Memorandum

To:	Nate Benoit. P.E. Multimodal Assistant Program Manager Maine Department of Transportation 16 State House Station Augusta, ME 04333	Date:	December 5, 2018
		Project #:	55237.00
From:	David Cloutier, P.E. Water Resources Engineer	Re:	Hydrology, Hydraulic and Scour Report Railroad Bridge #7831 and Bridge #2303 Gagnon Brook Crossing of MNR and US Route 1 (Main St) Frenchville, ME

VHB has prepared the following hydrologic, hydraulic and scour analysis for the proposed replacement culvert carrying the Maine Northern Railway (MNR) tracks and US Route 1 (Main Street) over Gagnon Brook in Frenchville, Maine. Due to presence of invasive species in the St. John River, the project has been designed to function as a barrier for aquatic species passage between Gagnon Brook and the St. John River. Accordingly, VHB has not evaluated the existing and proposed design for compatibility with Habitat Connectivity Design (HCD) or the Maine Atlantic Salmon Programmatic Consultation (MAP) User Guide (March 2017). The location of the project is shown in Figure 1.

All elevations in this memorandum are referenced to the North American Vertical Datum of 1988 (NAVD88).

Existing Conditions

Railroad Bridge #7831, at M.P. 259.11, carrying the Madawaska Subdivision of Maine Northern Railway (MNR) over Gagnon Brook carries freight traffic to and from Madawaska and Van Buren. Immediately upstream (east) of Bridge #7831, Bridge #2303 carries U.S. Route 1 over Gagnon Brook. Gagnon Brook is a tributary to the St. John River, with the confluence of the rivers located immediately downstream (west) of Bridge #7831. Due to this close proximity, hydraulics for both bridges are affected by backwater from the St. John River.

The existing railroad bridge (#7831) is a 61.5-foot long, 12-foot wide by 8-foot tall cast-in-place concrete arch culvert with concrete floor slab and flared concrete wingwalls. The date of construction of the existing bridge is unknown. The existing highway bridge (#2303) is an 85-foot long, four-sided cast-in-place 10-foot wide by 10-foot tall concrete box culvert with flared concrete wingwalls constructed in 1930. The channel through the two culverts varies significantly: the upstream highway culvert has a very steep slope (over 9%) and is skewed approximately 30° to the roadway, while the downstream railroad culvert has a relatively gentle slope (1.3%) and is perpendicular to the railroad tracks. The two culverts are connected via a 12-foot wide concrete channel with vertical walls, which bends to the right at a 20° angle at the roadway culvert outlet, then back to the left at a 45° angle at the railroad culvert inlet. There are overhead utilities along the highway corridor, with a service-drop across the road and street light on the northeast corner of the culvert; there are no utilities along the railroad corridor.

The railroad bridge (#7831) is in serious condition with the southwest wingwall having completely failed, leaving a 15-foot diameter scour hole on the embankment where the wingwall once stood. The failed wingwall leaves the railroad embankment susceptible to further erosion and potential localized failures. The stream channel downstream of the

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culvert is also heavily scoured, with channel degradation resulting in a nearly 2-foot drop from the culvert outlet apron to the channel bed.

The Route 1 box culvert (#2303) is listed in “poor” condition in the inspection report from the July 31, 2017 MaineDOT inspection. However, the concrete floor of this culvert is heavily scoured and reinforcing steel is exposed. This scour appears to be a result of high flow velocities through the culvert caused by the unusually steep culvert slope.

Channel composition upstream of the crossing consists of a cobble-boulder bed with a bankfull width of approximately 20 feet and a channel profile slope of approximately 2%. Downstream of the crossing, Gagnon Brook immediately enters the channel of the St. John River, with a shallow delta deposit of gravel and cobbles extending approximately 75 feet into the St. John River. The existing highway culvert (#2303) presents a barrier to fish passage and to terrestrial wildlife passage, due to the steep slope and extended length of the structure.

Photographs of the project area are included in Appendix A.

Information Collection

For this evaluation, VHB reviewed the following data:

- Topographic field survey of the existing culverts, channel bathymetry, and surrounding area provided by MaineDOT and collected August 7, 2017.
- Bridge Inspection Reports of the existing bridge dated January 30, 2013 (MaineDOT inspection) and October 3, 2016 (VHB inspection)
- Hydrologic analysis of Gagnon Brook performed by MaineDOT and dated July 3, 2018
- USGS Historic streamflow data from Gage 01014000 (St. John River below Fish River, Fort Kent, ME) and Gage 01015000 (St. John River at Van Buren, ME) retrieved October 26, 2018 from https://waterdata.usgs.gov.
- Current and historic USGS topographic maps and aerial imagery for Frenchville, Maine.
- VHB conducted a field inspection of the crossing on September 25, 2017. Photographs are included in Appendix A.

There is no effective Flood Insurance Study (FIS) for the Town of Frenchville. The proposed crossing is located within flood Zone A as depicted on Flood Insurance Rate Map (FIRM) 230165B, Panels 02 and 03, Effective Date December 4, 1985. Zone A areas are determined by approximate methods and there is no flood elevation data or other hydrologic/ hydrologic data for Black Stream provided by FEMA. The crossing is not located within a regulatory floodway, and therefore is not subject to the NFIP 60.3.(d)3 “No-Rise” requirement.

Hydrologic Analysis

There is no streamgage data available for Gagnon Brook. The MaineDOT Environmental Office prepared the hydrologic evaluation for this crossing using USGS Maine regression equations for ungaged streams. VHB applied the peak flow estimates from this hydrologic analysis for hydraulic modeling. Table 2 presents a summary of peak flows at the crossing; the MaineDOT hydrologic analysis is included in Appendix B.

Table 1 Hydrologic Data for Proposed Design

Drainage Area	7.0 sq. mi
Bankfull Discharge ($Q_{1.1}$)	121.3 cfs
Q_2	256.7 cfs
Q_5	410.5 cfs
Q_{10}	522.3 cfs
Q_{25}	686.3 cfs
Design Discharge (Q_{50})	809.2 cfs
Check Discharge (Q_{100})	948.2 cfs
Q_{500}	1,292.3 cfs
Flood of Record	Unknown

Tailwater Conditions

Visual inspection of the existing structure indicates that the bankfull height of the St. John River is approximately equal to the headwall elevation of the railroad culvert (#7831) outlet, approximate elevation 470 ft. Due to the crossing location immediately upstream of the confluence of Gagnon Brook with the St. John River, hydraulic analysis should include evaluation of high-tailwater conditions due to backwater from the larger river.

Historic discharge and flood stage data is available for the St. John River for USGS gage 01014000 located approximately 14 miles upstream of the study location. The river watershed, channel width, and floodplain geometry at this location are similar to the study location, and flood stage depths at the gage are therefore assumed also to be similar. Gage 01014000 has a 90-year period of record dating back to 1927.

Gage data indicates that water levels in the St. John River are highly variable, changing by over 15 feet in a normal year. Peak annual flows are normally associated with the annual spring snowmelt, but large rain events in the summer or fall can also cause water levels to rise to bankfull stage. VHB performed a percentile analysis of the 8 years of stage data available for Gage 01014000 to illustrate this variability in Table 2:

Table 2 St. John River Tailwater Variability and Recurrence Frequency

St. John River Tailwater Elevation (ft NAVD88)	Percentile Chance Exceeding	Number of days per year exceeding
472	0.3%	1
466	2.4%	9
464	4.6%	17
462	7.8%	28
460	15.0%	55
458	30.0%	110
456	75.0%	274
454	99.0%	361

Notes: 1.) Source: Percentile analysis of USGS Gage 01014000 historic gage height data, October 2010-October 2018

For larger flood events, VHB performed a Bulletin 17b statistical analysis of peak annual discharge records for USGS gage 01014000 to estimate return frequency discharge rates, and then performed a regression analysis of peak annual discharge and flood stage depths (r^2 = .97) Using MaineDOT survey data for St. John River elevations at the study location, in conjunction with gage height measurements for the date of the topographic survey, VHB transformed USGS gage depths to equivalent flood stage elevations at the study location. Table 2 below presents a summary of the results of this analysis; detailed calculations are included in Appendix C.

Table 2 Hydraulic Data Summary for Existing and Proposed Design (Free Discharge)

Flood Frequency Event	USGS Gage 01014000 Discharge (cfs)[1]	USGS Gage 01014000 Flood Stage (ft)[2]	Gagnon Brook Confluence Tailwater Elevation (ft NAVD88)[3,4]
(August 7, 2017 field survey)	1,650	3.9	454.8
Bankfull Event ($Q_{1.1}$)	57,755	16.5	464.4
2-Year Flood (Q_2)	84,542	20.1	**471.0**
5-Year Flood (Q_5)	108,539	22.9	**473.8**
10-Year Flood (Q_{10})	123,667	24.5	**475.5**
50-Year Flood (Q_{50})	155,470	27.6	**478.6**
100-Year Flood (Q_{100})	168,542	28.8	**479.7**
500-Year Flood (Q_{500})	198,446	31.4	**482.3**

Notes: 1.) Source: HEC-SSP Bulletin 17B analysis of USGS Gage 01014000 historic discharge data
2.) Source: Regression analysis of USGS Gage 01014000 historic discharge and gage height data
3.) Calibrated using August 7, 2017 measurements
4.) Elevations higher than 471 ft NAVD88 result in tailwater affecting Gagnon Brook upstream of crossing

Due to the significant difference between Gagnon Brook and the St. John River in drainage area (7 vs. 5,929 square miles, respectively) and watershed centroid location (approximately 60 miles west-southwest), the probability of concurrent flooding is significantly lower than the probability of isolated flooding in Gagnon Brook. USGS Water Resources Investigation Report (WRIR) 98-4238 provides guidance on estimating the probability that streamflows at two streams concurrently equal or exceed the 2-year flood threshold if at least one of the two streams equals or exceeds the 2-year flood threshold, calculated from the difference in drainage area and centroid distance vector between the two watersheds. Based on WRIR 98-4238 guidance, the probability of concurrent flooding of the St. John River and Gagnon Brook is approximately 10%; therefore, the probability of a 10-year flood in Gagnon Brook with a tailwater condition of a 2-year or greater flood in the St. John River is comparable to the probability of an isolated 100-year flood event for Gagnon Brook.

Proposed Design

The proposed design will replace the two existing structures with a single 210-foot-long, 10-foot wide by 12-foot high precast concrete box culvert crossing both the MNR tracks and US Route 1. This structure will be located immediately to the south of the existing culverts to allow for flow to be maintained through the existing culvert during construction. The proposed design incorporates two modifications to address site-specific challenges:

1) The culvert outlet is raised 5 feet above the downstream channel, with this vertical drop serving as a barrier against fish passage, and

2) The culvert incorporates a series of internal baffles to reduce velocities through the culvert barrier via energy dissipation by increased roughness.

Hydraulic analysis indicates that the extended culvert length, low-friction concrete surface, and 11-foot vertical drop across the structure lead to excessive flow velocities within the culvert and at the culvert outlet. Given the observed scour damage to the existing culverts and culvert outlet wingwalls, VHB evaluated energy dissipation solutions presented in the FHWA publication HEC-14, "Hydraulic Design of Energy Dissipators for Culverts and Channels" (2006), assessing the following approaches individually and in combination:

- Broken-back culvert profile
- Tumbling flow
- Internal baffles for increased resistance
- Reduced culvert slope with outlet drop
- Outlet weirs and stilling basins
- Streambed level dissipators

VHB and MaineDOT staff reviewed the feasibility, advantages, and disadvantages of alternative designs on a November 8, 2018 conference call. Based on the limitations of the site, including a highly variable St. John River tailwater, VHB selected the internal baffle approach in conjunction with an outlet drop as the most effective design to address the scour velocity and fish passage barrier design considerations. Stilling basins and streambed level dissipators require a reliable high tailwater to be effective, tumbling flow requires predictable flow velocities to be effective, and broken-back and reduced culvert slope designs do not adequately address internal culvert velocities.

The proposed design incorporates a drop at the culvert outlet, with the outlet invert set at elevation 463.4 to minimize the average number of days per year when St. John River tailwater elevations would be high enough for fish to enter the culvert. It also incorporates eighteen (18) internal baffles for increased resistance, designed in accordance with HEC-14 Section 7.2.2 guidelines. Baffles are placed along the floor of the culvert, are 1 foot high, spaced at 10-foot intervals starting at the downstream outlet, and extend across the entire 10-foot width of the culvert. To avoid ponding, each baffle will incorporate small (6-inch) slots for drainage. Detailed design calculations for the baffles are included in Appendix E.

Hydraulic Analysis

VHB developed a hydraulic model using the Federal Highway Administration (FHWA) HY-8 software, version 7.50, to evaluate hydraulic performance of the proposed design. Hydraulic analysis included evaluation of the bankfull 1.1-year ($Q_{1.1}$), design discharge 50-year (Q_{50}), and check discharge 100-year (Q_{100}) flood events. VHB also evaluated the proposed design for low-flow conditions (represented by the annual median flow rate) to evaluate fish passage conditions. Flow discharge rates were sourced from the hydrologic analysis provided by MaineDOT.

HY-8 model geometry is based on topographic and bathymetric field survey performed by MaineDOT in August 2017, supplemented by structure geometry for the proposed VHB design. To account for backwater from the St. John River, VHB evaluated culvert hydraulic performance for two scenarios: assuming free discharge at the culvert outlet, and a high-tailwater scenario associated with the 10-year flood in the St. John River. Detailed supporting calculations are provided in Appendix D; summaries of results from both scenarios are presented in Tables 3 and 4 below.

