2.3 Onondaga Lake Low Water Level

During low and typical flow conditions, the hydraulic grade line upstream of the Phoenix Dam (including the Seneca and Oneida rivers) is relatively flat. As described above, at low flows, the headpond elevation at the Phoenix Dam is maintained to an elevation 361.92 feet NAVD88. Based on the measurements collected during the past 38 years, Onondaga Lake water levels have rarely dropped below 362.0 feet NAVD88. The lake elevation of 362.0 feet has been exceeded approximately 96.6% of the analyzed time period. Since the hydroelectric plant synchronized its generating units in December 1990, the lake level was below 362.0 feet NAVD88 less than 1% of the time. Therefore, an Onondaga Lake level of **362.0 feet NAVD88** would be representative of the low water lake elevation for the model simulations.

2.4 Onondaga Lake Median Water Level

The typical operating headpond elevation that is maintained at the Phoenix Dam is 362.42 feet NAVD88. Based on the measurements collected during the past 38 years, the median water level for the lake was 362.58 feet. Therefore, an Onondaga Lake level of **362.5 feet NAVD88** would be representative of the median lake elevation for the model simulations.

2.5 Onondaga Lake Extreme Event Water Levels

As part of the design, model simulations were performed for various flow events in Ninemile Creek including the 2-year, 50-year, and 100-year events. The following procedure was used to calculate the water level in Onondaga Lake for these various extreme events:

1. Determine the 2-year, 50-year, and 100-year flow in the Oswego River.
2. Using the rating curve (Figure B-1), compute the headpond elevation for the given flow event.
3. Estimate the slope of the hydraulic grade line (water surface elevation profile) upstream of the Phoenix Dam into the Seneca River and Onondaga Lake.
4. Determine the water level in Onondaga Lake based on the hydraulic grade line for the given flow scenario.

Figure B-4 presents the estimated flood recurrence interval in the Oswego River at the Phoenix Dam (FERC 1996). Based on a review of the graph, the corresponding flows for the following flood recurrence intervals are as follows:

