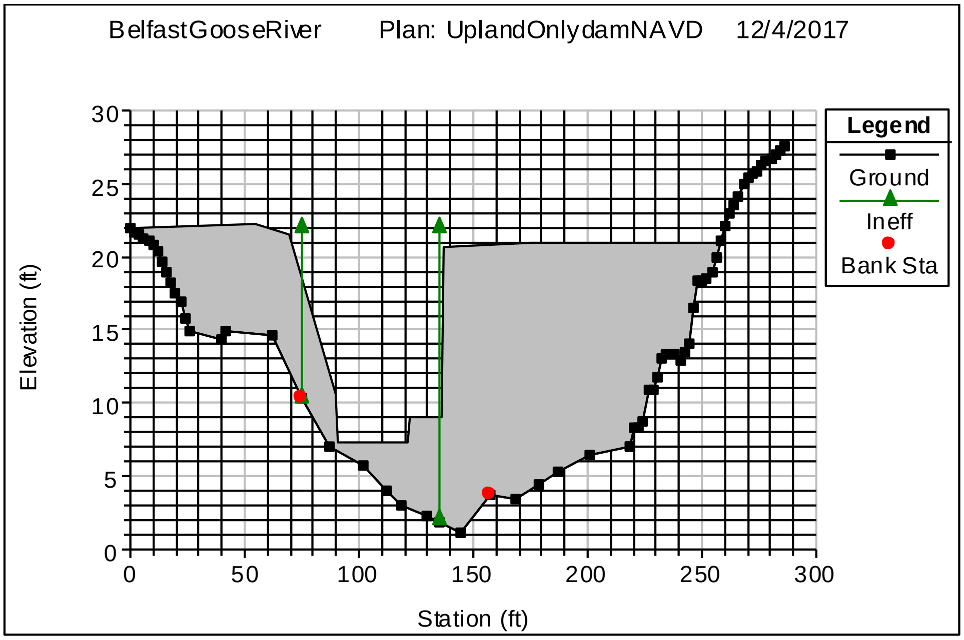

Figure 12. HECRAS model of existing dam, base elevation 7.3'. Additional model runs assumed the dam was fully removed and all "grey" area in the figure would be assumed removed. For full restoration, the top of dam might be at about 21'.

5.2 Flow Models: Upland flows must pass the bridge for all model scenarios. Daily tides could only impact the bridge if the dam were lowered below its current level. Storm surge could impact the bridge whether or not the dam were present. A series of models to simulate existing and potential site conditions were compiled and can be summarized as:

- Steady Flow – Primarily upland flow influence.
    - With existing dam in place, model starts downstream of dam: HAT combined with 1-, 2-, 10-, 25-, 50-, 100- and 500-year upland flows.
    - MHW plus 4' of sea level rise combined with 10-year upland flow, existing dam.
    - Assuming dam removed, model runs were done with tailwater at elevation 0.0 (NAVD) and 7.3' or HAT downstream of dam using same flow distribution as above.
- Unsteady Flow – Upland and tidal surge combined.
    - With existing dam in place – tidal hydrographs for 1-year, 100-year surge, and 100-year surge with wave setup added, combined with 1-year and 100-year upland flows.
    - Assuming removed dam – tidal hydrographs for storm tides and normal tides were run in combination with various upland flows.

Existing Condition Steady Flow Model Results:

The steady flow HECRAS model was used to simulate the existing flow conditions. Models were run assuming that the dam was in place as it is now (partially breached) and assuming that the dam was fully removed. Note that any assumptions of future dam conditions are estimates of possible future geometry and based on limited survey data at the dam and the channel up- and down-stream of the partially breached dam. For information, a possible "no dam" scenario is included in table 8.

Existing Bridge , LC is 10.2' NAVD						
Frequency	WSEL DS of dam	WSEL US of Dam	WSEL US of BR	Velocity, BR fps	HW in feet, US of BR	HW/D where D=height of BR = 10.2-1.7
With Dam		.p11	.f02	.g05		
1-year	7.3	9.2	9.2	1.9	7.5	0.88
2- year	7.3	10	10.1	3.1	8.4	0.99
10-year	7.3	11.1	11.7	5.4	10	1.18
25-year	7.3	11.6	12.6	6.8	10.9	1.28
50-year	7.3	12	13.4	7.8	11.7	1.38
100-year	7.3	12.4	14.2	8.9	12.5	1.47
500-year	7.3	13.2	16.3	11.5	14.6	1.72
Assumed Removed Dam		.p16	.f02	.g04		
25-year	7.3	7.4	10.3	11	8.6	1.0
50-year	7.3	7.5	12	7.9	10.3	1.2
100-year	7.3	7.5	12.7	9	11	1.3
500-year	7.3	7.6	15.6	11.5	13.9	1.6

Table 8. Summary of water levels and velocities for existing conditions and assuming dam removed conditions. Note that .p11, .f02, and .g05 (examples) denote HECRAS files for reference.

Figures 13-15 show the modeled river profile for existing conditions from tide interface (left side of profile) to upstream of bridge (right side) under existing and possible dam removed conditions. Figure 14 has downstream tide set at HAT. Figure 15 shows river profiles for tide at elevation 0.0. Note the following:

- With the dam partially breached (as it is now), downstream tide levels below top of dam do not effect water surface elevations at culvert.
- With the partially breached dam in place, the culvert surcharges (pressure flow) for flows of 10-year and greater. HW/D ≥ 1.
- While there is no chance of overtopping the roadway, the culvert does experience significant pressure flow which may be creating scour issues (see Section 6.0 below).

- Even with the dam assumed removed, tide levels downstream of the dam affect water levels downstream of culvert, but the culvert causes significant rise in water level at most flows.
- Bridge surcharges (pressure flow) for flows of 10-year and greater, HW/D ≥ 1.
- Critical/supercritical flow profiles occur through bridge with low tailwater, i.e. assuming the dam is removed and tide is low.

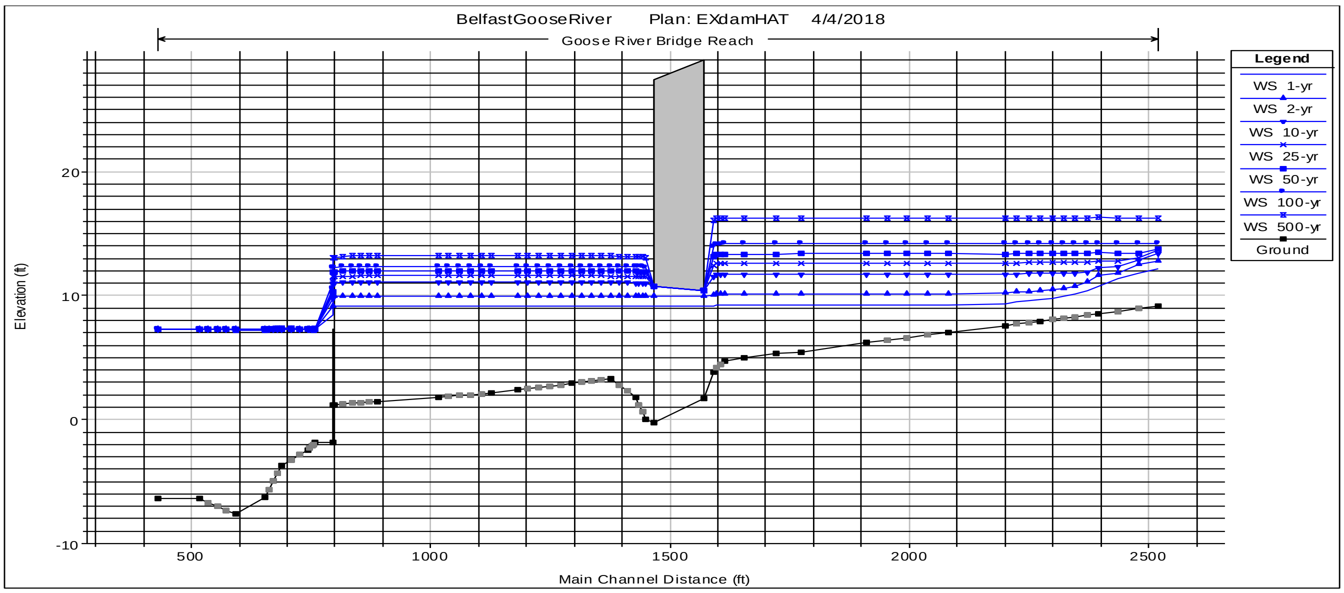

Figure 13. Existing bridge and dam conditions, upland flow with tailwater elevation assumed as HAT.