Table 3 Hydraulic Data Summary for Existing and Proposed Design (Free Discharge)

	Existing Structure	Proposed: 10 ft x 12 ft box culvert with internal baffles
Ordinary High Water ($Q_{1.1}$)	472.5 ft	473.2 ft
Discharge Velocity ($Q_{1.1}$)	10.0 fps	8.2 fps
Headwater Elevation (Q_{50})	479.4 ft	479.6 ft
Headwater Elevation (Q_{100})	480.6 ft	480.6 ft
Discharge Velocity (Q_{50})	16.2 fps	14.5 fps
Discharge Velocity (Q_{100})	16.9 fps	14.9 fps
Freeboard (Q_{50})	0.4 ft	3.1 ft
Freeboard (Q_{100})	(submerged)	2.1 ft

Notes: 1.) Headwater elevation measured upstream of US Route 1
2.) Discharge velocity measured downstream of MNR ROW for existing conditions
3.) Discharge velocity assumes internal culvert energy dissipation for proposed conditions

Table 4 Hydraulic Data Summary for Existing and Proposed Design (St. John River Q_{10} Backwater)

	Existing Structure	Proposed 10 ft x 12 ft box culvert
Ordinary High Water ($Q_{1.1}$)	475.6 ft	475.5 ft
Discharge Velocity ($Q_{1.1}$)	1.4 fps	1.0 fps
Headwater Elevation (Q_{50})	476.7 ft	476.3 ft
Headwater Elevation (Q_{100})	477.5 ft	477.3 ft
Discharge Velocity (Q_{50})	4.6 fps	3.4 fps
Discharge Velocity (Q_{100})	5.9 fps	4.4 fps
Freeboard (Q_{50})	3.1 ft	6.4 ft
Freeboard (Q_{100})	2.3 ft	5.4 ft

Notes: 1.) Headwater elevation measured upstream of US Route 1
2.) Discharge velocity measured downstream of MNR ROW
3.) Q_{50} discharge rate for St. John River Backwater condition is equal to the Q_5 discharge rate for free discharge
4.) Q_{100} discharge rate for St. John River Backwater condition is equal to the Q_{10} discharge rate for free discharge

The proposed design increases the vertical clearance of the structure, increasing the hydraulic opening and freeboard. HY-8 model results indicate an HW/D ratio less than 0.9 and freeboard of at least 2.0 feet for the Q_{50} design discharge, and 1.0 ft of freeboard for the Q_{100} discharge. Backwater effects from the St. John River significantly reduce flow velocities in the culvert, but do not appear to have a noticeable impact on headwater elevations.

VHB also

Table 5 Maximum Internal Culvert Flow Velocities (feet per second)

Flood Frequency Event	Existing Structure	10 ft x 12 ft box culvert without internal baffles	**Proposed 10 ft x 12 ft box culvert with internal baffles**
Bankfull Event ($Q_{1.1}$)	18.6	16.3	**8.4**
2-Year Flood (Q_2)	21.7	20.3	**10.5**
5-Year Flood (Q_5)	23.5	22.7	**12.1**
10-Year Flood (Q_{10})	24.4	23.8	**12.9**
50-Year Flood (Q_{50})	26.3	25.9	**14.5**
100-Year Flood (Q_{100})	27.0	26.7	**14.9**
500-Year Flood (Q_{500})	28.4	28.3	**16.1**

Notes: 1.) Existing velocity measured for Route 1 culvert
2.) Proposed velocity (without baffles) calculated assuming smooth concrete Manning's n roughness value of 0.012
3.) Proposed velocity (with baffles) calculated with HEC-14 baffle-adjusted Manning's n roughness value of 0.037

Preliminary Habitat Connectivity Design (Fish Passage Barrier Analysis)

Due to presence of invasive species in the St. John River, the project has been designed to function as a barrier for aquatic species passage between Gagnon Brook and the St. John River. VHB evaluated the culvert for fish passage conditions using the HY-8 model, represented by median flow conditions during the April through September season. Median monthly flows were estimated as part of the MaineDOT hydrologic analysis (refer to Appendix B).

Fish passage barriers can take the form of vertical drops, extended sections of channel too shallow for fish to swim, and extended sections of channel with higher velocity flows too great for fish to overcome. The proposed design incorporates a 5-foot vertical drop at the culvert outlet to provide this barrier. However, due to fluctuating water levels in the St. John River, tailwater elevations at the culvert are high enough for fish to enter the structure approximately 17 days per year (See Table 2). Under high tailwater conditions, fish could feasibly swim up the culvert via the shallow (0.65-foot-deep) pools between the internal energy dissipation baffles. These baffles do not extend along the entire length of the structure, and the uppermost 25-foot section of the culvert would provide a barrier due to water depths less than 6 inches. Under all fish passage conditions reviewed, flow through this upper section is too shallow for an adult Muskie to swim upstream. The extended length of the culvert also presents a deterrent to fish passage by blocking natural sunlight from the channel: the calculated openness ratio of 0.15 meters, significantly lower than the ratio of 0.6 meters recommended for aquatic organism passage in the MaineDOT "Waterway and Wildlife Crossing Policy and Design Guide" (2008). Table 6 presents a summary of low-flow conditions in this baffle-free culvert section:

Table 6 Fish Passage Barrier Analysis – High-Tailwater Conditions

	Discharge (cfs)	Maximum flow velocity (fps)	Minimum flow depth (ft)	Culvert distance: flow velocity > 10 fps	Culvert distance: flow depth < 0.5 ft
Median September Flow	1.49	0.9	0.17	0 ft	10 ft
Median Annual Flow	5.50	4.0	0.21	0 ft	8 ft
Median May Flow	24.37	7.6	0.32	0 ft	16 ft

Fish passage through the structure is theoretically possible during annual spring flooding in the St. John River, when backwater elevations from the main river can rise above the inlet elevation of the culvert. However, the extended length, lack of natural sunlight in the culvert, and submerged outlet reduce the likelihood of fish passage. Given that this condition is also met for the existing structure and there is no known evidence of fish passage under current conditions, the proposed structure is assumed to serve as an effective barrier to fish passage.

Scour Analysis

VHB estimated scour depths at the downstream culvert outlet and upstream culvert inlet based on the methodologies presented in Hydraulic Engineering Circular (HEC) 14 (2006) and HEC-18 (2012), respectively. Scour calculations are based on HY-8 model outputs for the Q100 design scour event and Q500 check scour event, supplemented by estimates of channel composition and hydraulics for the upstream and downstream channel. A summary of scour calculations is provided in Table 7 below; detailed scour calculations are provided in Appendix E.

Table 7 Scour Analysis Results

	Q_{100} Design Scour Event	Q_{500} Check Scour Event
Discharge (cfs)	948.2	1,292.3
Maximum Total Upstream Scour (ft)[1]	4.9	5.1
Maximum Total Downstream Scour (ft)[2]	7.6	8.6

Notes: 1.) Upstream scour calculated using HEC-18 Equation 6.10, scour in open-bottom culverts. Scour analysis assumes that 50% of the flow in the upstream channel is blocked by the inlet wingwalls.
2.) Downstream scour calculated using HEC-14 Equation 5.1 for culvert outlet scour in cohesionless soils. Scour analysis assumes a channel bed material standard deviation of 7.75.

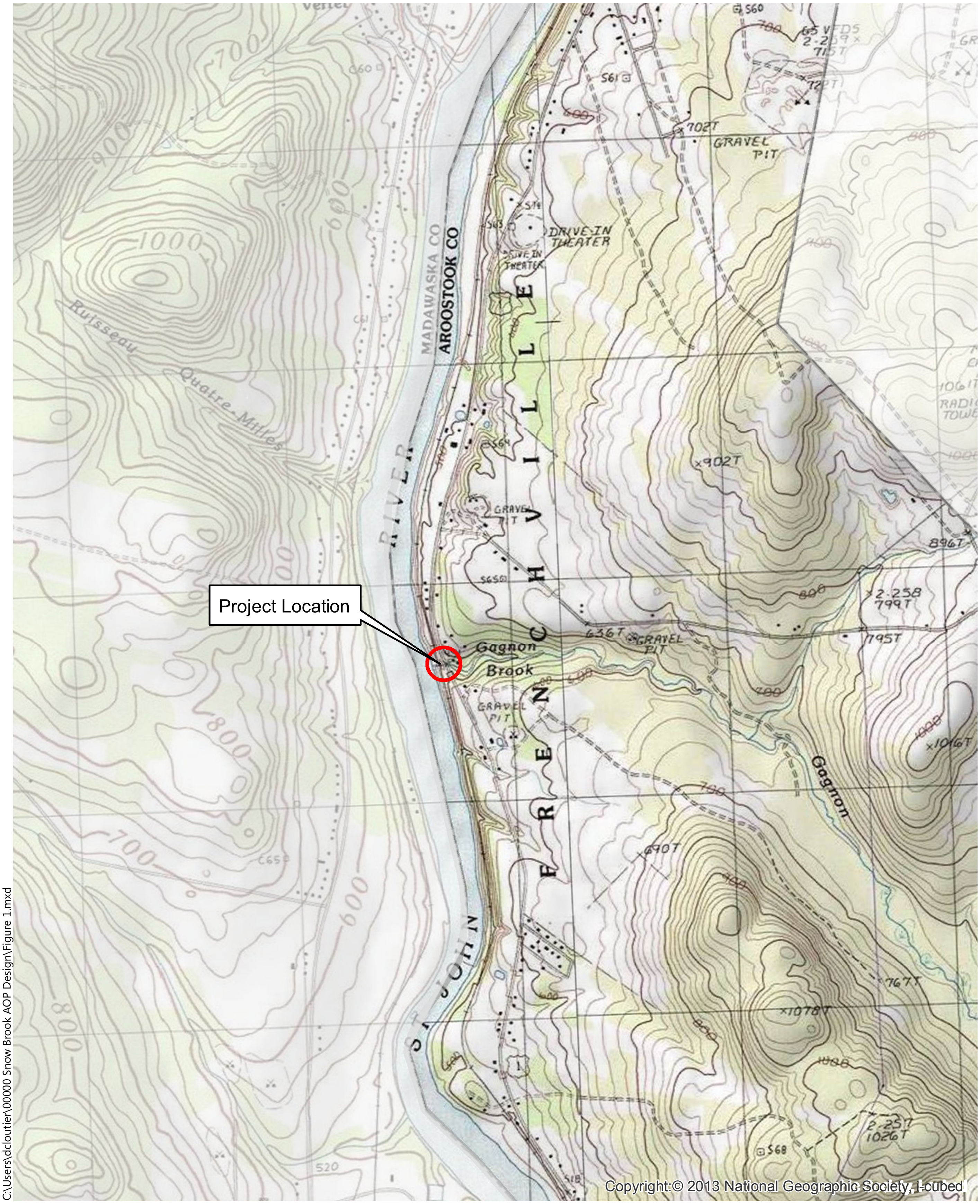
Scour analysis indicates the potential for up to 5.1 feet of scour at the culvert inlet and 8.6 feet of scour at the culvert outlet. Inlet scour is primarily a function of flow contracting from the upstream channel into the culvert box, while outlet scour is primarily a function of high flow velocities exiting the culvert. Existing channel bed material values were estimated to calculate scour, assuming values of D_{16}=3 mm, D_{50}=55mm, and D_{84}=180mm.

VHB recommends placing heavy riprap (MaineDOT Standard Specifications Item 703.28) protection at both the inlet and outlet of the proposed culvert to protect against scour, installed to a bed thickness of 6.0 feet and 3.0 feet, respectively. Riprap placement at the inlet should extend from the culvert inlet to the upstream limit of the wingwalls and extending across the entire channel. Due to the outlet drop, flow exiting the culvert will follow a falling trajectory before impacting the channel bed a maximum distance of 15 feet from the culvert outlet (Q_{500} discharge). To account for this unique trajectory, VHB recommends installing a riprap-lined splash pad extending at least 20 feet downstream of the culvert outlet. The splash pad should incorporate a buried concrete wall to hold the riprap in place within the splash pad and protect against material migrating downstream due to impact from culvert discharge.

Due to the close proximity to the St. John River, the culvert outlet and wingwalls are subject to flood flows along the right (East) bank of the St. John River. VHB recommends applying riprap slope protection for all disturbed areas behind the outlet wingwalls and above the culvert, extending up to the Q500 St. John River flood elevation (482.3 ft).

The channel geomorphology downstream of the culvert is part of the active channel bed of the St. John River. Any scour countermeasures extending beyond the bank slope of the St. John River would be subject to the active channel bed, and could be buried or undermined by river bed movement. Accordingly, VHB recommends minimizing the limit of downstream disturbance and does not recommend any further scour countermeasures extending beyond the splash pad.

Figures



C:\Users\dcloutier\00000 Snow Brook AOP Design\Figure 1.mxd

0 650 1300 2600 Feet

MNR/US Rt. 1 over Gagnon Brook | Frenchville, Maine

Figure 1: Locus Map

Source: USGS Topographic Map

Appendix A – Photos

Photo 1 View looking upstream from existing US Route 1 bridge

Photo 2 View looking downstream from existing MNR bridge

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Photo 3 View looking upstream from existing MNR bridge towards US Route 1 bridge

Photo 4 View looking downstream from existing US Route 1 bridge towards MNR bridge

Photo 5 Existing US Route 1 bridge upstream elevation

Photo 6 Existing US Route 1 bridge downstream elevation

Photo 7 Existing MNR bridge upstream elevation

Photo 8 Existing MNR bridge downstream elevation

Photo 9 Typical channel upstream (looking upstream)

Photo 10 Typical channel downstream (looking downstream)

Photo 11 Key Feature: Collapsed wingwall at downstream outlet

Photo 12 Key Feature: scour in floor of Rt 1 box culvert

Photo 13 St. John River upstream at confluence (looking left from Gagnon Brook)

Photo 14 St. John River downstream at confluence (looking right from Gagnon Brook)

Photo 15 MNR tracks looking left from crossing

Photo 16 MNR tracks looking right from crossing

Appendix B – Hydrology

WIN:	23565.00		**Project Name:**	GAGNON BROOK
Town:	Frenchville		**Stream Name:**	Gagnon Brook
Route No.	Route 1		**Bridge Name:**	
Asset ID:	2303		**Analysis by:**	meg
Lat:	47.31947	**Long:** -68.38157	**Date:**	7/3/2018

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	18.13	7.00	4480.0	Watershed Area *DRNAREA*
W	0.92	0.4	228.5	Wetlands area (by NWI)
P_c	550321	5239581		watershed centroid (E, N; UTM 19N; meters)
County	Aroostook N			*choose county from drop-down menu*
pptA	36.1			mean annual precipitation (inches; by look-up)
SG	0.02			sand & gravel aquifer as decimal fraction of watershed A

A (km^2)	18.13	**Conf Lvl**	0.67	
W (%)	5.10			NWI Wetlands % *STORNWI*

Ret Pd T (yr)	**Peak Flow Estimate Lower**	**Q_T (m^3/s)**	**Upper**	**Q_T (ft^3/s)**
1.1		3.43		121.3
2		7.27		256.7
5		11.63		410.5
10		14.79		522.3
25		19.44		686.3
50		22.92		809.2
100		26.85		948.2
500		36.60		1292.3