- 2-year: 20,000 cfs
- 50-year: 35,000 cfs
- 100-year: 38,000 cfs

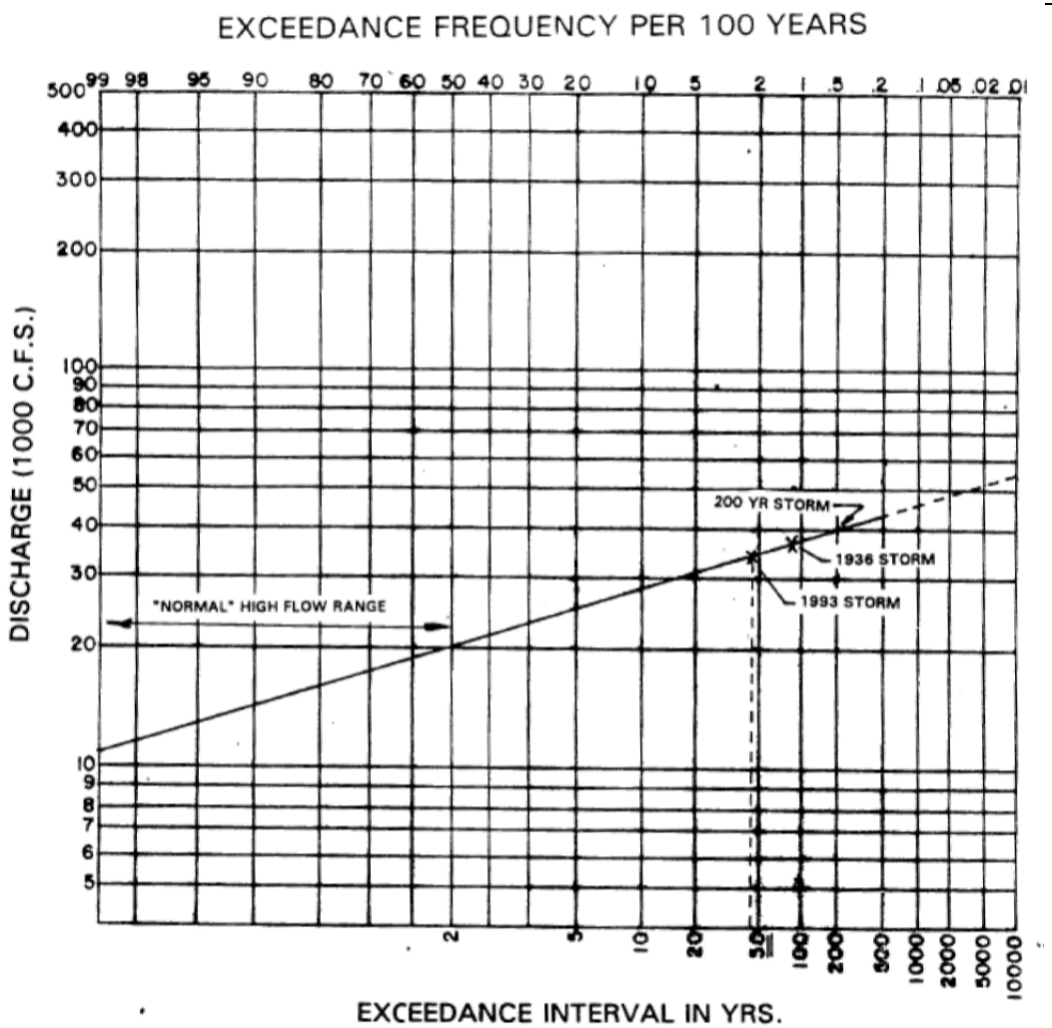


Figure B-4

Oswego River Discharge-Frequency Curve

Source: Figure F-15 of FERC 1996

Following winter, spring runoff occurs for varying lengths of time between March and May. Spring runoff is the most hydrologically significant time of the year and the time when historical flow records indicate flooding is most likely to occur in the Oswego Basin (FERC 1996). For example, an extreme flood event occurred in April 1993 during the spring snowmelt period. On March 14, 1993, Syracuse received 43 inches of snow during the "1993 Superstorm" or "The Storm of the Century." During the subsequent April snowmelt and spring runoff, a flood with a large peak of significant duration occurred in the Oswego Basin. This was an approximately 50-year flood in the Oswego River (see Figure B-4). The highest Onondaga Lake level in measurements collected during the past 38 years was 369.18 feet on April 28, 1993.

FERC (1996) developed a HEC-2 hydraulic model to simulate water surface elevations in the Oswego River Basin with varying elevations and flows at the Oswego Dam. The model was used to simulate the April 1993 flood in the Oswego Basin. The hydraulic grade line (water surface elevation profile) calculated by the model was used to estimate water levels in Onondaga Lake.

2-year: FERC (1996) used the HEC-2 hydraulic model to simulate a flow event with a flow of 20,000 cfs at Phoenix Dam. Figure B-5 shows the water surface elevation profile from the Phoenix Dam for this simulation as presented in FERC (1996). Using the headwater elevation of 363.5 feet BCD (based on the HFOP), the elevation in the Seneca River near Onondaga Lake is approximately 366.5 feet BCD (364.9 feet NAVD88). Therefore, an Onondaga Lake level of **365.0 feet NAVD88** would be representative of the 2-year lake elevation for the model simulations.