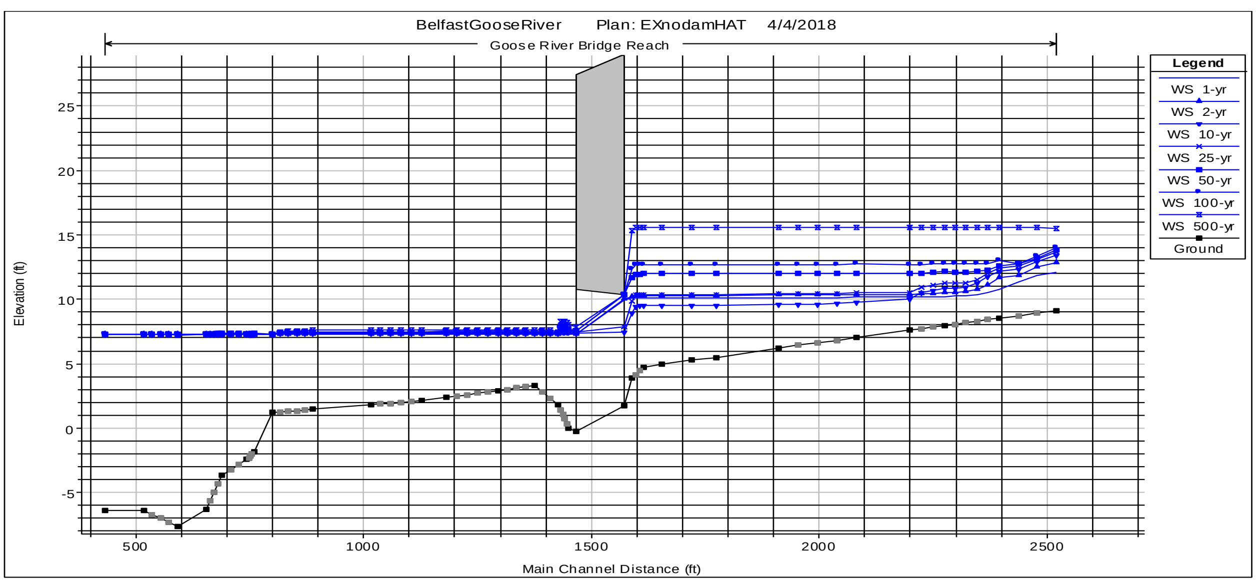

Figure 14. Existing conditions with dam assumed removed and tide at HAT.

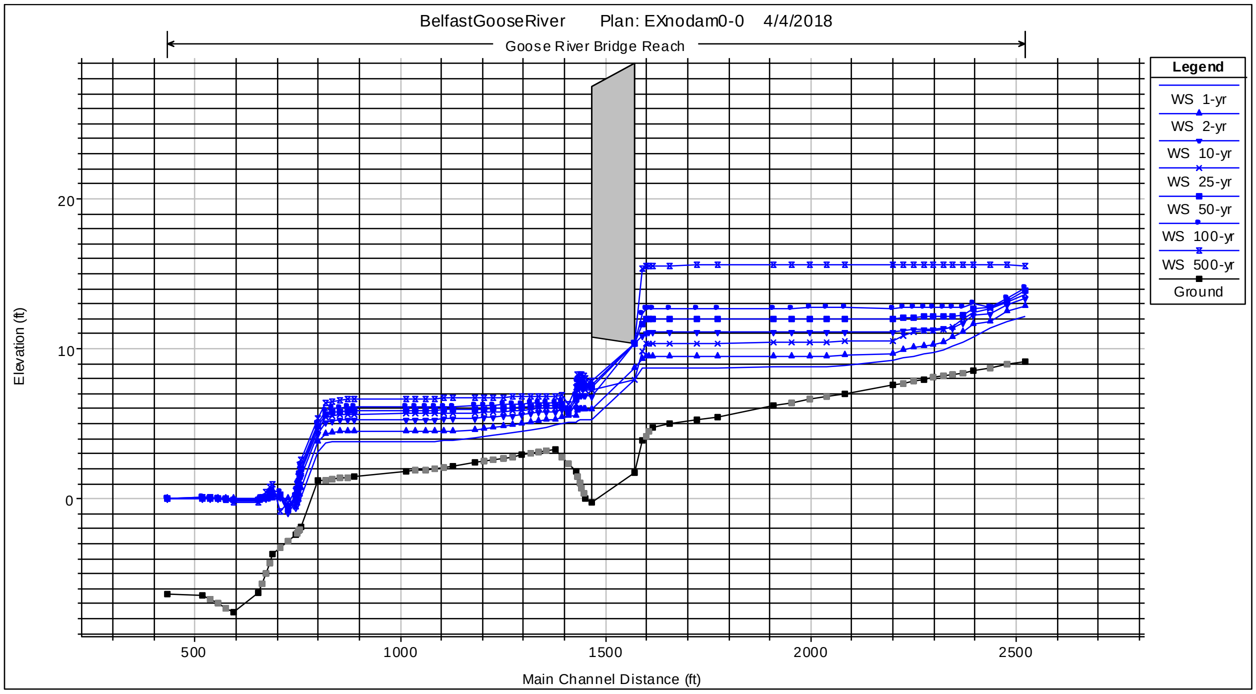

Figure 15. Existing conditions model with assumed removed dam and tide is at mid-tide level. Note high water levels upstream of culvert.

<u>Existing Condition, Unsteady Flow Methods and Results:</u>

To evaluate impacts of the existing bridge on storm surge propagation upstream, tide hydrographs were routed through the bridge from downstream to upstream.

Tidal hydrographs were developed using a tide generator spreadsheet coupled with a storm surge generator spreadsheet to create hydrographs with peak elevations matching HAT and FEMA 100-year and 100-year tides with waves. The following notes summarize modeling results.

- The dam as it exists now blocks daily tides at the bridge.
- The existing bridge is the control point for flow from upstream to downstream.
- Because upland flows are large compared to surge amounts, the bridge dampens tidal flow upstream assuming that upland flow is at least a 1-year high. This assumption is reasonable during a storm event. Tide hydrograph elevations appear to equilibrate from downstream to upstream due to relatively small storage area upstream.
- Design should primarily consider impacts of upland flows. Even with the dam as it exists now, the culvert exerts substantial control over flood elevations. Note that the "dam fully removed" condition model is based on limited survey at the dam and is a best estimate of channel configuration with potential removal. Existing condition models also are based on current channel configuration.
- Full dam removal would likely increase flow velocities.

Proposed Replacement Structures Analysis:

Preliminary Phase I. Preliminary options for structure replacement were investigated using hydraulic model HY-8. Note that HY-8 does not include downstream channel detail such as the dam or channel detail within the culvert. The following options were simulated with HY-8.

* Existing Structure, modeled as box culvert with inlet section smoothed across the opening to Elevation 4.5 and assuming low chord of structure at 10.2 ft. Downstream channel elevation was assumed to be 3.9 ft and the span was modeled as 24 ft. A cross section approximately 74 feet downstream of the existing outlet was used for the downstream control section in HY-8. This section represents the shallowest section in the immediate downstream reach.
* Proposed box structure, same notes as existing with span of 30' and rise of 6'.
* Proposed box structure, same notes as existing with span of 30' and rise of 10'.
* Proposed box structure, same notes as existing with span of 40' and rise of 10'.

Structure	Water Surface Elevations Upstream, ft NAVD			HW/D	Velocity at outlet, fps
Frequency	10-year	50-year	100-year	50-year	50-year Velocity
Existing- 24X5.7' Box (note, span is 20' perpendicular to stream, so results are low)	9.5	11.0	11.7	1.1	13.6
30'X6' Box	8.8	10.0	10.5	0.92	13.4
30' X 10' Box	8.9	10.0	10.5	0.55	13.4
40' X 10' Box	8.2	9.1	9.5	0.46	5.9

Table 9. Summary of HY-8 Preliminary proposed hydraulic model.

Preliminary Phase II. A second round of analyses using model HY-8 were run with culverts in the range of 24 to 26 foot span and 8.5 to 12 foot height. Table 10 summarizes preliminary model results:

Dam condition	Culvert span, ft	Culvert height, ft	Embed-ment, ft	Net height, ft	Low Chord Elev.	Q50 elev. Upstream	HW/D
existing w/dam	24	8.5	0	8.5	10.2		-0.20
with dam	26	10	2	8	11.7	12.6	1.11
	26	11	2	9	12.7	12.5	0.98
	26	12	2	10	13.7	12.5	0.88
no dam	26	10	2	8	11.7	10.2	0.81

Table 10. Summary of HY-8 analyses of box culvert options.

Following targeted HY-8 hydraulic analyses, the project team investigated a box culverts with a range of spans and heights, including 20', 24' and 26' spans and heights of 10' and 12' for preliminary design.

Final Design. Following analysis of PDR results, the 24'X 10' box option was selected and modeled, with inverts raised above the existing scoured inverts and with the culvert located to the northeast of the existing culvert. Table 11 (following page) summarizes existing condition hydraulics compared to the 24' X10' option.

Table 12 (second page following) summarizes additional hydraulic data for the existing culvert and the 24 X 10'option.

Figure 16 shows the water surface profiles for the 24' X 10' option with the partially breached dam in place. The culvert is shifted to the east/northeast and the channel will be rebuilt to match the culvert.