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ver. 2017 Jun. 09

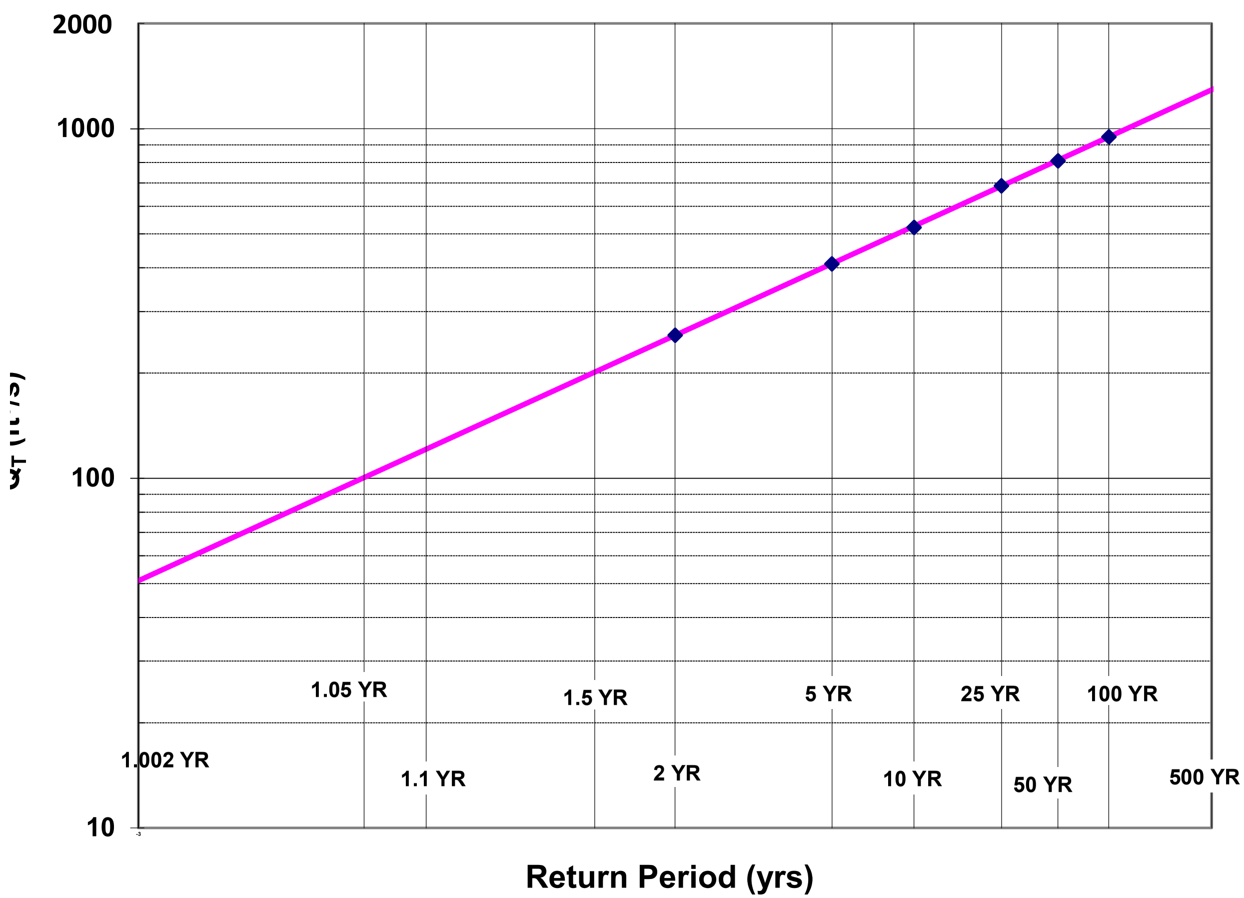
References:

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

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

Log-Normal Probability Plot



WIN:	23565.00	**Project Name:**	GAGNON BROOK
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DO NOT ENTER ANY DATA ON THIS PAGE; EVERYTHING IS CALCULATED

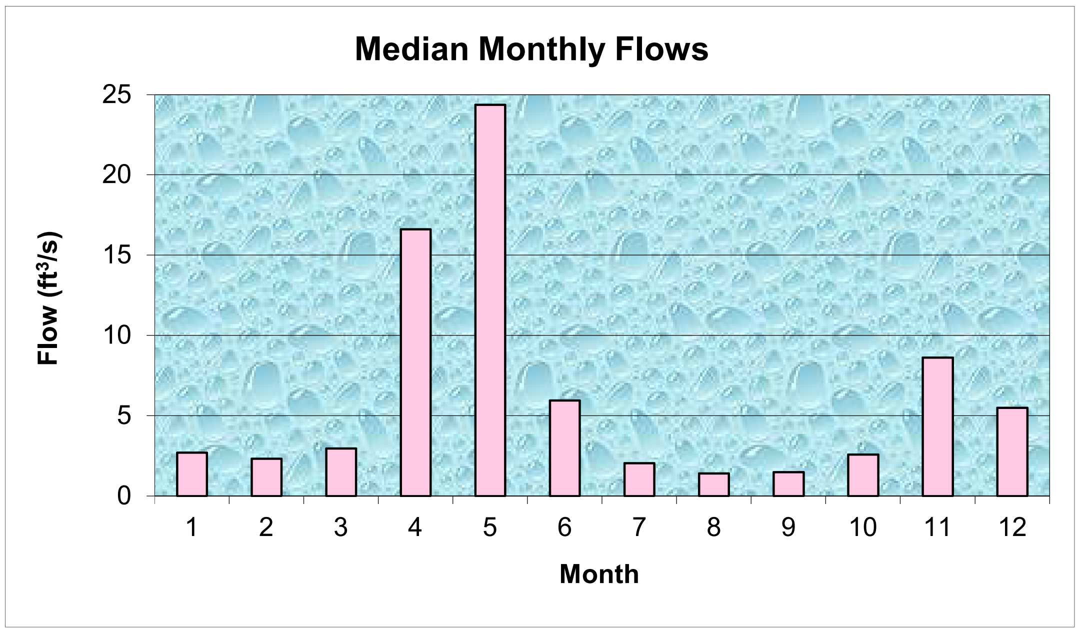
MAINE MONTHLY MEDIAN FLOWS and HYDRAULIC GEOMETRY BY USGS REGRESSION EQUATIONS (2004, 2013)

	Value	Variable	Explanation
	7.00	*A*	Area (mi^2)
550321.4	5239580.74	P_c	Watershed centroid (E,N; UTM; Zone 19; meters)
	203.62	*DIST*	Distance from Coastal reference line (mi)
	36.1	*pptA*	Mean Annual Precipitation (inches)
	0.02	*SG*	Sand & Gravel Aquifer (decimal fraction of watershed area)

Month	Q_{median} (ft3/s)	(m^3/s)
Jan	**2.71**	0.0767
Feb	**2.33**	0.0660
Mar	**2.96**	0.0840
Apr	**16.61**	0.4707
May	**24.37**	0.6907
Jun	**5.96**	0.1688
Jul	**2.04**	0.0579
Aug	**1.41**	0.0401
Sep	**1.49**	0.0422
Oct	**2.59**	0.0735
Nov	**8.62**	0.2443
Dec	**5.49**	0.1557

Q_{bf}	**40.0**	
ann avg	**12.8**	
ann med	**5.5**	
$Q_{1.002}$	**50.9**	
$Q_{1.01}$	**69.3**	
$Q_{1.05}$	**100.5**	
Q_{bf}	**112.5**	assume v = 4ft/s

W_{bf}	**24.4**	estimated bankfull width (ft)
d_{bf}	**1.2**	estimated bankfull depth (ft)
A_{bf}	**24.3**	estimated bankfull flow area (ft^2)



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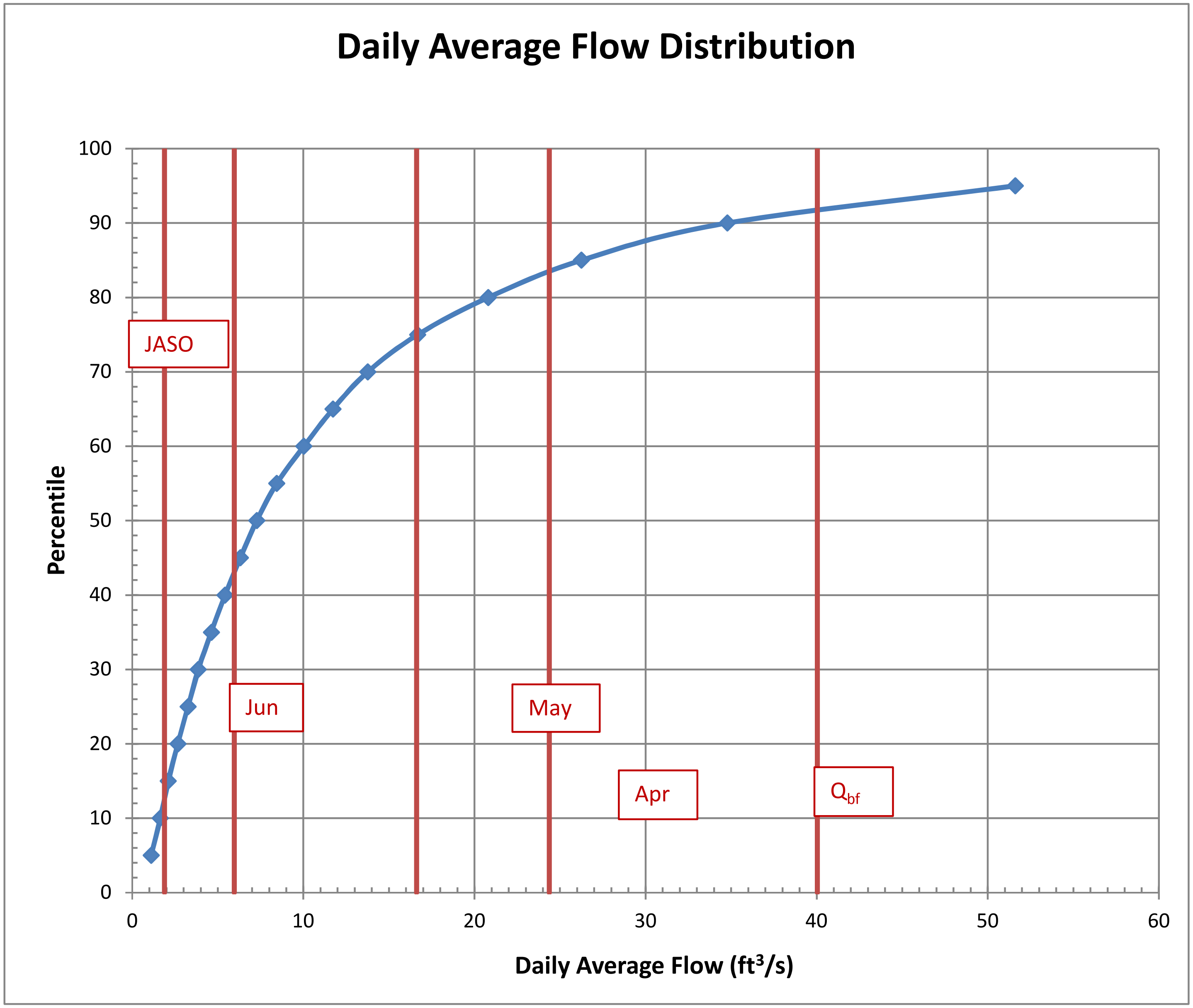
Dudley, R.W., 2004. Estimating Monthly Streamflows □ , SIR 2004-5026



Daily Avg Flow Dist

A_{ws} = (mi^2) 7.0

Q (ft^3/s)

Pctl	Median	84th pctl
5	1.10	1.77
10	1.64	2.46
15	2.10	3.07
20	2.66	3.73
25	3.26	4.37
30	3.86	4.97
35	4.62	5.69
40	5.42	6.54
45	6.32	7.39
50	7.27	8.73
55	8.44	10.16
60	10.03	11.93
65	11.73	13.89
70	13.76	16.21
75	16.68	19.49
80	20.81	23.27
85	26.25	29.82
90	34.77	40.05
95	51.61	62.28

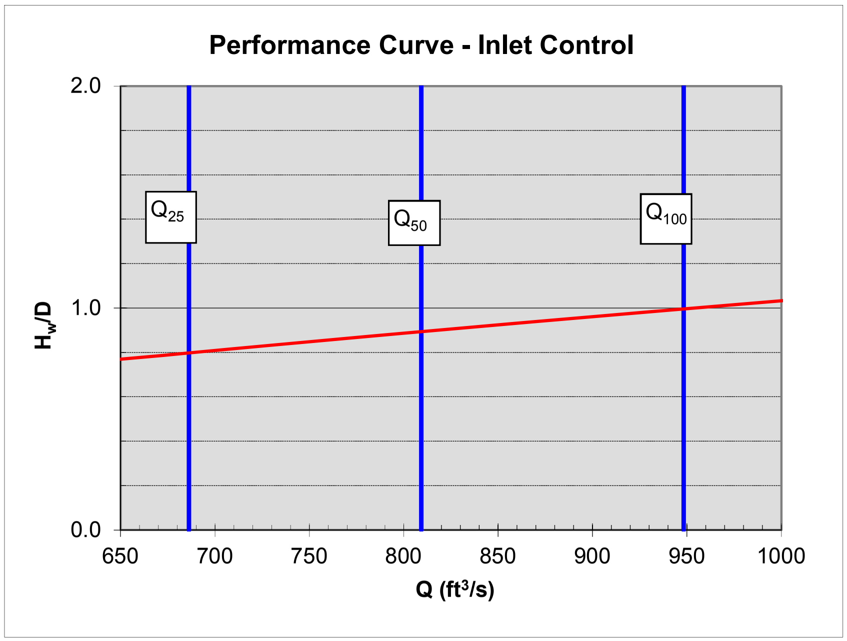
Q_{bf}	40.0
$Q_{1.002}$	50.9
$Q_{1.1}$	121.3
Q_2	256.7

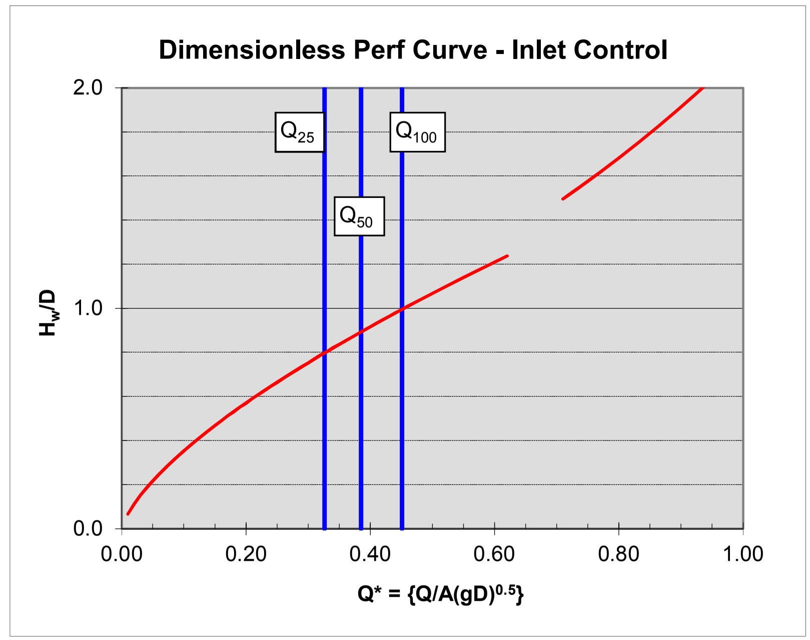
NOTE: ***This page is for preliminary sizing only.***
Final design should be done with HY8 or HDS-5