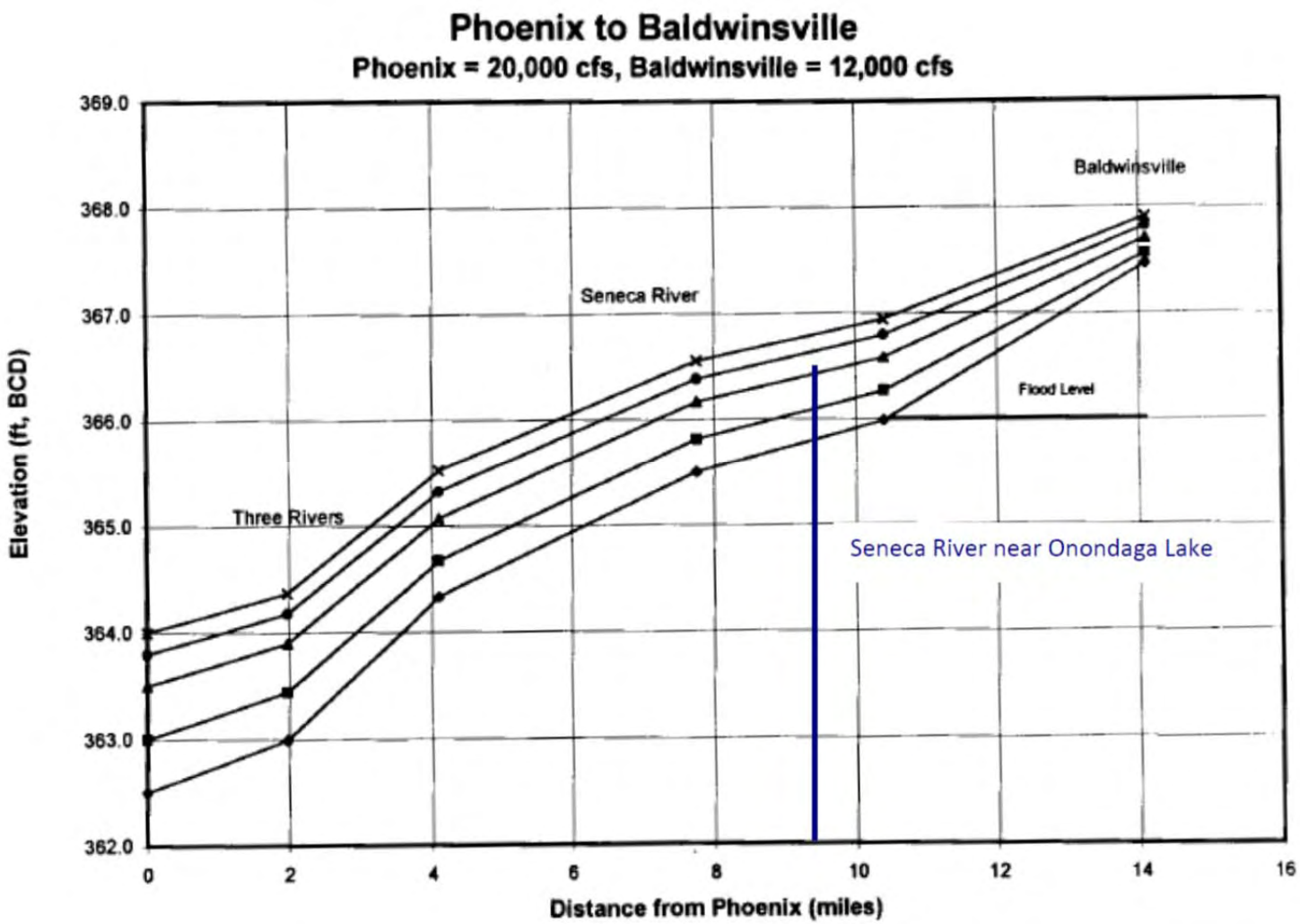


Figure B-5

Oswego-Seneca River 2-year Hydraulic Grade Line

Source: Figure F-15 of FERC 1996

50-year: As described above, the April 1993 event was an approximately 50-year flood. The flow during this event was estimated to be 33,000 cfs (FERC 1996). FERC used the HEC-2 hydraulic model to simulate this flood event. Figure B-6 presents the water surface elevation profile for this event. Also shown in Figure B-6 is the maximum water surface elevation measured in Onondaga Lake. As can be seen in the figure, the elevation in the Seneca River near Onondaga Lake is approximately 370.5 feet BCD (368.9 feet NAVD88). It should be noted that the HEC-2 results presented in FERC (1996) did not include the water surface elevation profile into Onondaga Lake (from the Seneca River upstream past Klein Island into Onondaga Lake). The maximum water level measured in Onondaga Lake during the April 1993 flood was 370.70 feet BCD (369.18 feet NAVD88), or a 0.3-foot difference. Therefore, the water level of **369.0 feet NAVD88** was considered representative of a 50-year flood event for the model simulations.