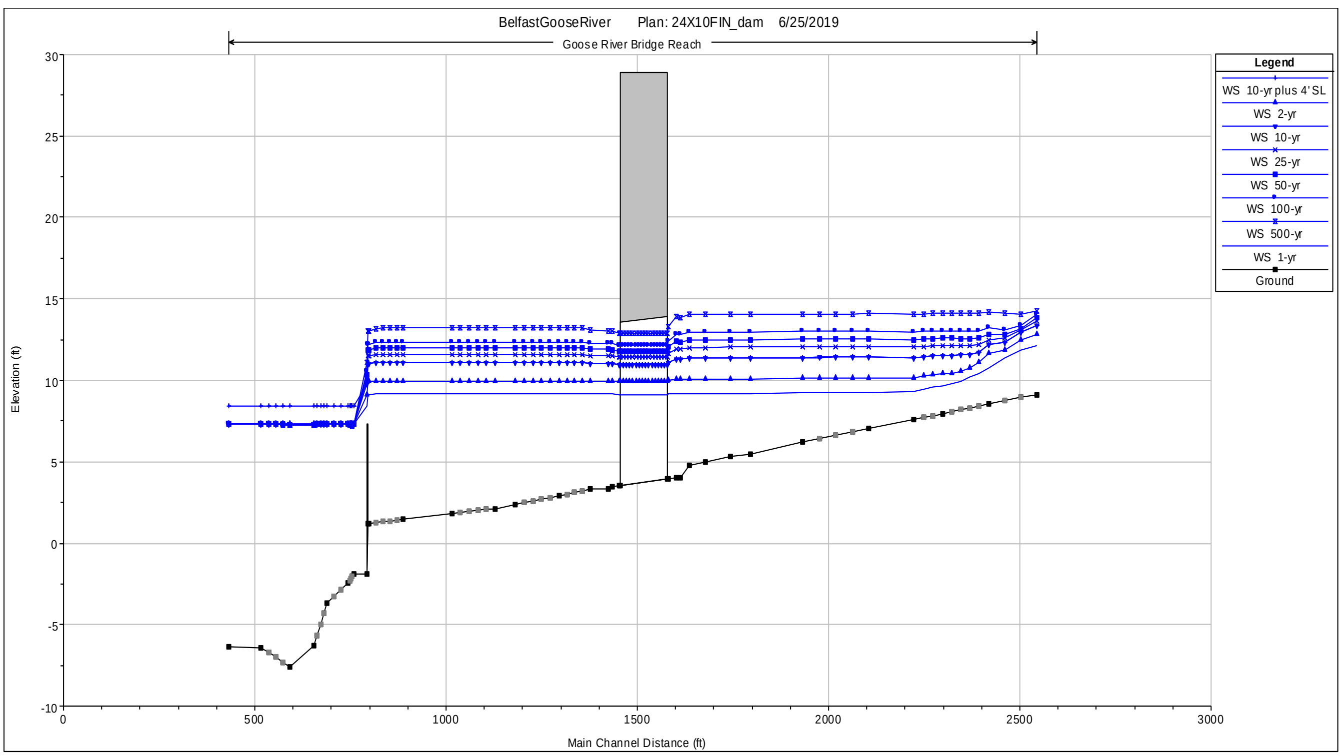

Figure 16. Proposed 24 X 10' box culvert with dam as it exists now. Modeled tide is HAT 2017 AND MHW plus 4' of SLR. Modeled flows range from 1.1 year to 500 year, with 10-year flow against MHW plus 4'.

Summary of Steady Flow Model Results										
Existing Bridge	LC=	10.2	US Inv=	1.7			**24X10 Box**	LC=13.93	Us inv =	3.93
Frequency	WSEL DS of dam, ft	WSEL US of Dam, ft	WSEL US of BR, ft	Velocity, BR fps	HW in feet, US of BR	HW/D where D=height of BR = 10.2-1.7	WSEL US of BR	Velocity, BR fps	HW in feet, US of BR	HW/D where D=height of BR = 10
		.p11	.f02	.g05				.p29	.f02	.g21
1-year	7.3	9.2	9.2	1.9	7.5	0.9	9.2	1.6	5.27	0.5
2- year	7.3	10	10.1	3.1	8.4	1.0	10.1	2.6	6.17	0.6
10-year	7.3	11.1	11.7	5.4	10	1.2	11.4	4.1	7.47	0.7
25-year	7.3	11.6	12.6	6.8	10.9	1.3	12	4.8	8.07	0.8
50-year	7.3	12	13.4	7.8	11.7	1.4	12.5	5.3	8.57	0.9
100-year	7.3	12.4	14.2	8.9	12.5	1.5	13	5.8	9.07	0.9
500-year	7.3	13.2	16.3	11.5	14.6	1.7	14.1	6.9	10.17	1.0
Assumed removed dam		.p16	.f02	.g04				.p31	.g22	.f02
1-year	7.3	7.3	10.1	1.7	8.4	1.0	7.5	2.5	3.57	0.4
50-year	7.3	7.5	12	7.9	10.3	1.2	10.5	11.0	6.57	0.7
100-year	7.3	7.5	12.7	9	11	1.3	11.1	11.1	7.17	0.7
500-yr	7.3	7.6	15.6	11.5	13.9	1.6	12.5	12.6	8.57	0.9

Table 11, Summary of Model Results

Belfast, Bridge #2319 Summary of Hydraulic Data	**Existing Structure – span 20' perpendicular to flow-Ex dam**	**Proposed Structure- 24' X 10' Box, no embed, EX dam**
Low Chord, ft	10.2	13.93
Minimum Top of Road, ft	29	29
DS Surge Level at 10-year Storm	8.1	8.1
DS Surge Level at 50-year Storm	9.1	9.1
DS Surge Level at 100-year tide/with waves	9.7/11.8	9.7/11.8
US Headwater, 100-year surge w/wo waves	10.9	9.7
Maximum Headwater, Upland Q10 and 1-year tide.	11.7	11.4
Maximum Headwater, Upland Q50 and 1-year tide.	13.4	12.5
Maximum Headwater, Upland Q100 and 1-year tide	14.2	13
Maximum Discharge Velocity at Q50, fps (1-year tide) w/ dam and assumed removed dam	7.8	5.3
Maximum Discharge Velocity at Q100, fps (1-year tide)	8.9	5.8
Ordinary High Water Elevation (1.1-yr tide), ft (HAT 2017)	9.2	9.2
Clearance @ Q10, HAT, ft	-1.5	2.53
Clearance @ Q50, HAT, ft	-3.2	1.43
Clearance @ Q100, HAT, ft	-4	0.93
Clearance @ 100-year tide no waves	0.5	4.23
HW/D Q50	1.4	0.9
Clearance @ Q10 plus MWH tide plus 4' SLR	-1.5	2.53
Bridge Opening Area, ft^2	128	240

Table 12. Summary of Hydraulic Data

6.0 Scour

Evidence of ongoing scour can be seen through examination of the river profile and contours on survey plan. Evidence includes:

- The downstream section is notably lower than the upstream.
- The downstream section has a low point in the center, much lower than the general stream profile.
- Downstream of the bridge and the apparent scour hole, contours indicate deposition of scoured material.
- The upstream section has a low point on the left or Eastern side of the cross section.

Available data for the stream profile suggests deposition due to the dam. The bridge area appears to have lower thalweg elevations than the general stream profile. Inspection reports do not pick up scour related issues but do show shifting bottom materials and a beaver dam. In the 2003 inspection report, water depths were 4' different from upstream right to downstream left, although water was essentially flat. This may be the result of a beaver dam. In 2008, and 2010, water depths were nearly the same throughout the bridge. Current contours based on project survey show significant differences in bottom elevation from upstream to downstream.

While there are signs of scour, footings currently appear to have adequate cover. An approximate plot of bridge configuration with estimated footing locations is shown in figure 17, based on existing bridge plans.

Two borings were collected by New England Test Borings and logged by Schonewald Engineering for Maine DOT in January of 2018. Geotechnical Data is summarized in Table 13.

Boring number	Depth of sample	Elevation	D50, mm
101	road	29.5	
	10-12'	17.5-19.5	0.075
	20-22'	7.5-9.5	<.075
	27-29'	0.5-2.5	2.5
	30-32'	-2.5 to -0.5	3
	35-37'	-5.5 to -7.5	0.15
	Basal till	-20	
	Rock	-27.1	
102	Road	28	
	Rock	-11	

Table 13. Summary of Geotechnical Data.

Estimated scour calculations were performed for the existing bridge using the steady flow model that assumes no dam, 100- and 500-year upland flow, and mid-tide start elevation. D50 was assumed to be 1 mm, a conservative assumption given D50 of approximately 3mm at the channel surface elevation.

Estimated calculated contraction scour for the existing bridge is as follows:

- 100-year- 15.5 feet below current bed depth, or elevation -13.8 on the upstream end.
- 500-year – approximately 25 feet below current bed depth or elevation -24.

Note that rock elevations at borings 101 and 102 respectively were found to be -27' and -11, so scour could reach rock. Scour calculations were done for overburden materials only.

Abutment scour was not calculated as normal approach to abutment scour is addition of scour protection materials. Long term bed scour is not apparent, based on footing depths, but site conditions indicate likely local and contraction scour occurring. For future dam configurations, the likelihood of scour could increase due to increased flow velocities, but reduced pressure flow could alleviate some scour as well.

The proposed bridge is a box culvert so scour is not expected to be an issue, but inlet and outlet erosion protection are included in the design.