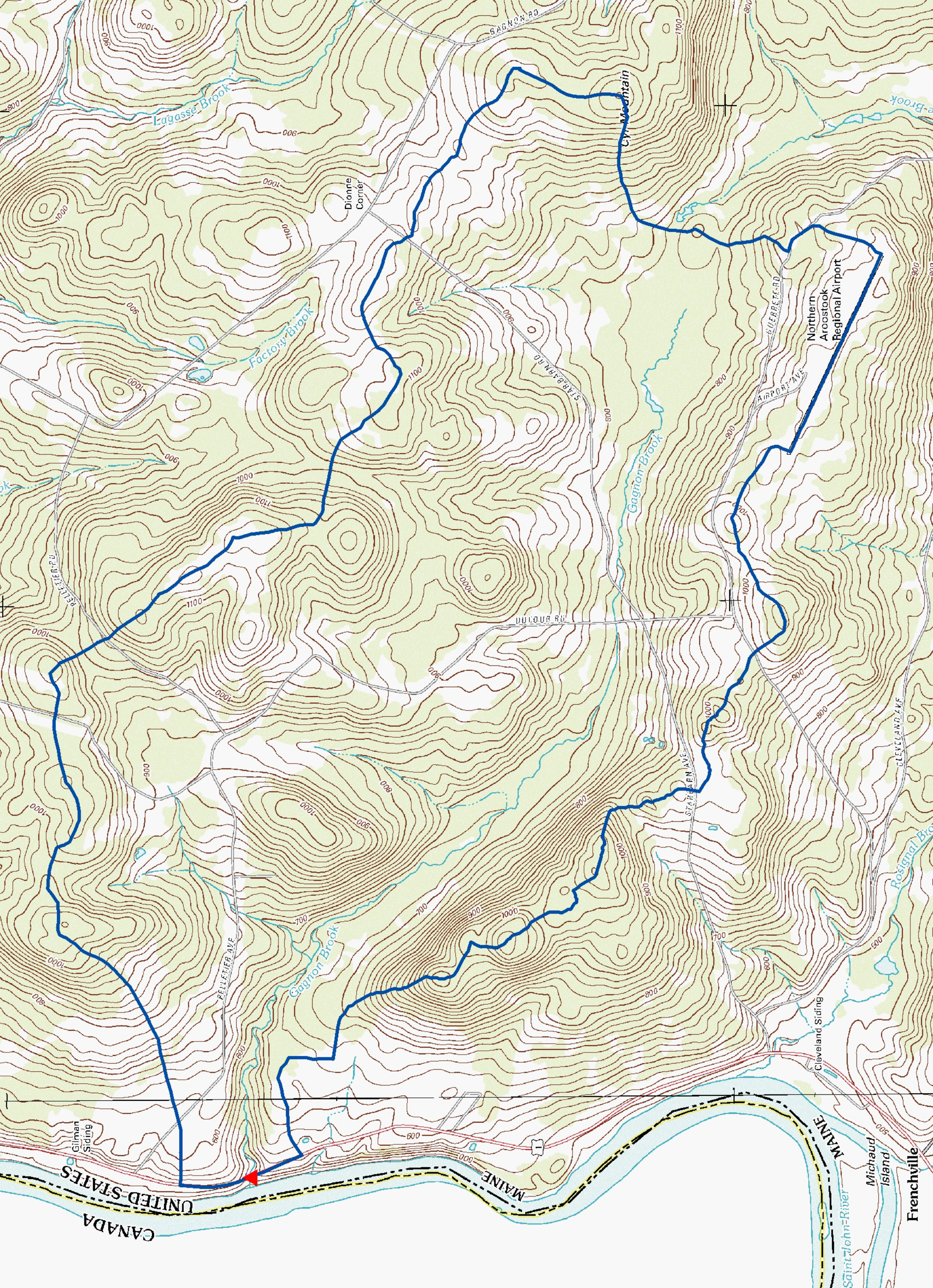
Preliminary Culvert Sizing - Round & Box Culverts

Shape:	Box					
Type:	Box 0 ww		Q_{25}	686.3		
D or R (ft)	7		Q_{50}	809.2	trial D / R =	12.1
w (ft)	*20*	*box width*	Q_{100}	948.2	trial w: BFW =	24.4
Slope (ft/ft)	0.02					
A (ft^2)	140.00					
g (ft/s^2)	32.2					

Note:
culvert dimensions are for open flow area; adjust for lost capacity due to embedding / backfilling (min {2' / 25% rise} embedment)

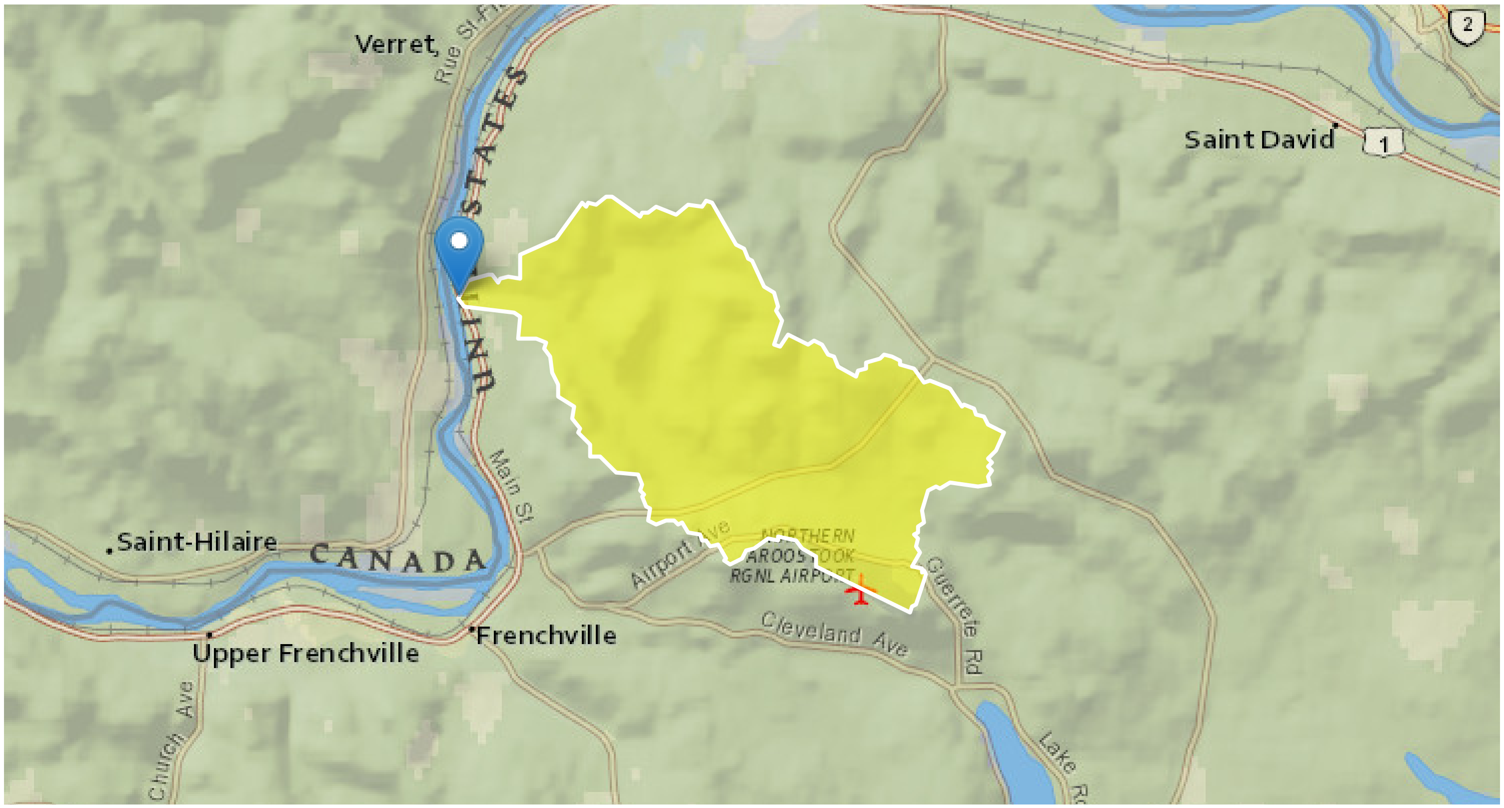





GAGNON RD
Lagasse Brook
Dionne Corner
Factory Brook
Cyr Mountain
Northern Aroostook Regional Airport
GUERRETTE RD
AIRPORT AVE
STAR BARN RD
Gagnon Brook
PELLETIER RD
DUFOUR RD
STAR BARN AVE
CLEVELAND AVE
PELLETIER AVE
Gagnon Brook
Cleveland Siding
Gilman Siding
UNITED STATES
CANADA
MAINE
MAINE
Saint John River
Michaud Island
Frenchville

23656 Frenchville Br # 2303 Gagnon Brook

Region ID: ME
Workspace ID: ME20181018153857667000
Clicked Point (Latitude, Longitude): 47.31947, -68.38202
Time: 2018-10-18 11:39:12 -0400



Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	6.9	square miles
STORNWI	Percentage of strorage (combined water bodies and wetlands) from the Nationa Wetlands Inventory	5.1	percent
SANDGRAVAF	Fraction of land surface underlain by sand and gravel aquifers	0.017	dimensionless
ELEV	Mean Basin Elevation	880	feet
BSLDEM10M	Mean basin slope computed from 10 m DEM	11.1	percent
CENTROIDX	Basin centroid horizontal (x) location in state plane coordinates	550321.01	feet
CENTROIDY	Basin centroid vertical (y) location in state plane units	5239580.89	feet
COASTDIST	Shortest distance from the coastline to the basin centroid	205	miles
ELEVMAX	Maximum basin elevation	1160.4	feet
LC06WATER	Percent of open water, class 11, from NLCD 2006	0.03	percent
LC11DEV	Percentage of developed (urban) land from NLCD 2011 classes 21-24	7.91	percent
LC11IMP	Average percentage of impervious area determined from NLCD 2011 impervious dataset	1.72	percent
PRECIP	Mean Annual Precipitation	38	inches
SANDGRAVAP	Percentage of land surface underlain by sand and gravel aquifers	1.71	percent
STATSGOA	Percentage of area of Hydrologic Soil Type A from STATSGO	0.53	percent

Peak-Flow Statistics Parameters [Statewide Peak Flow DA LT 12sqmi 2015 5049]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	6.9	square miles	0.31	12

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
STORNWI	Percentage of Storage from NWI	5.1	percent	0	22.2

Peak-Flow Statistics Flow Report [Statewide Peak Flow DA LT 12sqmi 2015 5049]

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

Statistic	Value	Unit	SEp
1.01 Year Peak Flood	71.8	ft^3/s	38
2 Year Peak Flood	253	ft^3/s	34
5 Year Peak Flood	406	ft^3/s	35
10 Year Peak Flood	516	ft^3/s	37
25 Year Peak Flood	678	ft^3/s	39
50 Year Peak Flood	799	ft^3/s	41
100 Year Peak Flood	937	ft^3/s	42
250 Year Peak Flood	1070	ft^3/s	44
500 Year Peak Flood	1280	ft^3/s	47

Peak-Flow Statistics Citations

Lombard, P.J., and Hodgkins, G.A.,2015, Peak flow regression equations for small, ungaged streams in Maine— Comparing map-based to field-based variables: U.S. Geological Survey Scientific Investigations Report 2015–5049, 12 p. (http://dx.doi.org/10.3133/sir20155049)

Annual Flow Statistics Parameters [Statewide Annual SIR 2015 5151]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	6.9	square miles	14.9	1419

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
SANDGRAVAF	Fraction of Sand and Gravel Aquifers	0.017	dimensionless	0	0.212
ELEV	Mean Basin Elevation	880	feet	239	2120

Annual Flow Statistics Disclaimers [Statewide Annual SIR 2015 5151]

One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors

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

Statistic	Value	Unit
Mean Annual Flow	16.2	ft^3/s

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)

Appendix C – St. John River Backwater Calculations

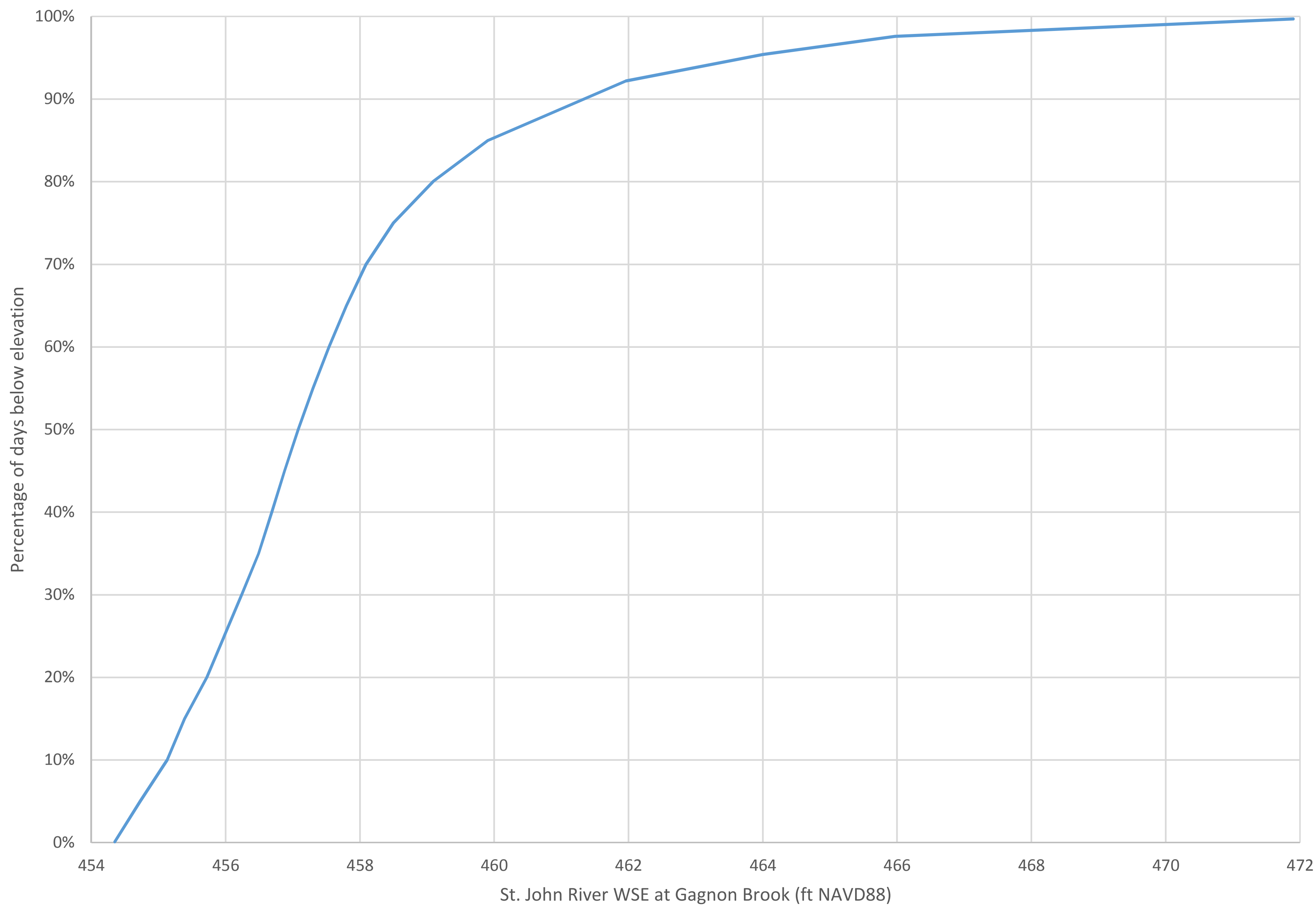
Appendix C: Calibration of St. John River Flood Elevations at Gagnon Brook