Figure 17 illustrates potential 100-year scour elevations for the upstream end of the existing bridge, and shows assumed footing elevations.

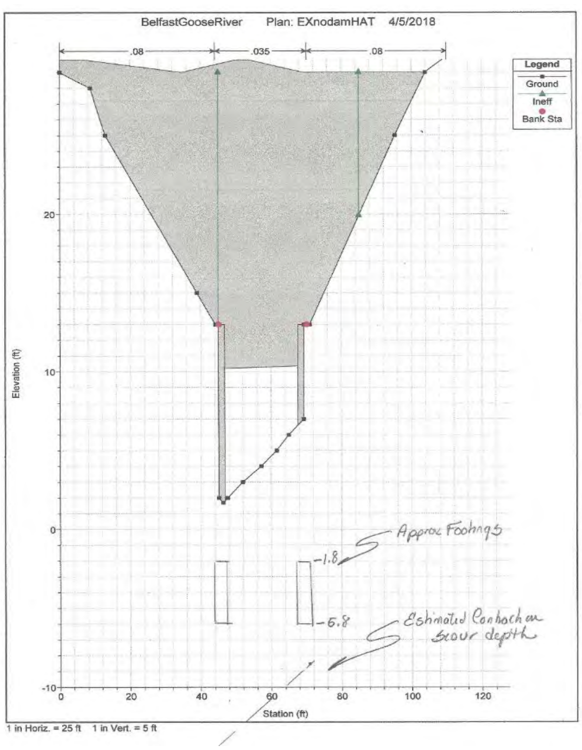

Figure 17. Contraction scour, 100-year, existing bridge assuming no dam.

7.0 Summary and Conclusions

Site Conditions Summary:

Primary flow at this bridge is related to runoff generated in the watershed of the Goose River with a drainage area of 21.10 square miles. The project is upstream of a partially breached dam which drains to Penobscot Bay. Due to the height of the partially breached dam, tidal waters rarely affect the bridge except during storm surge.

The top of dam elevation is 7.3'NAVD, the height of the highest annual predicted tide (HAT) in 2017. MHHW is 5.2', below the top of dam. FEMA mapped the bridge site at zone AE, Elevation 15, but wave action is expected to be minimal.

Bankfull width for a watershed of this size is 37' according to regression analysis in StreamStats (appendix).

The site is not considered Priority or High Value for Fish Passage.

Modeling Summary:

Upland flow through the culvert was modeled with HECRAS in steady flow mode, assuming starting tide levels of HAT, mean tide, and MWW plus 4' SLR. The model was run under existing channel conditions and with an assumed dam removed condition for the existing culvert.

Tidal storm surge effects were modeled with the unsteady flow version of HECRAS with peak tide elevations of HAT, 100-year surge (9.7') and 100-year surge with wave setup (11.8').

Model HY-8 was employed for trial runs for replacement alternatives, with options including spans of 20-40' and heights of 8.5-12'.

HECRAS was employed for final model runs for box culverts with spans of 20-, 24- and 26 ft. and height of 10' and 12' with 0' and 2' of embed.

Based on analysis of model results and site conditions, a final box culvert size of 24' X 10' was selected with inverts raised to match typical stream bed conditions. The culvert will be aligned with flow and will be located to the northeast of the existing bridge.

Summary of Model Results:

The HECRAS model was used to reach the following conclusions for the site.

Under existing conditions the bridge surcharges (HW/D >1) for upland flows of 10-years and greater, regardless of downstream conditions.

There is little to no chance of overtopping the roadway, but the bridge experiences significant pressure flow which could aggravate scour or erosion at inlet and outlet, as well as channel erosion.

With the dam in an assumed removed condition, tide levels below top of dam could potentially affect water levels downstream of the bridge, but modeling indicates little impact on levels upstream of the bridge during daily tides or storm conditions.

The model indicates that during a tidal surge event, the bridge would allow full transmittal of the tidal hydrograph upstream as occurs now.

Potential scour was estimated for the existing 20' span bridge only. Contraction scour could reach depths of 15-25' below current stream levels for the 100- and 500-year storms respectively if no bedrock were present. The bridge area shows some evidence of ongoing scour which is most likely due to contraction but may also reflect local scour at the edges of the opening. Borings showed bedrock at elevation -11 to -27 ft.

Summary of Design Guidance:

MaineDOT Bridge Design Guide specifies HW/D < 0.9 at 50-year flow for inlet controlled culverts, or 1' below pavement at Q100 for outlet controlled culverts.

Tidal structures require HW/D < 0.9 for Q50 plus MHW at culverts or Q10/Tide MHW plus 2' for bridges. Maine DOT recommends considering 4' of SLR at MHW plus upland Q10.

The design should primarily consider transmission of upland flows with tide impacts a minor consideration.

Modeling indicates that the existing bridge horizontal opening is not only somewhat narrow, but the low chord also is not high enough for the level of flows that this watershed generates and the effect of the dam.

It is recommended that inlet control design guidance for culverts be used for design for several reasons. The future of the dam is not known and dam changes could have significant impacts on site. The existing channel is irregular in and near the bridge and may change over time. Finally, upland flows are significant in relation to existing bridge size.

Summary of Recommendations/Conclusions:

The 24' span with a height of 10' is recommended. Q50 HW/D for the 24 foot X 10' span with existing dam conditions is 0.9 with US invert of 3.93'.

The proposed 24’ X 10’ culvert aligned with flow improves the hydraulic opening compared to the existing culvert. The culvert is over 10’ below roadway grade with no known flood history and therefore has substantial freeboard.

Under existing conditions, it is predicted that the 100-year upland flood would surcharge the existing bridge by about 4’, but would pass the 24’ X 10’ box with about 0.9’ of freeboard or an HW/D of 0.9.

The modeled final option was based on inverts set at 4’ upstream and 3.5’ downstream’. Inverts where the top of culvert starts are slightly different (3.93’ 3.56’).

Q10 at MHW plus 4’ of sea level rise for the new bridge causes a headwater elevation of 11.4’, which is more than 2’ below the proposed low chord of 14’. Therefore the 2’ of freeboard standard is met for tidal bridges.

8.0 References

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- Federal Emergency Management Agency. Flood Insurance Study and Flood Hazard Boundary Maps, Preliminary, Sagadohoc County, Maine. July 6, 2015
- Maine Dept. of Transportation. Bridge Design Manual. August 2003, updates to July, 2017
- Maine DOT, Bridge Plans, Benjamin River Bridge #2319, December 1940 and May, 1921, Scour Inspection Reports through 9/9/2016
- NOAA tide data: NOAA maintains subordinate stations at Belfast (8415191) and Rockland (8415190).
- NOAA tide data: Bar Harbor, Primary Gage, Station 8413320 and Portland Station 8418150. http://tidesandcurrents.noaa.gov/noaatidepredictions/NOAATidesFacade.jsp?Stationid=8413320
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- U.S. Army Corps of Engineers, Hydrologic Engineering Center. HEC-RAS River Analysis System. Version 5.03. 2016 Davis, CA
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- U.S. Department of Transportation. Federal Highway Administration. Bridge Scour and Stream Instability Countermeasures. HEC-23. Volume 2. September, 2009. FHWA-NHI-09-112. DG 14, Rock Riprap at Bridge Abutments and DG 4, Riprap Revetment
- U.S. Dept of Transportation, Federal Highway Administration. HY-8 Model, Version 7.40 February 25, 2015. Environmental Modeling and Research Laboratory.
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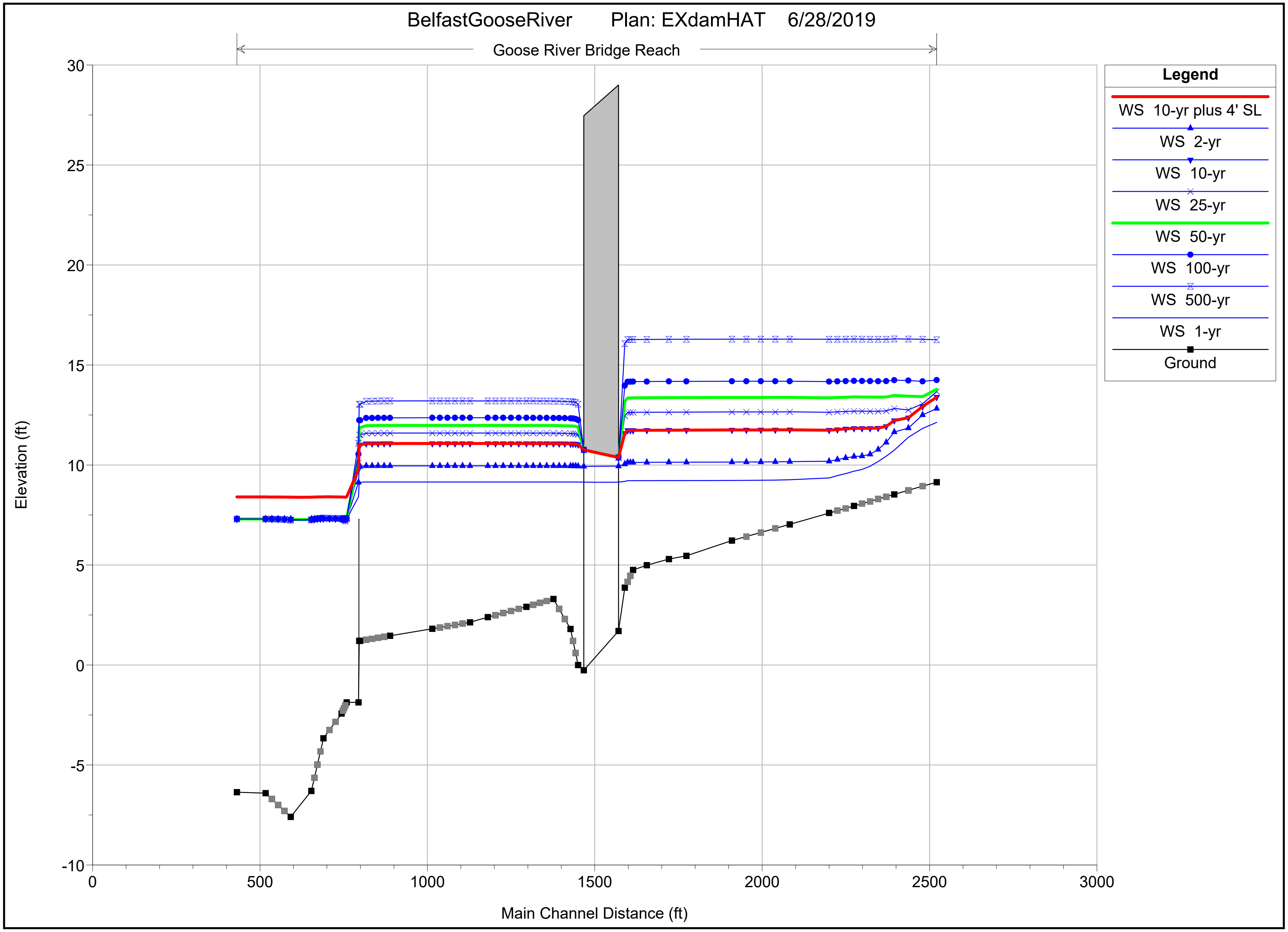
- Maine Dept. of Transportation. Soil/Rock Exploration Log. DRAFT. Goose River Bridge #2319. Belfast, Maine. 1/9,11,19/2018
- U. S. Dept. of the Interior, Geological Survey, with Maine Dept. of Transportation. Estimating the Magnitude and Frequency of Peak Flows for Streams in Maine for Selected Recurrence Intervals. Water Resources Investigations Report 99-4008.
- https://streamstats.usgs.gov/ss/. USGS Streamstats. Beta Version 4.