MNR/US Route 1 Crossing of Gagnon Brook, Frenchville, ME

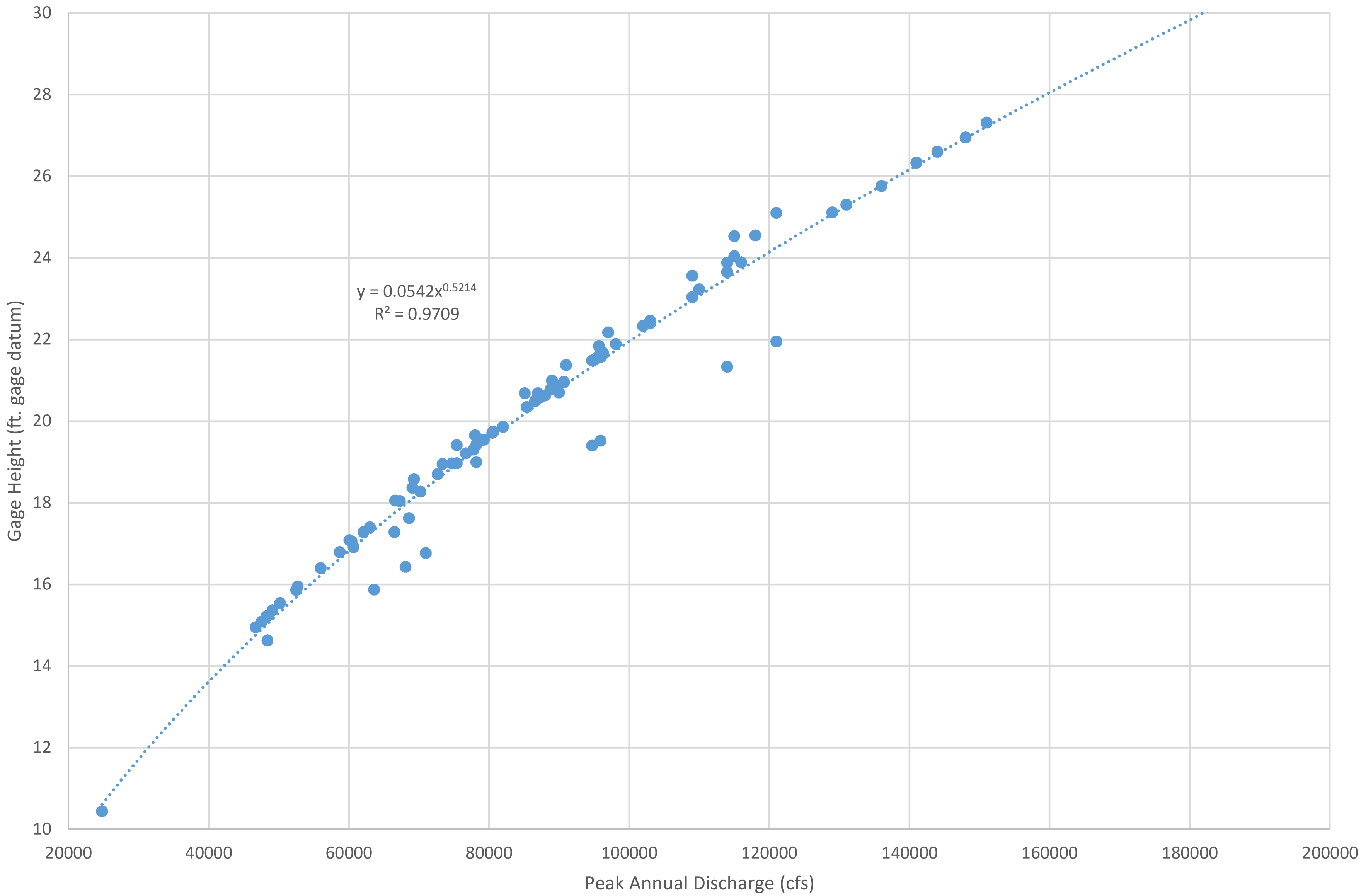
Annual % Chance	Recurrence Frequency (years)	Discharge, D (cfs)[1]	Gage Height, H (ft)[2]	Elevation at Gagnon Brook[4]
0.2	500	198,446.07	31.3	482.3
0.5	200	181,461.81	29.9	480.9
1	100	168,542.21	28.8	479.7
2	50	155,470.26	27.6	478.6
5	20	137,730.84	25.9	476.9
10	10	123,667.94	24.5	475.4
20	5	108,539.03	22.9	473.8
50	2	84,542.03	20.1	471.0
80	1.3	65,831.22	17.6	468.6
90	1.1	57,755.31	16.5	467.4
95	1.1	51,835.31	15.6	466.5
99	1.0	42,311.57	14.0	465.0
August 7, 2017 MEDOT Survey[3]		1,650.00	3.9	454.8

1. Discharge values for selected recurrence frequencies from HEC-SSP Bulletin 17B Analysis
2. Gage height calculated based on regression analysis of historic gage data, $H = 0.0542 \times (D)^{0.5214}$
3. Gage height and discharge from USGS Gage 01014000 records from date of survey
4. Elevation calibrated from August 7, 2017 survey: (Gagnon Brook WSE) = (Gage WSE) + 450.9 ft

Appendix C: St. John River Daily Water Level Records, Gage 01014000, October 2010-October 2018



Appendix C: St. John River Peak Annual Discharge Vs. Gage Height Regression Analysis, USGS Gage 01014000, Water Years 1927-2017



Bulletin 17B Frequency Analysis
26 Oct 2018 10:27 AM

--- Input Data ---

Analysis Name: St John River 1927-2017
Description: USGS Gage 01014000 St John River below Fish River at Fort Kent 1927-2017

Data Set Name: USGS Gage 01014000
DSS File Name: C:\Users\dcloutier\OneDrive - VHB\HEC-RAS\55237 Gagnon Brook Frenchvile ME\HEC-SSP\St_John\St_John.dss
DSS Pathname: ////01jan1900/IR-CENTURY//

Report File Name: C:\Users\dcloutier\OneDrive - VHB\HEC-RAS\55237 Gagnon Brook Frenchvile ME\HEC-SSP\St_John\Bulletin17Results\St_John_River_1927-2017\St_John_River_1927-2017.rpt
XML File Name: C:\Users\dcloutier\OneDrive - VHB\HEC-RAS\55237 Gagnon Brook Frenchvile ME\HEC-SSP\St_John\Bulletin17Results\St_John_River_1927-2017\St_John_River_1927-2017.xml

Start Date:
End Date:

Skew Option: Use Station Skew
Regional Skew: -Infinity
Regional Skew MSE: -Infinity

Plotting Position Type: Median

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use non-standard frequencies
Frequency: 0.2
Frequency: 0.5
Frequency: 1.0
Frequency: 2.0
Frequency: 5.0
Frequency: 10.0
Frequency: 20.0
Frequency: 50.0
Frequency: 80.0
Frequency: 90.0
Frequency: 95.0
Frequency: 99.0

Display ordinate values using 3 digits in fraction part of value

--- End of Input Data ---

--- Preliminary Results ---

<< Skew Weighting >>

Based on 91 events, mean-square error of station skew = 0.087
Mean-square error of regional skew = -?

<< Frequency Curve >>
USGS Gage 01014000

Computed Curve FLOW, cfs	Expected Probability FLOW, cfs	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, cfs	Confidence Limits 0.95 FLOW, cfs
174,328.517	---	0.2	196,299.065	158,328.916
164,916.428	---	0.5	184,467.715	150,526.647
157,051.283	---	1.0	174,663.559	143,959.018
148,400.496	---	2.0	163,973.741	136,679.575
135,412.442	---	5.0	148,127.991	125,624.176
123,973.704	---	10.0	134,403.828	115,736.654
110,411.313	---	20.0	118,470.473	103,777.874
85,961.456	---	50.0	90,999.849	81,271.212
64,327.240	---	80.0	68,385.290	60,028.052
54,378.739	---	90.0	58,392.381	49,980.689
46,919.938	---	95.0	50,958.809	42,446.341
34,804.692	---	99.0	38,829.453	30,373.854

<< Systematic Statistics >>
USGS Gage 01014000

Log Transform: FLOW, cfs		Number of Events	
Mean	4.922	Historic Events	0
Standard Dev	0.141	High Outliers	0
Station Skew	-0.518	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	-0.518	Systematic Events	91

|------------------------------|-------------------------------|

--- End of Preliminary Results ---

<< Low Outlier Test >>

Based on 91 events, 10 percent outlier test deviate K(N) = 2.984
Computed low outlier test value = 31,717.182

1 low outlier(s) identified below test value of 31,717.182

Statistics and frequency curve adjusted for 1 low outlier(s)

<< Systematic Statistics >>
USGS Gage 01014000

Log Transform: FLOW, cfs		Number of Events	
Mean	4.928	Historic Events	0
Standard Dev	0.130	High Outliers	0
Station Skew	-0.039	Low Outliers	1
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	-0.518	Systematic Events	91

<< High Outlier Test >>

Based on 90 events, 10 percent outlier test deviate K(N) = 2.981
Computed high outlier test value = 207,109.8434

0 high outlier(s) identified above test value of 207,109.8434

Note: Statistics and frequency curve were modified
using conditional probablity adjustment.

--- Final Results ---

<< Plotting Positions >>

USGS Gage 01014000

Events Analyzed			Ordered Events			
		FLOW		Water	FLOW	Median
Day Mon Year		cfs	Rank	Year	cfs	Plot Pos
23 Apr 1927		66,500.000	1	2008	183,000.000	0.77
07 May 1928		90,000.000	2	1979	151,000.000	1.86
05 May 1929		78,200.000	3	1974	148,000.000	2.95
03 May 1930		96,300.000	4	1994	144,000.000	4.05
23 Apr 1931		48,400.000	5	1983	141,000.000	5.14
23 Apr 1932		68,600.000	6	1973	136,000.000	6.24
04 May 1933		121,000.000	7	1961	131,000.000	7.33
25 Apr 1934		95,700.000	8	1969	129,000.000	8.42
01 May 1935		75,400.000	9	2014	121,000.000	9.52
22 Mar 1936		82,000.000	10	1933	121,000.000	10.61
30 Apr 1937		60,700.000	11	1958	118,000.000	11.71
21 Apr 1938		70,200.000	12	2005	116,000.000	12.80
10 May 1939		115,000.000	13	1998	115,000.000	13.89
04 May 1940		87,000.000	14	1942	115,000.000	14.99
21 Apr 1941		109,000.000	15	1939	115,000.000	16.08
04 May 1942		115,000.000	16	2011	114,000.000	17.18
12 May 1943		89,000.000	17	1987	114,000.000	18.27
06 May 1944		73,400.000	18	1947	114,000.000	19.37
02 Apr 1945		78,000.000	19	1984	110,000.000	20.46
17 May 1946		69,100.000	20	1996	109,000.000	21.55
08 May 1947		114,000.000	21	1941	109,000.000	22.65
09 May 1948		60,100.000	22	1997	103,000.000	23.74
03 May 1949		49,100.000	23	1982	103,000.000	24.84
22 Apr 1950		66,600.000	24	1992	102,000.000	25.93
09 Apr 1951		77,800.000	25	1977	98,100.000	27.02
29 Apr 1952		69,300.000	26	1954	97,000.000	28.12
31 Mar 1953		75,400.000	27	1978	96,300.000	29.21
23 Apr 1954		97,000.000	28	1930	96,300.000	30.31
04 May 1955		85,100.000	29	2009	96,000.000	31.40
15 May 1956		48,300.000	30	2017	95,900.000	32.49
23 Apr 1957		50,200.000	31	1934	95,700.000	33.59
25 Apr 1958		118,000.000	32	1976	95,600.000	34.68
27 Apr 1959		52,700.000	33	1970	95,000.000	35.78
07 May 1960		91,000.000	34	2012	94,700.000	36.87
15 May 1961		131,000.000	35	2001	94,700.000	37.96
07 May 1962		46,700.000	36	1960	91,000.000	39.06
02 May 1963		76,700.000	37	2010	90,700.000	40.15
09 Nov 1963		60,400.000	38	1968	90,700.000	41.25

13 May 1965	24,800.000	39	1928	90,000.000	42.34
20 May 1966	58,700.000	40	1971	89,600.000	43.44
04 May 1967	67,300.000	41	1943	89,000.000	44.53
16 Apr 1968	90,700.000	42	1981	88,900.000	45.62
10 May 1969	129,000.000	43	2007	88,800.000	46.72
02 May 1970	95,000.000	44	1972	88,000.000	47.81
05 May 1971	89,600.000	45	1991	87,400.000	48.91
16 May 1972	88,000.000	46	1940	87,000.000	50.00
29 Apr 1973	136,000.000	47	2002	86,600.000	51.09
30 Apr 1974	148,000.000	48	1993	86,600.000	52.19
12 May 1975	79,300.000	49	1990	85,400.000	53.28
21 Apr 1976	95,600.000	50	1955	85,100.000	54.38
23 Apr 1977	98,100.000	51	1936	82,000.000	55.47
10 May 1978	96,300.000	52	2000	80,600.000	56.56
29 Apr 1979	151,000.000	53	2004	80,500.000	57.66
15 Apr 1980	56,000.000	54	1975	79,300.000	58.75
06 Aug 1981	88,900.000	55	1985	78,200.000	59.85
28 Apr 1982	103,000.000	56	1929	78,200.000	60.94
18 Apr 1983	141,000.000	57	1945	78,000.000	62.04
01 May 1984	110,000.000	58	1951	77,800.000	63.13
27 Apr 1985	78,200.000	59	1963	76,700.000	64.22
03 Apr 1986	63,000.000	60	1953	75,400.000	65.32
01 Apr 1987	114,000.000	61	1935	75,400.000	66.41
05 Apr 1988	47,600.000	62	2006	74,700.000	67.51
08 Apr 1989	72,700.000	63	1944	73,400.000	68.60
28 Apr 1990	85,400.000	64	1989	72,700.000	69.69
27 Apr 1991	87,400.000	65	2013	71,000.000	70.79
23 Apr 1992	102,000.000	66	1938	70,200.000	71.88
12 Apr 1993	86,600.000	67	1952	69,300.000	72.98
16 Apr 1994	144,000.000	68	1946	69,100.000	74.07
22 Apr 1995	52,500.000	69	1932	68,600.000	75.16
24 Apr 1996	109,000.000	70	2015	68,100.000	76.26
17 May 1997	103,000.000	71	1967	67,300.000	77.35
02 Apr 1998	115,000.000	72	1950	66,600.000	78.45
22 Apr 1999	48,500.000	73	1927	66,500.000	79.54
24 Apr 2000	80,600.000	74	2016	63,600.000	80.63
25 Apr 2001	94,700.000	75	1986	63,000.000	81.73
18 Apr 2002	86,600.000	76	2003	62,100.000	82.82
24 Apr 2003	62,100.000	77	1937	60,700.000	83.92
20 Apr 2004	80,500.000	78	1964	60,400.000	85.01
25 Apr 2005	116,000.000	79	1948	60,100.000	86.11
16 Apr 2006	74,700.000	80	1966	58,700.000	87.20
26 Apr 2007	88,800.000	81	1980	56,000.000	88.29
30 Apr 2008	183,000.000	82	1959	52,700.000	89.39
24 Apr 2009	96,000.000	83	1995	52,500.000	90.48
07 Apr 2010	90,700.000	84	1957	50,200.000	91.58
06 May 2011	114,000.000	85	1949	49,100.000	92.67
23 Mar 2012	94,700.000	86	1999	48,500.000	93.76

21 Apr 2013	71,000.000	87	1931	48,400.000	94.86
17 Apr 2014	121,000.000	88	1956	48,300.000	95.95
24 Apr 2015	68,100.000	89	1988	47,600.000	97.05
24 Apr 2016	63,600.000	90	1962	46,700.000	98.14
29 Apr 2017	95,900.000	91	1965	24,800.000*	99.23

* Outlier

<< Skew Weighting >>

Based on 91 events, mean-square error of station skew = 0.059
Mean-square error of regional skew = -?

<< Frequency Curve >>
USGS Gage 01014000

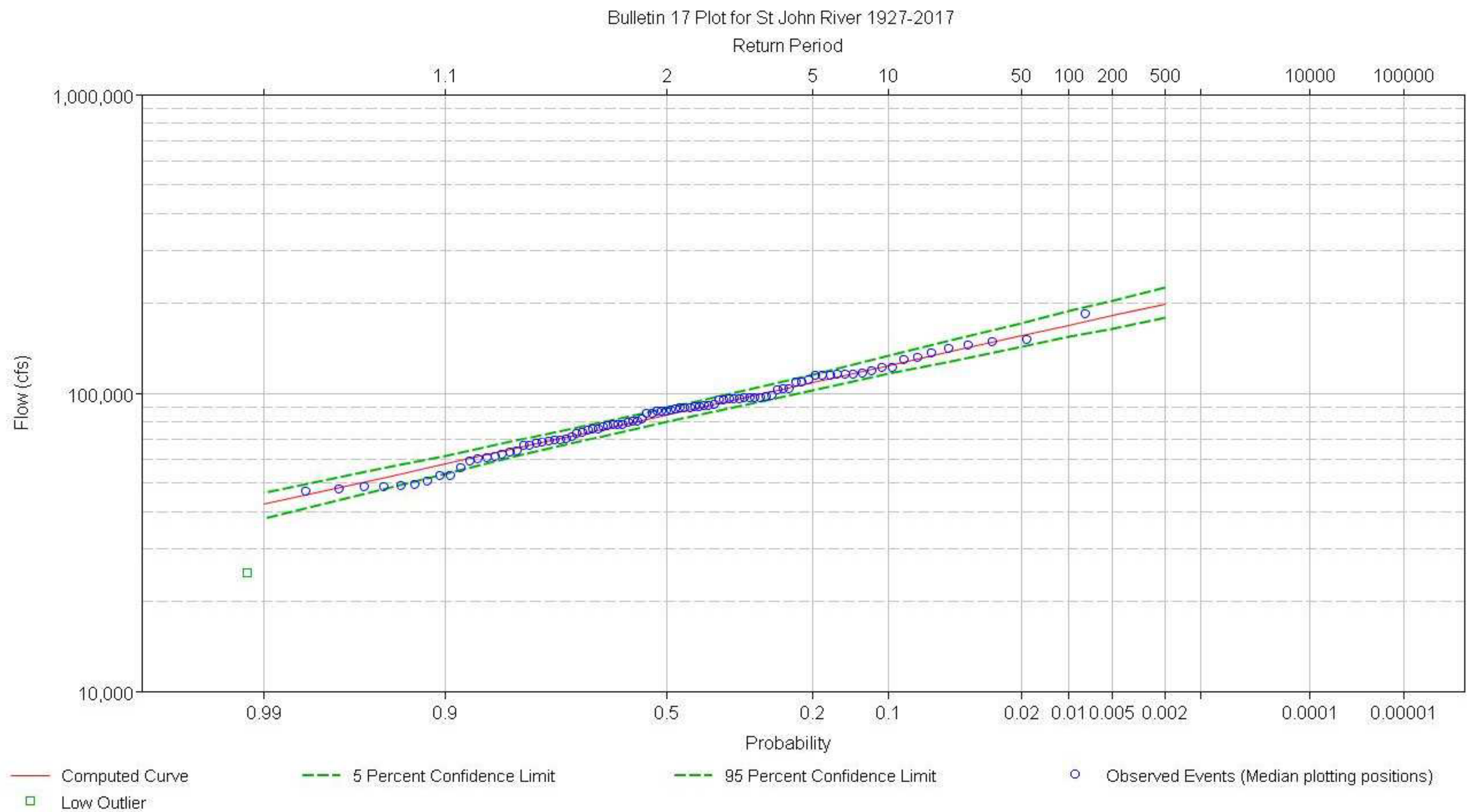
Computed Curve FLOW, cfs	Expected Probability FLOW, cfs	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, cfs	Confidence Limits 0.95 FLOW, cfs
198,446.068	---	0.2	226,251.676	178,651.167
181,461.810	---	0.5	204,568.499	164,762.528
168,542.212	---	1.0	188,280.478	154,084.812
155,470.259	---	2.0	172,001.185	143,166.321
137,730.840	---	5.0	150,277.590	128,126.797
123,667.937	---	10.0	133,414.471	115,972.635
108,539.025	---	20.0	115,722.631	102,581.288
84,542.034	---	50.0	89,020.151	80,289.694
65,831.224	---	80.0	69,654.169	61,745.276
57,755.311	---	90.0	61,588.768	53,534.600
51,835.307	---	95.0	55,723.893	47,503.837
42,311.574	---	99.0	46,289.338	37,867.386

<< Synthetic Statistics >>
USGS Gage 01014000

Log Transform: FLOW, cfs		Number of Events	
Mean	4.927	Historic Events	0
Standard Dev	0.129	High Outliers	0
Station Skew	-0.004	Low Outliers	1

```
|  Regional Skew         ---  |  Zero Events          0     |
|  Weighted Skew         ---  |  Missing Events       0     |
|  Adopted Skew       -0.004  |  Systematic Events      91  |
|-----------------------------|-----------------------------|
```

--- End of Analytical Frequency Curve ---

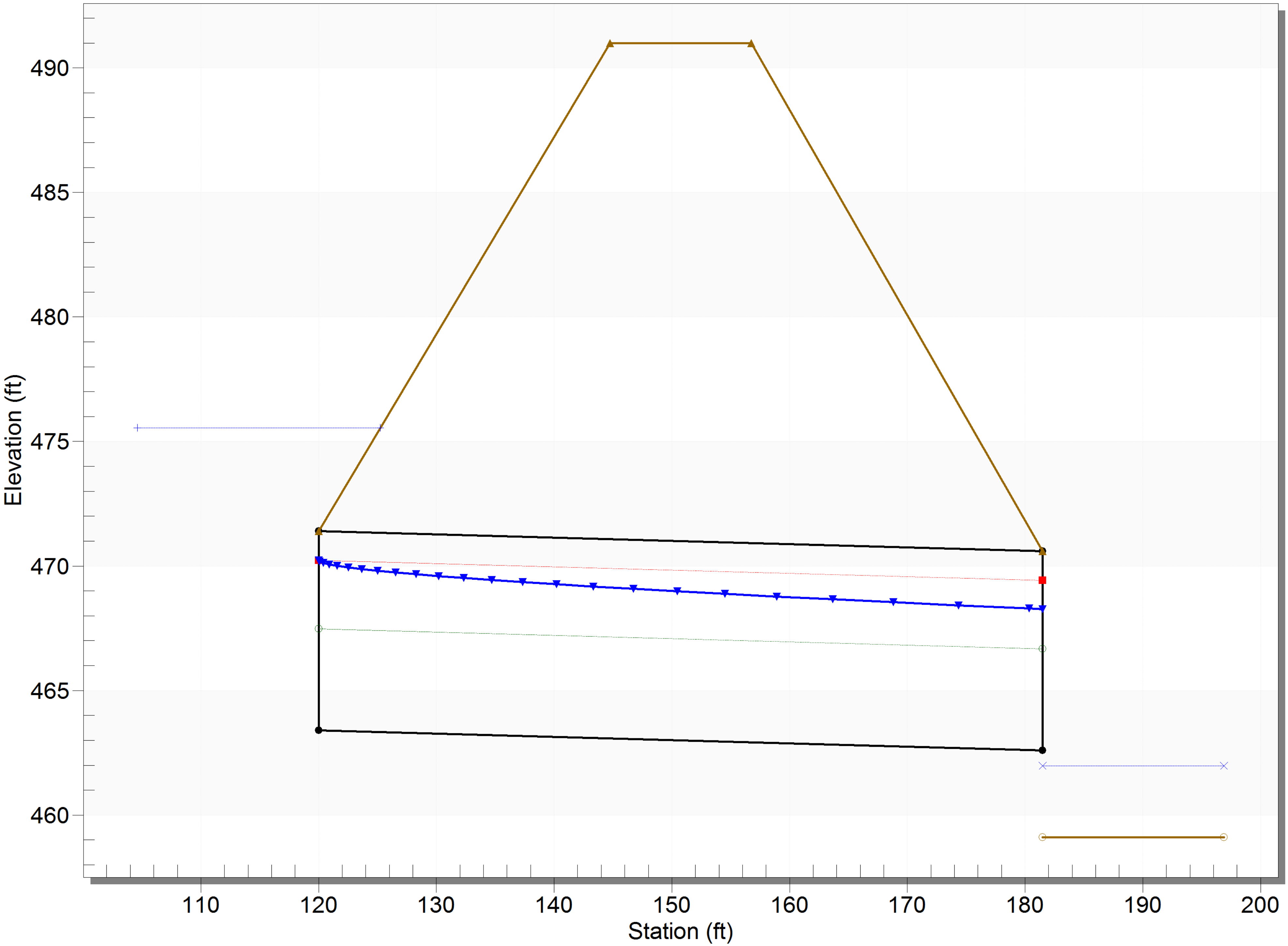


Bulletin 17 Plot for St John River 1927-2017
Return Period
1.1
2
5
10
50
100
200
500
10000
100000
1,000,000
100,000
10,000
Flow (cfs)
0.99
0.9
0.5
0.2
0.1
0.02
0.01
0.005
0.002
0.0001
0.00001
Probability
Computed Curve
5 Percent Confidence Limit
95 Percent Confidence Limit
Observed Events (Median plotting positions)
Low Outlier