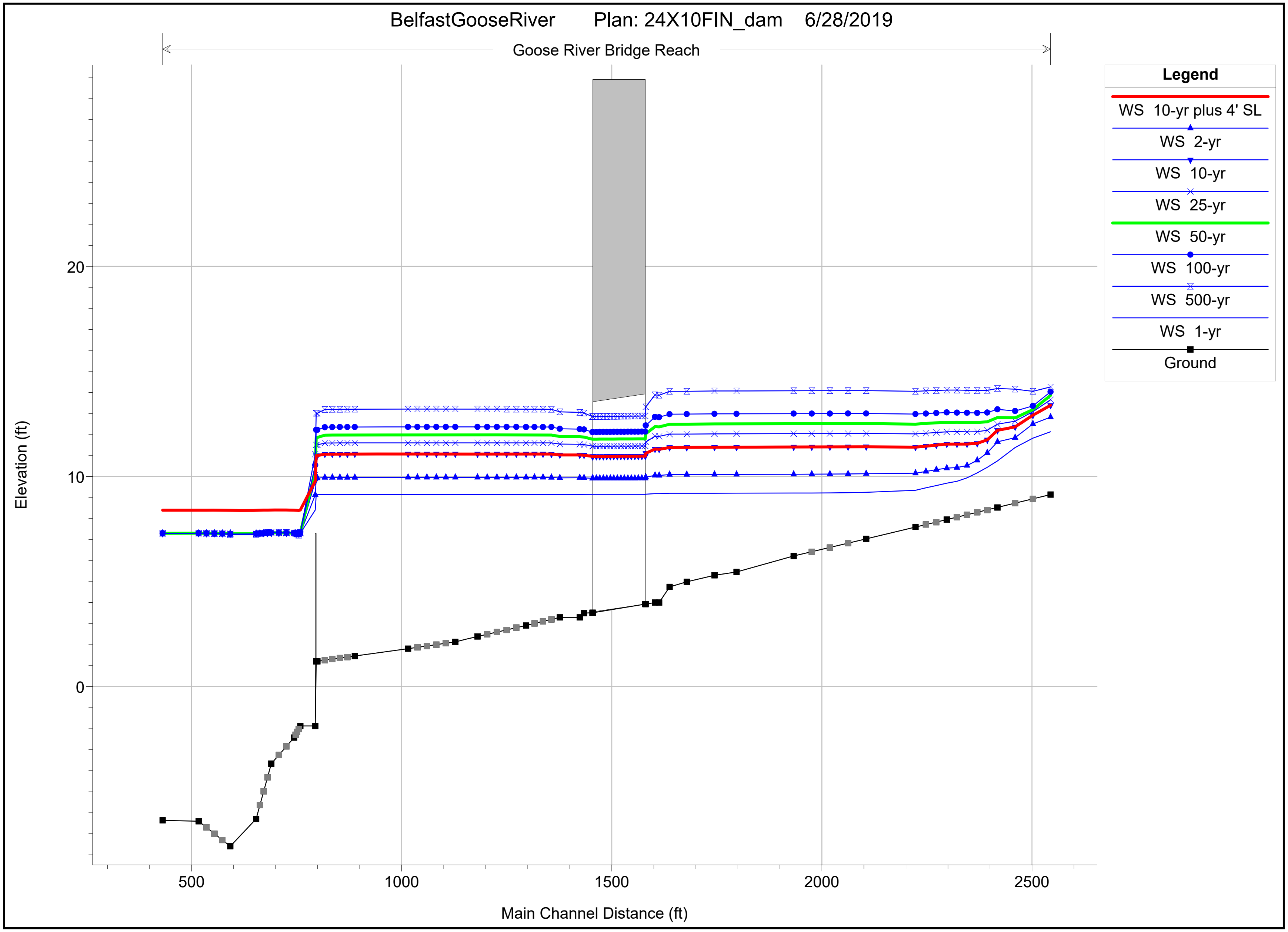
Appendix:

- Tide Level Abbreviations
- Water Surface Profiles, Q1.1, Q10, Q25, Q50, Q100 and Q500 against HAT 2017 and check on MHW plus 4' against Q10.
    - Existing Bridge
    - Proposed Bridge
- Contraction Scour, Existing Bridge
- Hydrology, StreamStats

Tide Level Abbreviations

MHHW- Mean Higher High Water
MHW – Mean High Water
NGVD – National Geodetic Vertical Datum of 1929
NAVD – North American Vertical Datum 1988
MSL- Mean Sea Level
MTL- Mean Tide Level
MLW – Mean Low Water
MLLW – Mean Lower Low Water
HAT predicted 12/4/17 – Highest Annual Tide
LAT Lowest Annual Tide
SLR, Sea Level Rise


BelfastGooseRiver Plan: EXdamHAT 6/28/2019
Goose River Bridge Reach
Legend
WS 10-yr plus 4' SL
WS 2-yr
WS 10-yr
WS 25-yr
WS 50-yr
WS 100-yr
WS 500-yr
WS 1-yr
Ground
Elevation (ft)
Main Channel Distance (ft)
30
25
20
15
10
5
0
-5
-10
0
500
1000
1500
2000
2500
3000


BelfastGooseRiver Plan: 24X10FIN_dam 6/28/2019
Goose River Bridge Reach
Legend
WS 10-yr plus 4' SL
WS 2-yr
WS 10-yr
WS 25-yr
WS 50-yr
WS 100-yr
WS 500-yr
WS 1-yr
Ground
Elevation (ft)
20
10
0
500
1000
1500
2000
2500
Main Channel Distance (ft)

Contraction Scour, Existing Bridge.