Appendix D – HY-8 Hydraulic Model Results

Crossing - Gagnon Brook Existing RR, Design Discharge - 1292.3 cfs

Culvert - Railroad Culvert, Culvert Discharge - 1292.3 cfs



HY-8 Analysis Results

Culvert Summary Table - Railroad Culvert

Culvert Crossing: Gagnon Brook Existing RR

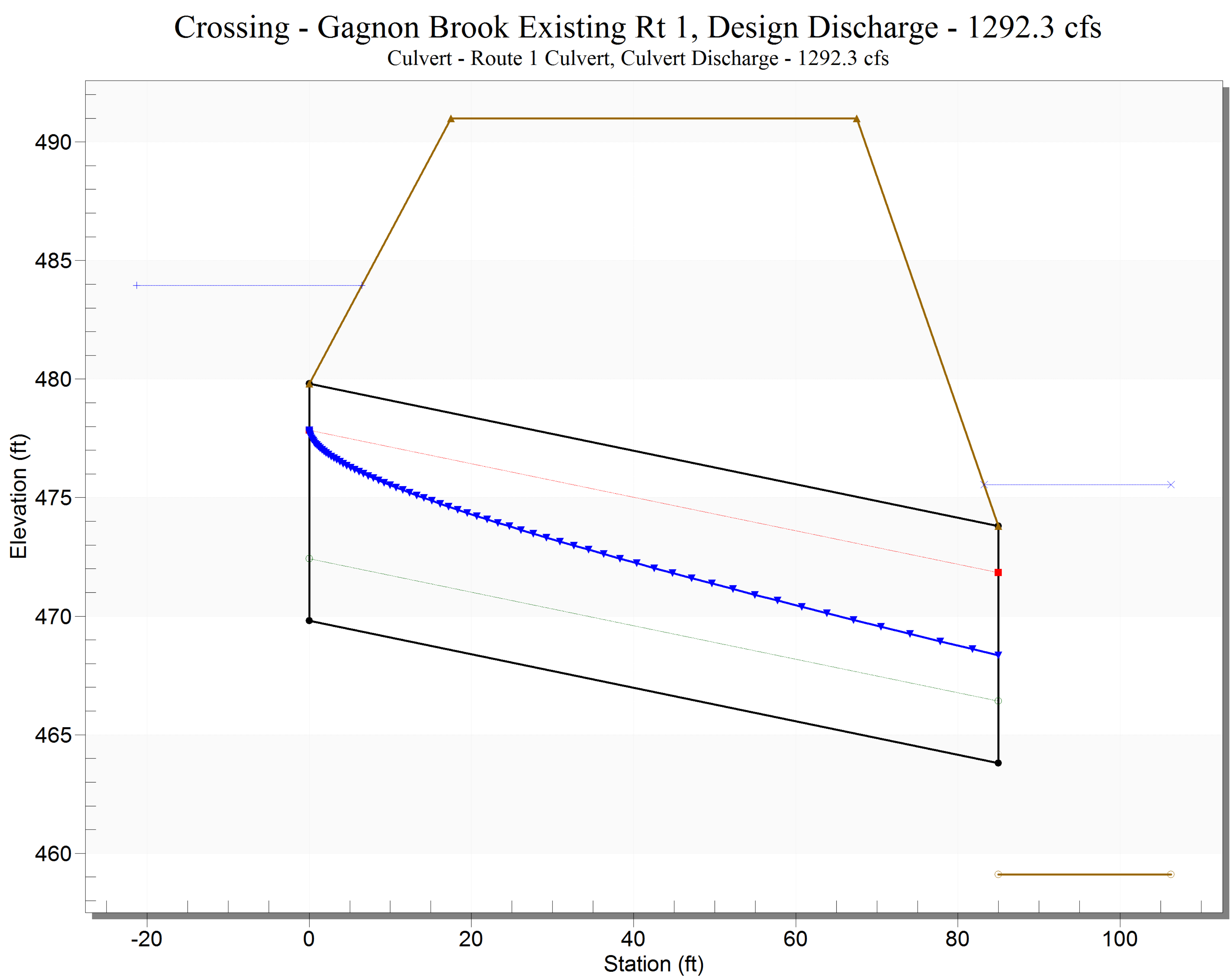
Discharge Names	Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth(ft)	Outlet Control Depth(ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
1 year	121.30	121.30	465.67	2.27	0.71	1-S2n	0.84	1.46	0.99	0.71	9.95	6.52
2 year	256.70	256.70	467.14	3.74	1.86	1-S2n	1.36	2.43	1.73	1.11	12.09	8.61
5 year	410.50	410.50	468.46	5.06	3.11	1-S2n	1.85	3.32	2.45	1.47	13.59	10.20
10 year	522.30	522.30	469.26	5.86	4.05	1-S2n	2.17	3.90	2.94	1.70	14.45	11.11
25 year	686.30	686.30	470.33	6.93	5.50	1-S2n	2.61	4.66	3.60	1.99	15.48	12.22
50 year	809.20	809.20	471.16	7.76	6.66	1-S2n	2.93	5.19	4.07	2.19	16.15	12.93
100 year	948.20	948.20	472.20	8.80	8.05	5-S2n	3.27	5.72	4.57	2.41	16.87	13.65
500 year	1292.30	1292.30	475.54	12.14	-1.42	5-S2n	4.07	6.83	5.67	2.88	18.59	15.14

HY-8 Analysis Results

Culvert Summary Table - Railroad Culvert

Culvert Crossing: Gagnon Brook Q10 Tailwater Existing RR

Discharge Names	Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth(ft)	Outlet Control Depth(ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
1 year	121.30	121.30	475.50	2.27	12.10	4-FFf	0.84	1.46	8.00	16.35	1.36	0.00
2 year	256.70	256.70	475.68	3.74	12.28	4-FFf	1.36	2.43	8.00	16.35	2.88	0.00
5 year	410.50	410.50	476.04	5.06	12.64	4-FFf	1.85	3.32	8.00	16.35	4.61	0.00
10 year	522.30	522.30	476.40	5.86	13.00	4-FFf	2.17	3.90	8.00	16.35	5.86	0.00
25 year	686.30	686.30	477.09	6.93	13.69	4-FFf	2.61	4.66	8.00	16.35	7.70	0.00
50 year	809.20	809.20	477.73	7.76	14.33	4-FFf	2.93	5.19	8.00	16.35	9.08	0.00
100 year	948.20	948.20	478.58	8.80	15.18	4-FFf	3.27	5.72	8.00	16.35	10.64	0.00
500 year	1292.30	1292.30	481.26	12.14	17.86	4-FFf	4.07	6.83	8.00	16.35	14.50	0.00


Crossing - Gagnon Brook Existing Rt 1, Design Discharge - 1292.3 cfs
Culvert - Route 1 Culvert, Culvert Discharge - 1292.3 cfs
Elevation (ft)
490
485
480
475
470
465
460
Station (ft)
-20
0
20
40
60
80
100

HY-8 Analysis Results

Culvert Summary Table - Route 1 Culvert

Culvert Crossing: Gagnon Brook Existing Rt 1

Discharge Names	Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth(ft)	Outlet Control Depth(ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
1 year	121.30	121.30	472.45	2.65	-4.09	1-S2n	0.55	1.66	0.65	6.57	18.62	5.41
2 year	256.70	256.70	474.18	4.38	-2.50	1-S2n	0.89	2.74	1.18	8.04	21.68	6.40
5 year	410.50	410.50	475.82	6.02	-0.92	1-S2n	1.21	3.74	1.75	9.36	23.48	7.34
10 year	522.30	522.30	476.89	7.09	0.14	1-S2n	1.42	4.39	2.14	10.16	24.43	7.97
25 year	686.30	686.30	478.36	8.56	1.70	1-S2n	1.70	5.27	2.69	11.23	25.54	8.76
50 year	809.20	809.20	479.43	9.63	2.99	1-S2n	1.90	5.88	3.08	12.06	26.25	9.16
100 year	948.20	948.20	480.64	10.84	4.64	5-S2n	2.12	6.54	3.52	13.10	26.96	9.41
500 year	1292.30	1292.30	483.96	14.16	9.89	5-S2n	2.63	8.03	4.55	16.44	28.43	9.17

HY-8 Analysis Results

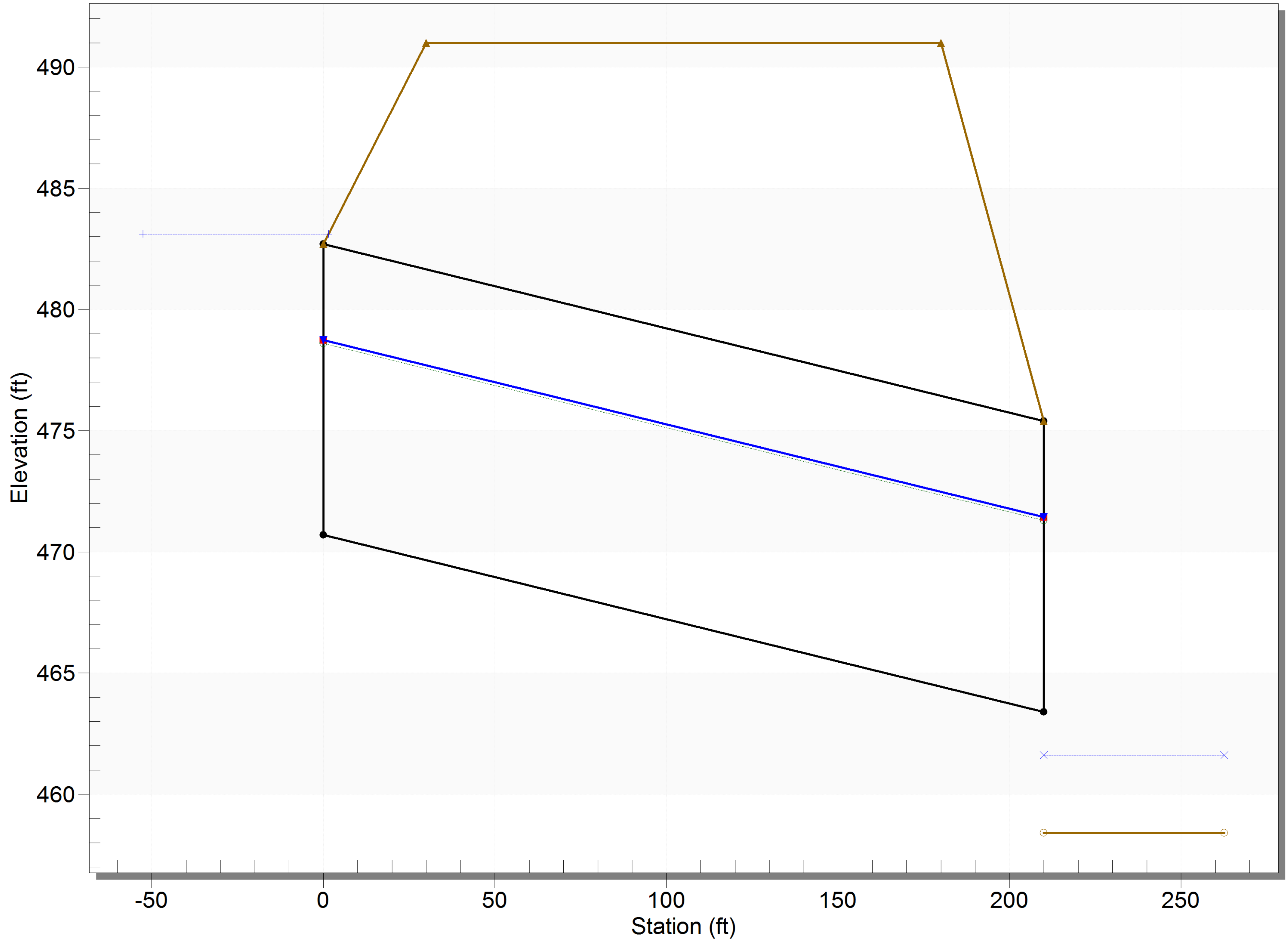
Culvert Summary Table - Route 1 Culvert

Culvert Crossing: Gagnon Brook Q10 Tailwater Existing Rt 1

Discharge Names	Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth(ft)	Outlet Control Depth(ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
1 year	121.30	121.30	475.56	2.65	5.76	1-S1f	0.55	1.66	10.00	16.40	1.21	0.86
2 year	256.70	256.70	475.95	4.38	6.15	1-S1f	0.89	2.74	10.00	16.58	2.57	1.80
5 year	410.50	410.50	476.73	6.02	6.93	1-S1f	1.21	3.74	10.00	16.94	4.11	2.79
10 year	522.30	522.30	477.50	7.09	7.70	1-S1f	1.42	4.39	10.00	17.30	5.22	3.45
25 year	686.30	686.30	478.86	8.56	9.06	1-S1f	1.70	5.27	10.00	17.99	6.86	4.30
50 year	809.20	809.20	479.91	9.63	10.11	1-S1f	1.90	5.88	10.00	18.63	8.09	4.84
100 year	948.20	948.20	481.14	10.84	11.34	1-S1f	2.12	6.54	10.00	19.48	9.48	5.35
500 year	1292.30	1292.30	485.41	14.16	15.61	4-FFf	2.63	8.03	10.00	22.16	12.92	6.17

Crossing - Gagnon Brook PR Free Discharge Increased Roughness, Design Discharge - 1292.3 cfs

Culvert - Culvert 1, Culvert Discharge - 1292.3 cfs



HY-8 Analysis Results

Culvert Summary Table - Culvert 1

Culvert Crossing: Gagnon Brook PR Free Discharge Drop Outlet

Discharge Names	Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth(ft)	Outlet Control Depth(ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
1 year	121.30	121.30	473.17	2.47	-5.61	1-S2n	0.69	1.66	0.74	0.81	16.28	5.65
2 year	256.70	256.70	474.77	4.07	-4.45	1-S2n	1.12	2.74	1.26	1.26	20.33	7.42
5 year	410.50	410.50	476.26	5.56	-3.26	1-S2n	1.53	3.74	1.81	1.66	22.65	8.75
10 year	522.30	522.30	477.27	6.57	-2.43	1-S2n	1.80	4.39	2.19	1.91	23.82	9.51
25 year	686.30	686.30	478.64	7.94	-1.20	1-S2n	2.17	5.27	2.73	2.23	25.12	10.43
50 year	809.20	809.20	479.58	8.88	-0.27	1-S2n	2.43	5.88	3.12	2.46	25.92	11.01
100 year	948.20	948.20	480.61	9.91	0.82	1-S2n	2.71	6.54	3.55	2.69	26.69	11.60
500 year	1292.30	1292.30	483.11	12.41	3.67	5-S2n	3.38	8.03	4.57	3.21	28.26	12.81

HY-8 Energy Dissipation Report

Internal Energy Dissipator

Parameter	Value	Units
Select Culvert and Flow		
Crossing	Gagnon Brook PR Free Discharge Drop Outlet	
Culvert	Culvert 1	
Flow	809.20	cfs
Culvert Data		
Culvert Width (including multiple barrels)	10.0	ft
Culvert Height	12.0	ft
Outlet Depth	3.12	ft
Outlet Velocity	25.92	ft/s
Froude Number	2.58	
Tailwater Depth	2.46	ft
Tailwater Velocity	11.01	ft/s
Tailwater Slope (SO)	0.0348	
Internal Dissipator Data		
Type of Dissipator	Increased Resistance	
Restrictions		
Special Limitations	Culvert must be either a Concrete Box or Circular	
Input Data		
Roughness Element Height to Hydraulic Radius (h/Ri)		
Note:	h/Ri is taken above the roughness element crest	
Note:	0.1 < h/Ri < 0.4 ft	
Roughness Element Height to Hydraulic Radius (h/Ri)	0.377	ft/ft
Height of Roughened Section	12.000	ft
Results		
Dissipator Height	12.000	ft
Opening Height	10.998	ft
Number of Rows (N)	18	
Manning's n (nLow)	0.037	
Exit Depth (YLow)	5.674	ft
Exit Velocity (Vout)	14.262	ft/s
Element Spacing (L/h) = 10		
Space to First Element (L/2)	5.010	ft
Space Between Elements (L)	10.020	ft
Space At End (L/2)	5.010	ft
Total Length (L)N	180.361	ft
Element Dimensions (h/Ri) = 0.38		
Height (h)	1.002	ft
Ratio (Lr/P)	0.238	
Full Flow Capacity Check		
Discharge	1504.194	cfs
Velocity	13.677	ft/s
Depth	10.998	ft
Manning's n	0.038	