Goose River Bridge, Belfast #2319

Contraction Scour EOB 12/15/17

REV 4/5/18

Live Bed Scour

$$y_2/y_1 = \left(Q_2/Q_1\right)^{6/7}\left(\frac{W_1}{W_2}\right)^{K_1}$$

section 1 = upstream main channel
assume section 1706

section 2 = Contracted section @ Bridge

y_0 = existing depth @ section 2

$y_s = y_2 - y_0$

$K_1 = 0.59$ w/ D50 assumed = 1MM

100-year

$$y_2/6.7 = \left(\frac{1138}{1135}\right)^{6/7}\left(\frac{177}{20}\right)^{.59}$$

$y_2 = 24.3$, $y_0 = 24.3 - 8.7 = 15.5$

HecRas = 12.9

500-year

$$y_2/9.4 = \left(\frac{1477}{1463}\right)^{6/7}\left(\frac{177}{20}\right)^{.59} = 34.$$

$34.0 - 8.7 = 25.3$

HecRas = 15.3

Scour Elev 100 – $1.7 - 15.5 = -13.8$

500 – $1.7 - 25.3 = -23.6$

WIN:	21874.00		**Project Name:**	Belfast, Goose River Bridge #2139	
Town:	Belfast		**Stream Name:**	Goose River	
Route No.	US-1		**Bridge Name:**	Goose River Bridge	
Asset ID:	2139		**Analysis by:**	DFB	
Lat:	44.4328	**Long:** -68.99425	**Date:**	8/7/2017	

Peak Flow Calculations by USGS Regression Equations (Hodgkins, 1999 & Lombard/Hodgkins, 2015)

Enter data in blue cells only!

	km^2	mi^2	ac	
				Enter data in [mi^2]
A	54.65	21.10	13504.0	Watershed Area *DRNAREA*
W	9.75	3.8	2410.5	Wetlands area (by NWI)
P_c	501138	4928877		watershed centroid (E, N; UTM 19N; meters)
County	Somerset S			*choose county from drop-down menu*
pptA	39.5			mean annual precipitation (inches; by look-up)
SG	0.05			sand & gravel aquifer as decimal fraction of watershed A

Worksheet prepared by:
Charles S. Hebson, PE
Environmental Office
Maine Dept. Transportation
Augusta, ME 04333-0016
207-557-1052
Charles.Hebson@maine.gov
ver. 2017 Jun. 09

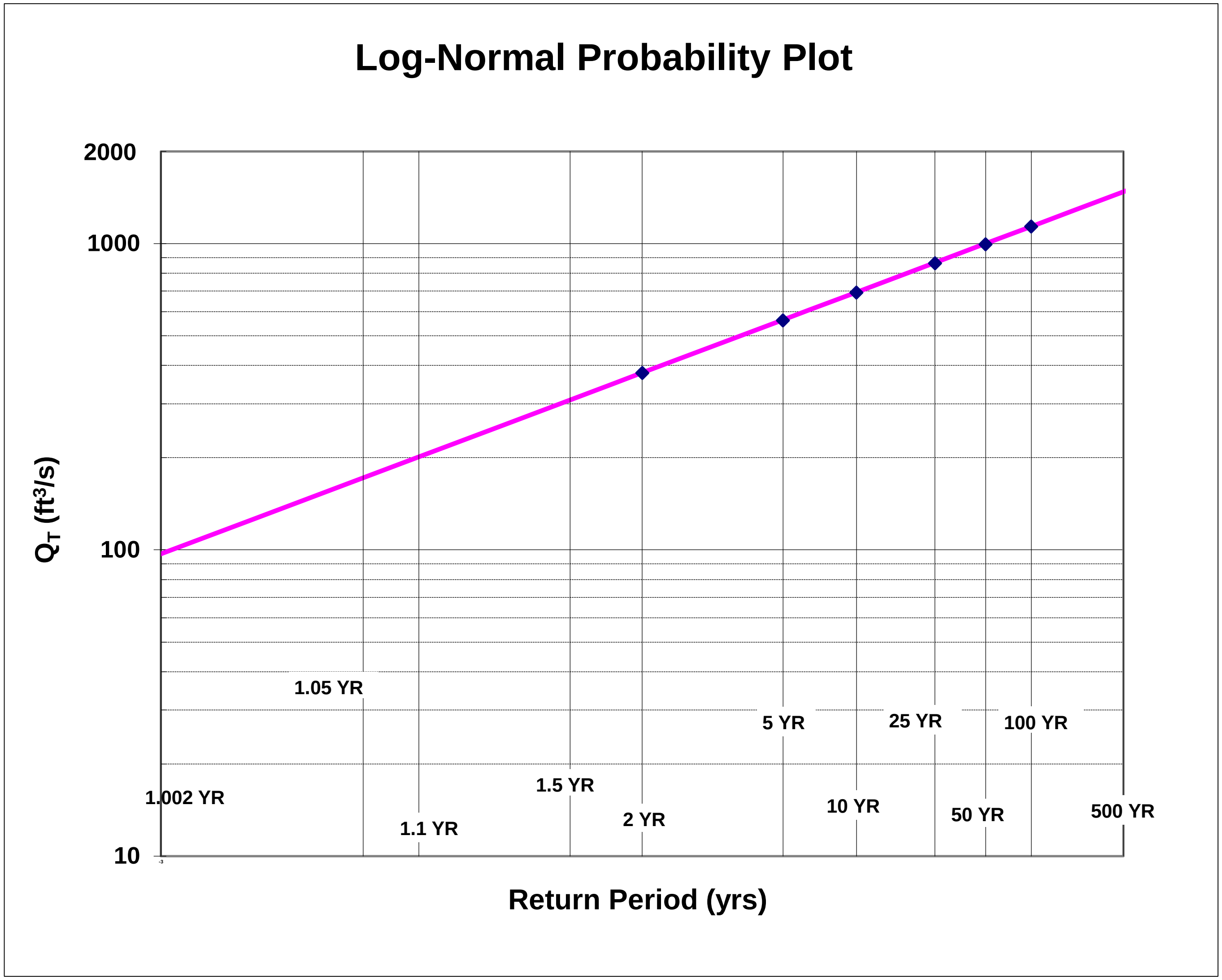
A (km^2)	54.65	**Conf Lvl**	0.67
W (%)	17.85		NWI Wetlands % *STORNWI*

References:
Hodgkins, G.A., 1999.
Estimating the magnitude of peak flows for streams
in Maine for selected recurrence intervals
WRIR 99-4008, USGS Augusta, ME

Lombard, P.J. & G.A. Hodgkins, 2015.
Peak flow regression equations for small, ungaged streams in
Maine - Comparing map-based to field-based variables
SIR 2015-4059, USGS, Augusta, ME

Ret Pd	**Peak Flow Estimate**			
T (yr)	**Lower**	**Q_T (m^3/s)**	**Upper**	**Q_T (ft^3/s)**
1.1		5.70		201.2
2		10.72		378.4
5		15.89		561.2
10		19.60		691.9
25		24.47		864.1
50		28.21		996.0
100		32.23		1137.9
500		41.82		1476.8

$Q_T = b \times A^a \times 10^{-wW}$


Log-Normal Probability Plot
2000
1000
100
10
Q_T (ft³/s)
1.05 YR
5 YR
25 YR
100 YR
1.5 YR
1.002 YR
10 YR
50 YR
500 YR
2 YR
1.1 YR
Return Period (yrs)

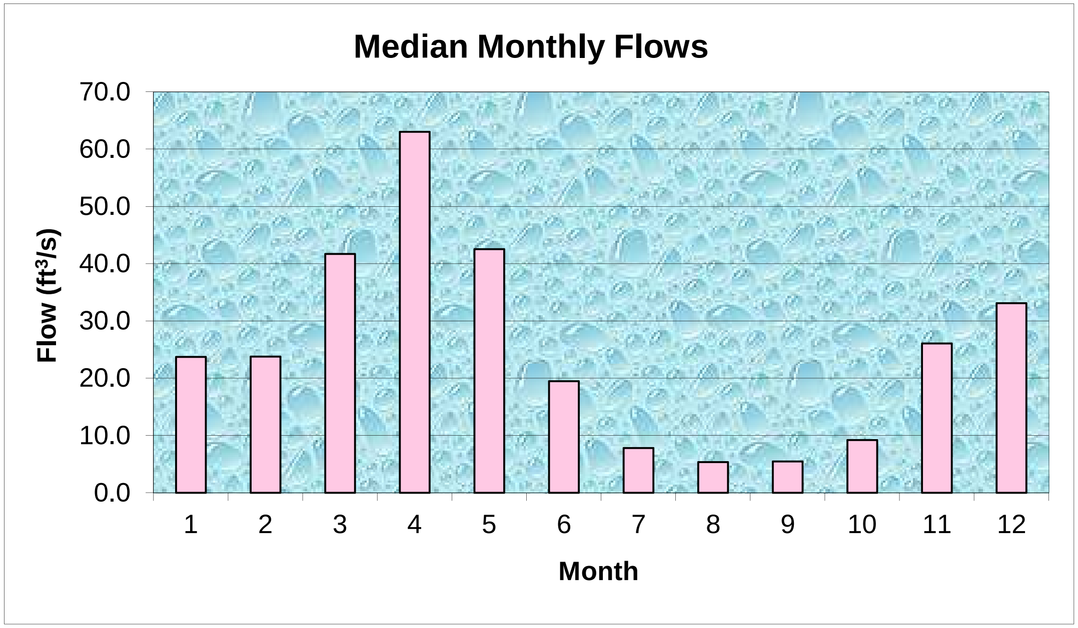
WIN:	21874.00	**Project Name:**	Belfast, Goose River Bridge #2139
Town:	Belfast	**Stream Name:**	Goose River
Route No.	US-1	**Bridge Name:**	Goose River Bridge
Asset ID:	2139	**Analysis by:**	DFB
Lat:	44.43280 **Long:** -68.99425	**Date:**	8/7/2017