HY-8 Analysis Results

Culvert Summary Table - Culvert 1

Culvert Crossing: Gagnon Brook PR Free Discharge Increased Roughness

Discharge Names	Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth(ft)	Outlet Control Depth(ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
1 year	121.30	121.30	473.17	2.47	-11.49	1-S2n	1.44	1.66	1.44	0.81	8.43	5.65
2 year	256.70	256.70	474.77	4.07	-4.31	1-S2n	2.39	2.74	2.44	1.26	10.54	7.42
5 year	410.50	410.50	476.26	5.56	-2.91	1-S2n	3.33	3.74	3.40	1.66	12.08	8.75
10 year	522.30	522.30	477.27	6.57	-1.85	1-S2n	3.96	4.39	4.05	1.91	12.89	9.51
25 year	686.30	686.30	478.64	7.94	-0.21	1-S2n	4.85	5.27	4.96	2.23	13.83	10.43
50 year	809.20	809.20	479.58	8.88	1.11	1-S2n	5.49	5.88	5.58	2.46	14.50	11.01
100 year	948.20	948.20	480.61	9.91	2.72	1-S2n	6.20	6.54	6.36	2.69	14.91	11.60
500 year	1292.30	1292.30	483.11	12.41	7.20	5-S2n	7.90	8.03	8.03	3.21	16.09	12.81

HY-8 Analysis Results

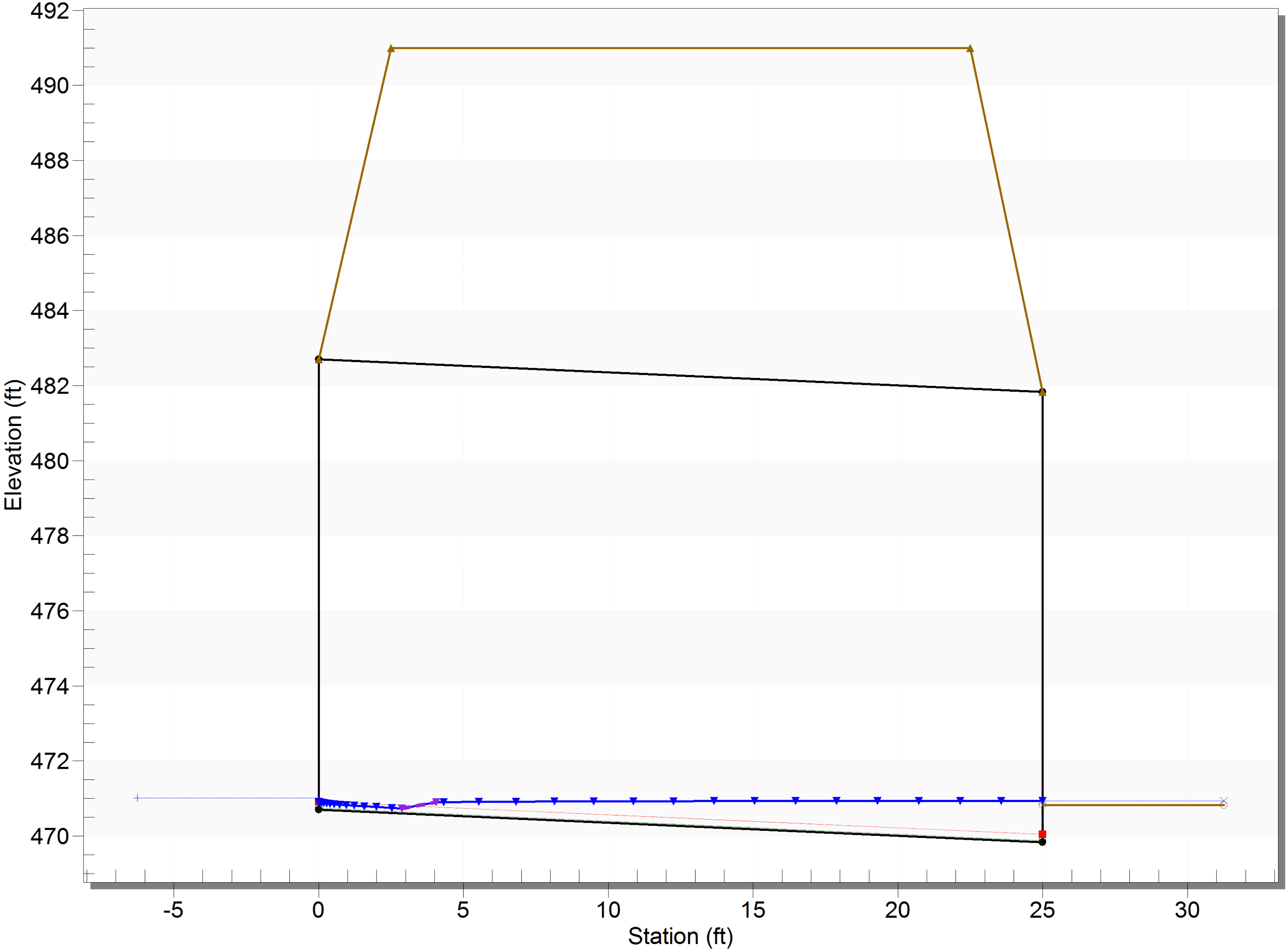
Culvert Summary Table - Culvert 1

Culvert Crossing: Gagnon Brook PR Q10 Tailwater

Discharge Names	Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth(ft)	Outlet Control Depth(ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
1 year	121.30	121.30	475.52	2.47	4.82	1-S1f	0.69	1.66	12.00	17.05	1.01	0.00
2 year	256.70	256.70	475.78	4.07	5.08	1-S1f	1.12	2.74	12.00	17.05	2.14	0.00
5 year	410.50	410.50	476.26	5.56	5.04	1-JS1f	1.53	3.74	12.00	17.05	3.42	0.00
10 year	522.30	522.30	477.27	6.57	5.23	1-JS1f	1.80	4.39	12.00	17.05	4.35	0.00
25 year	686.30	686.30	478.64	7.94	5.57	1-JS1f	2.17	5.27	12.00	17.05	5.72	0.00
50 year	809.20	809.20	479.58	8.88	5.90	1-JS1f	2.43	5.88	12.00	17.05	6.74	0.00
100 year	948.20	948.20	480.61	9.91	6.33	1-S2n	2.71	6.54	3.55	17.05	26.69	0.00
500 year	1292.30	1292.30	483.11	12.41	7.68	5-S2n	3.38	8.03	4.57	17.05	28.26	0.00

Crossing - Gagnon Brook PR Free Discharge Increased Roughness Drop Outlet Low Flow, Design Discharge - 5.5 cfs

Culvert - Culvert 1, Culvert Discharge - 5.5 cfs



HY-8 Analysis Results

Culvert Summary Table - Culvert 1

Culvert Crossing: Gagnon Brook PR Free Discharge Increased Roughness Drop Outlet Low Fl

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth(ft)	Outlet Control Depth(ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
1.49	1.49	470.88	0.13	0.18	1-S1t	0.01	0.09	1.05	0.05	0.14	3.06
3.78	3.78	470.98	0.24	0.28	1-S1t	0.04	0.16	1.09	0.09	0.35	4.42
5.50	5.50	471.01	0.31	0.24	1-JS1t	0.05	0.21	1.11	0.11	0.50	5.14
8.35	8.35	471.11	0.41	0.27	1-JS1t	0.08	0.28	1.14	0.14	0.73	6.05
10.64	10.64	471.19	0.49	0.29	1-JS1t	0.10	0.33	1.16	0.16	0.92	6.66
12.93	12.93	471.25	0.55	0.31	1-JS1t	0.12	0.37	1.18	0.18	1.10	7.19
15.22	15.22	471.32	0.62	0.33	1-JS1t	0.14	0.42	1.20	0.20	1.27	7.66
17.51	17.51	471.38	0.68	0.35	1-JS1t	0.17	0.46	1.22	0.22	1.44	8.09
19.79	19.79	471.44	0.74	0.36	1-JS1t	0.19	0.50	1.23	0.23	1.61	8.49
22.08	22.08	471.49	0.79	0.38	1-JS1t	0.21	0.53	1.25	0.25	1.77	8.86
24.37	24.37	471.55	0.85	0.40	1-JS1t	0.23	0.57	1.26	0.26	1.93	9.20

Appendix E – Scour Calculations

Scour Calculation Worksheet **Project No.: 55237**
Bridge Scour Calculations
Proposed 10' w x 12' h box culvert

Project: Gagnon Brook **Computed by:** DWC
Location: Frenchville, ME **Checked by:**
Notes: Calculations based on methodology outlined in HEC-18 5th Edition (FHWA, 2012)

Open-Bottom Culvert Scour Computations - Proposed Bridge

1. Determine Live-Bed or Clear-Water Scour

Notes *1. Open-bottom culvert scour equaltion only applies for clear-water scour*

A. Calculate Critical Velocity (V_c) and Compare to Average Velocity in Main Channel

$V_c = K_u y^{1/6} D^{1/3}$ *Equation 6.1*

K_u = 11.17
y = Average Depth (ft)
$D = D_{50}$ = 55.00 mm
0.180 ft

Storm Event	Y_1 (ft)	V_c (ft/s)	V_1 (ft/s)	Live Bed or Clear Water
100-Year	9.90	9.25	3.20	Clear-Water
500-Year	12.40	9.60	2.36	Clear-Water

$D = D_{50}$ = 0.18 ft

Notes
1. Y_1 is headwater depth at culvert inlet
2. V_1 isestimated channel velocity, assuming a 20-foot wide trapezoidal channel with headwater flow depth
3. K_u is 6.19 for SI Units and 11.17 for English Units
4. Estimated D50 of sand/gravel streambed to be 55 mm
5. If Vc > V1 ; Clear-Water condition exists; else Live Bed Condition

2. Use Section 2a for wingwall case, use Section 2b for no wingwall case

2a. Determine ys for open-bottom culvert with wingwalls (Clear Water Condition ONLY)

$$y_{max} = K_u Q_{BI}^{0.28} \left(\frac{Q}{W_c D_{50}^{1/3}} \right)^{0.26}$$ *Equation 6.10*

K_u = 0.84 K_u = 0.84 for wingwall condition
D_{50} = 0.18 ft

Storm Event	Q (ft^3/s)	Q_{BI} (ft^3/s)	W_c (ft)	y_{max} (ft)
100-Year	948.2	237.05	10.00	14.71
500-Year	1292.3	323.08	10.00	17.39

Notes
1. Q is flow through the culvert opening in main channel
2. Q_{BI} is flow blocked by road embankment on one side of culvert (assumed to be 25% of total Q)
3. Wc is width of main channel through culvert opening
4. D_{50} is median bed diameter from Section 1

3a. Compute Combined Contraction and Abutment Scour (wingwall condition)

$y_s = y_{max} - y_0$ *Equation 6.11, 6.13*

Storm Event	y_{max} (ft)	y_0 (ft)	y_s (ft)
25-Year	14.71	9.8	**4.91**
50-Year	17.39	12.3	**5.09**

1. y_{max} - computed flow depth combinging contraction and local scour

2. y_0 = average existing flow depth in contracted section (RS 300 BR U)

NOTE: THIS EQUATION IS NOT APPLICABLE FOR SCOUR UNDER PRESSURE CONDITIONS.
FOR PRESSURE FLOW CONDITION, USE THE APPLICABLE CONTRACTION SCOUR EQUATIONS.

HY-8 Energy Dissipation Report

Scour Hole Geometry

Parameter	Value	Units
Select Culvert and Flow		
Crossing	Gagnon Brook PR Increased Roughness Velocities	
Culvert	Culvert 1	
Flow	948.20	cfs
Culvert Data		
Culvert Width (including multiple barrels)	10.0	ft
Culvert Height	12.0	ft
Outlet Depth	6.36	ft
Outlet Velocity	14.91	ft/s
Froude Number	1.04	
Tailwater Depth	2.69	ft
Tailwater Velocity	11.60	ft/s
Tailwater Slope (SO)	0.0348	
Scour Data		
Time to Peak		
Note:	if Time to Peak is unknown, enter 30 min	
Time to Peak	30.00	min
Cohesion	Noncohesive	
D16 Value	3.00	mm
D84 Value	180.00	mm
Tailwater Flow Depth after Culvert Outlet	Normal Depth	
Results		
Assumptions		
Soil Sigma	7.75	
Scour Hole Dimensions		
Length	83.794	ft
Width	50.551	ft
Depth	7.613	ft
Volume	30219.366	ft^3
DS at .4(LS)	33.518	ft
Tailwater Depth (TW)	2.691	ft
Velocity with TW and WS	6.300	ft/s

HY-8 Energy Dissipation Report

Scour Hole Geometry

Parameter	Value	Units
Select Culvert and Flow		
Crossing	Gagnon Brook PR Increased Roughness Velocities	
Culvert	Culvert 1	
Flow	1292.30	cfs
Culvert Data		
Culvert Width (including multiple barrels)	10.0	ft
Culvert Height	12.0	ft
Outlet Depth	8.03	ft
Outlet Velocity	16.09	ft/s
Froude Number	1.00	
Tailwater Depth	3.21	ft
Tailwater Velocity	12.81	ft/s
Tailwater Slope (SO)	0.0348	
Scour Data		
Time to Peak		
Note:	if Time to Peak is unknown, enter 30 min	
Time to Peak	30.00	min
Cohesion	Noncohesive	
D16 Value	3.00	mm
D84 Value	180.00	mm
Tailwater Flow Depth after Culvert Outlet	Normal Depth	
Results		
Assumptions		
Soil Sigma	7.75	
Scour Hole Dimensions		
Length	95.082	ft
Width	57.486	ft
Depth	8.614	ft
Volume	43880.362	ft^3
DS at .4(LS)	38.033	ft
Tailwater Depth (TW)	3.210	ft
Velocity with TW and WS	6.300	ft/s

Appendix E: Riprap Sizing Worksheet

Project: Gagnon Brook **Computed by:** DC
Location: Frenchville, ME **Checked by:**
Notes: Calculations based on methodology outlined in HEC-23 3rd Edition (FHWA-NHI-09-112, 2009), Design Guide 8

1. Determine input variables

	Q100	Q500	
V_g [1]	14.50	16.00	average velocity at the culvert entrance, ft/s
S_g	2.65	2.65	specific gravity of rock riprap, assumed 2.65
g	32.2	32.2	gravity, 32.2 ft/s^2
y_0 [2]	6.50	8.00	average flow depth at the culvert entrance, ft
Fr	1.00	1.00	Froude Number
K_r	0.38	0.38	sizing coefficient equal to 0.38 from the best fit lab data

2. Calculate Riprap size using HEC-23 equation 18.1

$$d_{50} = \frac{K_r y_0}{(S_g - 1)} \left(\frac{V_{AC}^2}{g y_0} \right)^{0.33}$$ *equation 18.1*

	Q100	Q500	
D_{50}	**1.50**	**1.84**	median stone diameter, ft

NOTE: Use MaineDOT Specification 703.28, Heavy Riprap (D50=2.0 ft)

3. Determine riprap thickness.

	Left	Right	
Thickness, ft	4.50	5.52	Riprap thickness should not be less than 3xd50.