DO NOT ENTER ANY DATA ON THIS PAGE; EVERYTHING IS CALCULATED

MAINE MONTHLY MEDIAN FLOWS and HYDRAULIC GEOMETRY BY USGS REGRESSION EQUATIONS (2004, 2013)

	Value	Variable	Explanation
	21.10	*A*	Area (mi^2)
501138	4928877	P_c	Watershed centroid (E,N; UTM; Zone 19; meters)
	52.74	*DIST*	Distance from Coastal reference line (mi)
	39.5	*pptA*	Mean Annual Precipitation (inches)
	0.05	*SG*	Sand & Gravel Aquifer (decimal fraction of watershed area)

Month	Q_{median} (ft3/s)	(m^3/s)
Jan	**23.76**	0.6734
Feb	**23.82**	0.6749
Mar	**41.72**	1.1824
Apr	**63.03**	1.7862
May	**42.58**	1.2066
Jun	**19.53**	0.5534
Jul	**7.85**	0.2224
Aug	**5.38**	0.1524
Sep	**5.47**	0.1550
Oct	**9.22**	0.2614
Nov	**26.10**	0.7397
Dec	**33.11**	0.9384

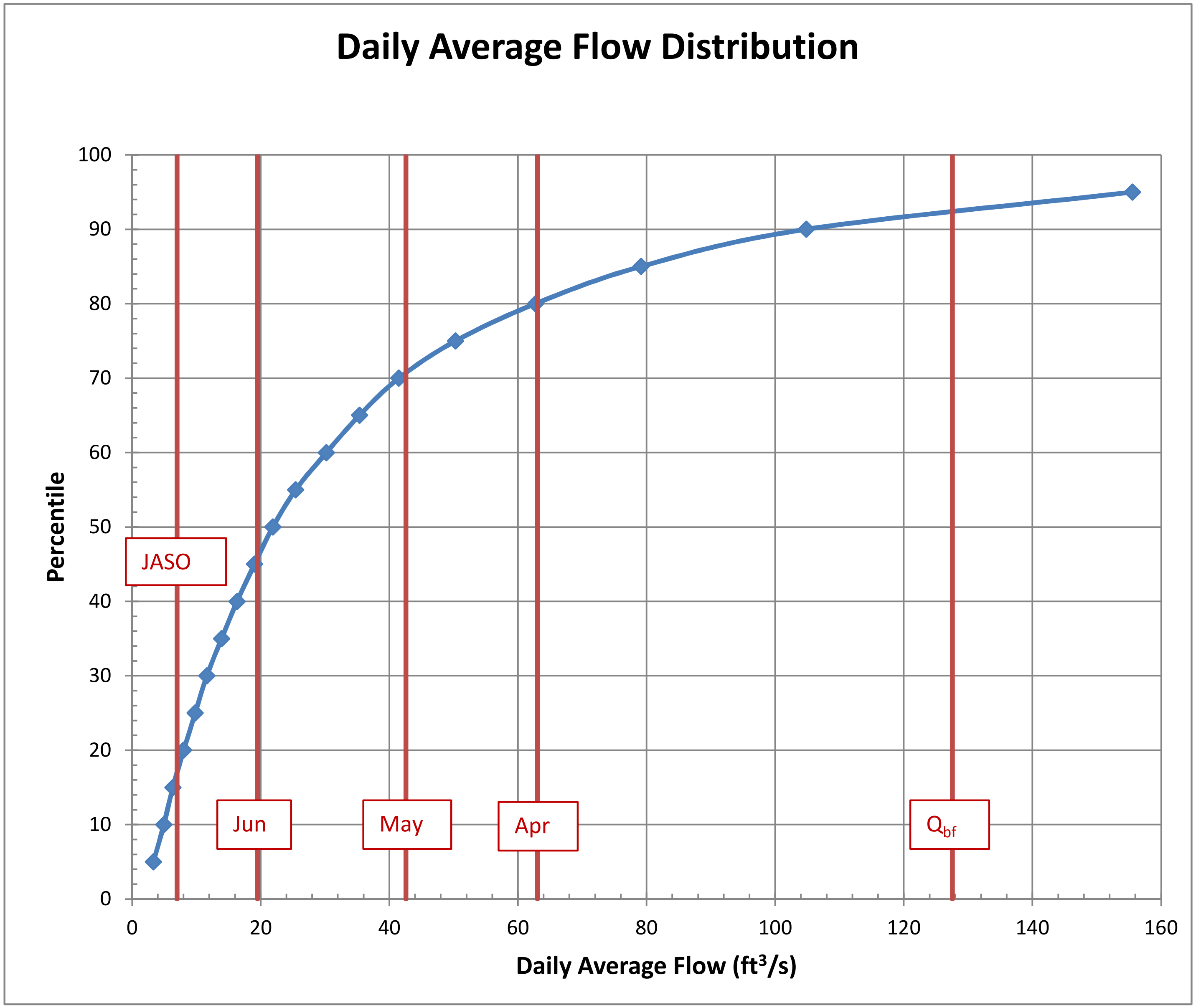


Q_{bf}	**127.5**	
ann avg	**39.9**	
ann med	**18.8**	
$Q_{1.002}$	**96.9**	
$Q_{1.01}$	**125.6**	
$Q_{1.05}$	**171.7**	
Q_{bf}	**263.0**	assume v = 4ft/s

W_{bf}	**39.3**	estimated bankfull width (ft)
d_{bf}	**1.7**	estimated bankfull depth (ft)
A_{bf}	**62.6**	estimated bankfull flow area (ft^2)

References

Dudley, R.W., 2013. FY2013 Progress Report - Phase 1 …, USFWS QRP Project
Dudley, R.W., 2004. Estimating Monthly Streamflows … , SIR 2004-5026



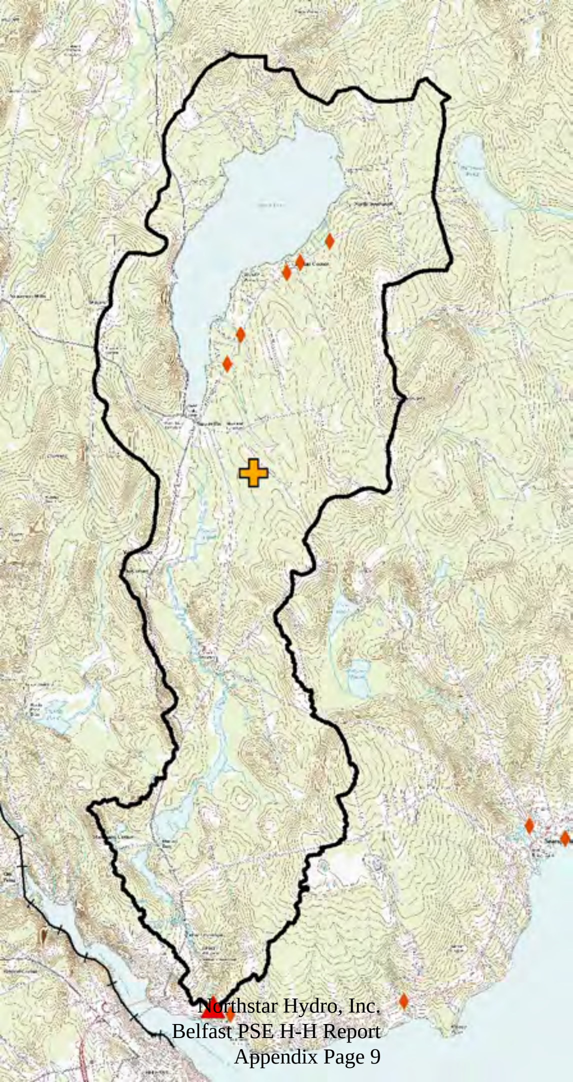
Daily Avg Flow Dist

A_{ws} = (mi^2) 21.1

Q (ft^3/s)

Pctl	Median	84th pctl
5	3.32	5.35
10	4.93	7.42
15	6.34	9.26
20	8.03	11.23
25	9.82	13.17
30	11.63	15.00
35	13.93	17.14
40	16.33	19.71
45	19.04	22.29
50	21.92	26.31
55	25.45	30.62
60	30.23	35.95
65	35.36	41.88
70	41.48	48.86
75	50.29	58.76
80	62.71	70.15
85	79.13	89.90
90	104.82	120.71
95	155.56	187.72

Q_{bf}	127.5
$Q_{1.002}$	96.9
$Q_{1.1}$	201.2
Q_2	378.4



Belfast 21874 Goose River B2139

Region ID: ME
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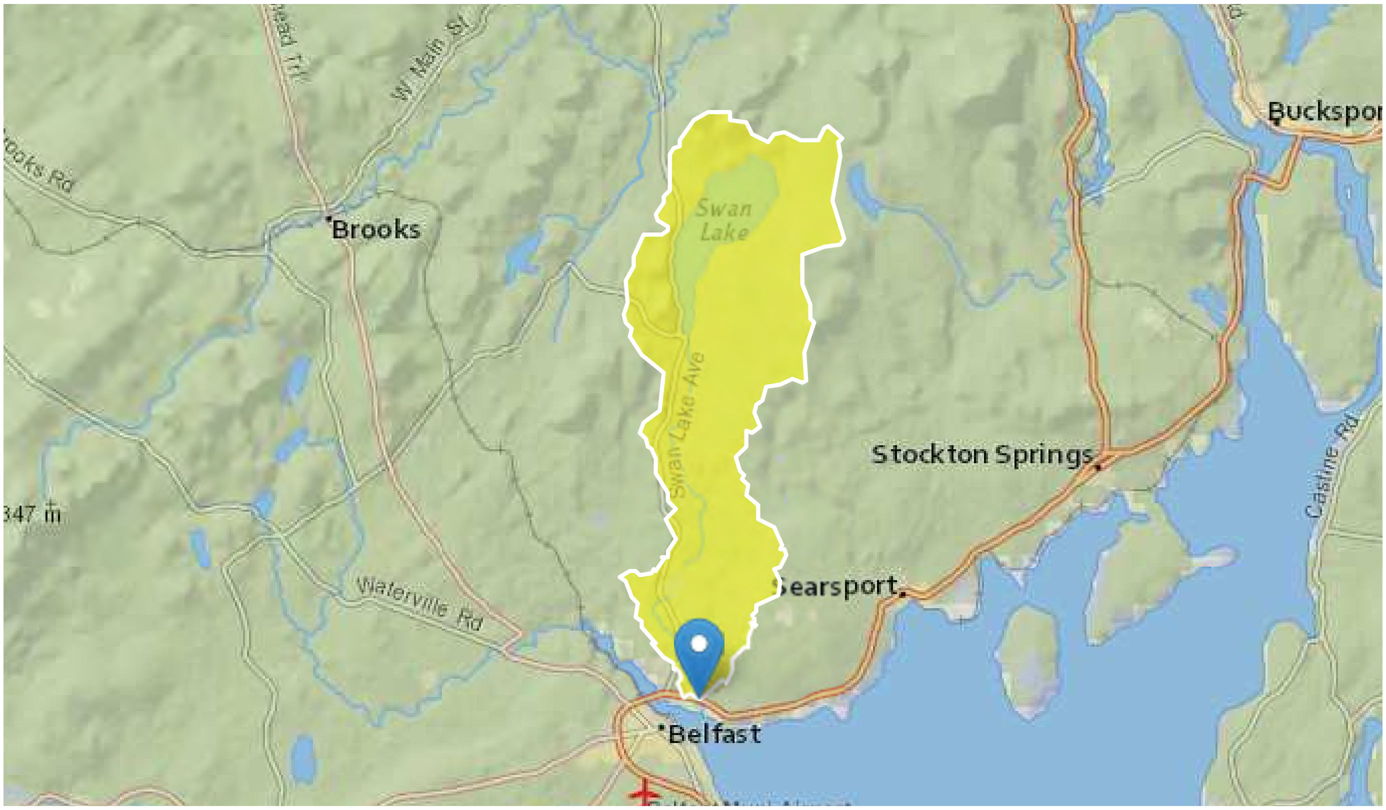
Clicked Point (Latitude, Longitude): 44.43283, -68.99425
Time: 2017-08-07 13:31:38 -0400



Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	21.1	square miles
STORNWI	Percentage of strorage (combined water bodies and wetlands) from the Nationa Wetlands Inventory	17.85	percent
SANDGRAVAF	Fraction of land surface underlain by sand and gravel aquifers	0.049	dimensionless
ELEV	Mean Basin Elevation	270.6	feet
BSLDEM10M	Mean basin slope computed from 10 m DEM	5.56	percent
COASTDIST	Shortest distance from the coastline to the basin centroid	53.7	miles
ELEVMAX	Maximum basin elevation	743.6	feet
LC06WATER	Percent of open water, class 11, from NLCD 2006	11.05	percent
LC11DEV	Percentage of developed (urban) land from NLCD 2011 classes 21-24	8.46	percent
LC11IMP	Average percentage of impervious area determined from NLCD 2011 impervious dataset	1.67	percent

Parameter Code	Parameter Description	Value	Unit
PRECIP	Mean Annual Precipitation	46.2	inches
SANDGRAVAP	Percentage of land surface underlain by sand and gravel aquifers	4.94	percent
STATSGOA	Percentage of area of Hydrologic Soil Type A from STATSGO	0.98	percent

Bankfull Statistics Parameters [Central and Coastal Bankfull 2004 5042]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	21.1	square miles	2.92	298

Bankfull Statistics Flow Report [Central and Coastal Bankfull 2004 5042]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SEe
Bankfull Streamflow	128	ft^3/s	54.1
Bankfull Width	37.4	ft	33
Bankfull Depth	1.68	ft	26.2
Bankfull Area	62.6	ft^2	57.4

Bankfull Statistics Citations

Dudley, R.W.,2004, Hydraulic-Geometry Relations for Rivers in Coastal and Central Maine: U.S. Geological Survey Scientific Investigations Report 2004-5042, 30 p (http://pubs.usgs.gov/sir/2004/5042/pdf/sir2004-5042.pdf)

Peak-Flow Statistics Parameters [Statewide Peak Flow Full GT 12sqmi WRI 99 4008]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	21.1	square miles	0.93	1653
STORNWI	Percentage of Storage from NWI	17.85	percent	0.7	26.7

Peak-Flow Statistics Flow Report [Statewide Peak Flow Full GT 12sqmi WRI 99 4008]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PIl	PIu	SE	SEp	Equiv. Yrs.
2 Year Peak Flood	378	ft^3/s	211	679	35.1	35.1	1.8
5 Year Peak Flood	561	ft^3/s	310	1020	36.1	36.1	2.5
10 Year Peak Flood	692	ft^3/s	376	1270	36.8	36.8	3.2
25 Year Peak Flood	864	ft^3/s	457	1630	38.6	38.6	4.1
50 Year Peak Flood	996	ft^3/s	516	1920	39.9	39.9	4.8

Statistic	Value	Unit	PIl	PIu	SE	SEp	Equiv. Yrs.
100 Year Peak Flood	1140	ft^3/s	577	2240	41.2	41.2	5.4
500 Year Peak Flood	1480	ft^3/s	707	3080	44.9	44.9	6.4

Peak-Flow Statistics Citations

Hodgkins, G. A.,1999, Estimating the Magnitude of Peak Flows for Streams in Maine for Selected Recurrence Intervals: U.S. Geological Survey Water-Resources Investigations Report 99-4008, 45 p. (http://me.water.usgs.gov/99-4008.pdf)

Low-Flow Statistics Parameters [Statewide LowFlow SIR 2004 5026]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	21.1	square miles	9.79	1418
SANDGRAVAF	Fraction of Sand and Gravel Aquifers	0.049	dimensionless	0	0.455

Low-Flow Statistics Flow Report [Statewide LowFlow SIR 2004 5026]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SE	SEp	Equiv. Yrs.
7 Day 10 Year Low Flow	1.1	ft^3/s	44.3	44.3	2.9

Low-Flow Statistics Citations

Dudley, R.W.,2004, Estimating Monthly, Annual, and Low 7-Day, 10-Year Streamflows for Ungaged Rivers in Maine: U.S. Geological Survey Scientific Investigations Report 2004-5026, 22 p. (http://water.usgs.gov/pubs/sir/2004/5026/pdf/sir2004-5026.pdf)

Flow-Duration Statistics Parameters [Statewide Annual SIR 2015 5151]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	21.1	square miles	14.9	1419
SANDGRAVAF	Fraction of Sand and Gravel Aquifers	0.049	dimensionless	0	0.212
ELEV	Mean Basin Elevation	270.6	feet	239	2120

Flow-Duration Statistics Flow Report [Statewide Annual SIR 2015 5151]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SEp
1 Percent Duration	0.235	ft^3/s	144
5 Percent Duration	0.894	ft^3/s	62
10 Percent Duration	1.92	ft^3/s	41

Statistic	Value	Unit	SEp
25 Percent Duration	6.81	ft^3/s	22
50 Percent Duration	20.1	ft^3/s	20
75 Percent Duration	49.9	ft^3/s	17
90 Percent Duration	107	ft^3/s	17
95 Percent Duration	164	ft^3/s	18
99 Percent Duration	363	ft^3/s	29

Flow-Duration Statistics Citations

Dudley, R.W.,2015, Regression equations for monthly and annual mean and selected percentile streamflows for ungaged rivers in Maine: U.S. Geological Survey Scientific Investigations Report 2015–5151, 35 p. (http://dx.doi.org/10.3133/sir20155151)

Annual Flow Statistics Parameters [Statewide Annual SIR 2015 5151]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	21.1	square miles	14.9	1419
SANDGRAVAF	Fraction of Sand and Gravel Aquifers	0.049	dimensionless	0	0.212
ELEV	Mean Basin Elevation	270.6	feet	239	2120

Annual Flow Statistics Flow Report [Statewide Annual SIR 2015 5151]

PII: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SEp
Mean Annual Flow	44.1	ft^3/s	16

Annual Flow Statistics Citations

Dudley, R.W.,2015, Regression equations for monthly and annual mean and selected percentile streamflows for ungaged rivers in Maine: U.S. Geological Survey Scientific Investigations Report 2015–5151, 35 p. (http://dx.doi.org/10.3133/sir20155151)