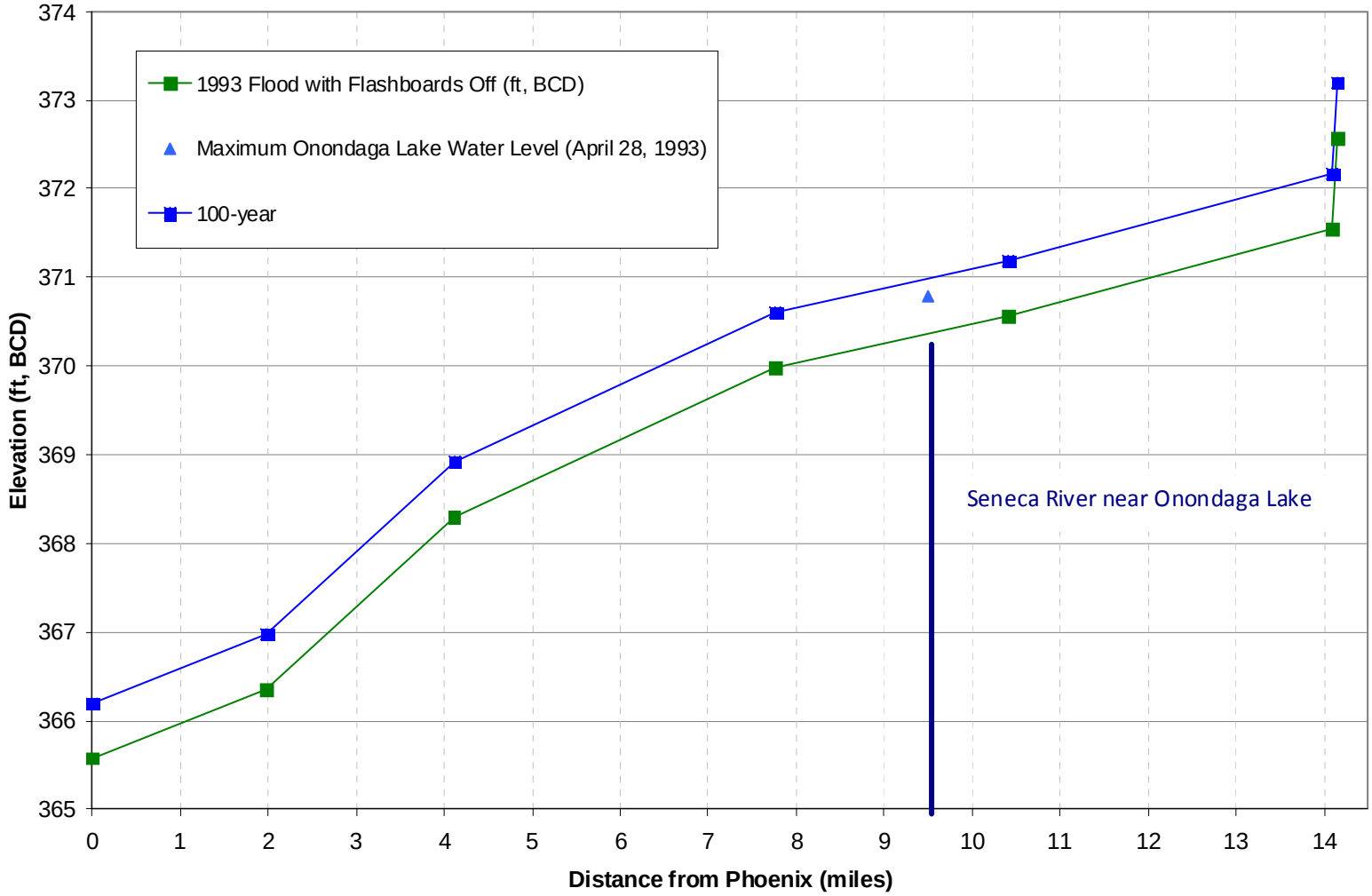


Figure B-6

Oswego-Seneca River 1993 Flood and 100-year Hydraulic Grade Line

Source for 1993 Flood HEC-2 Simulation: Table 4-2 of FERC 1996

100-year: The 100-year water surface elevation in Onondaga Lake was computed using a 100-year flow of 38,000 cfs (Figure B-4) and headpond elevation of 366.2 feet BCD (364.6 feet NAVD88; Figure B-1). The slope of the hydraulic grade line (water surface elevation profile) between the Phoenix Dam and Onondaga Lake was assumed to be the same as the April 1993 flood simulation. Figure B-6 presents the water surface elevation profile for this event. As can be seen in the figure, the elevation in Seneca River near Onondaga Lake is approximately 371.0 feet BCD (369.4 feet NAVD88). Assuming the water level is 0.3 higher in Onondaga Lake (similar to the April 1993 flood event), then the elevation in Onondaga Lake would be 369.7 feet NAVD88. Therefore, the water level of **369.7 feet NAVD88** was considered representative of a 100-year flood event for the model simulations.

3 NINEMILE CREEK HYDROLOGY

The evaluation of Ninemile Creek hydrology for design purposes was originally developed for use in the Geddes Brook floodplain restoration design. A summary of the findings from this evaluation and the design values adopted for the Ninemile Creek project are presented herein.

3.1 Flood Frequency Analysis

To develop discharge magnitudes for standard return periods, a Log Pearson type III (LP-III) hydrologic frequency analysis was conducted using discharge data from the sources described in the *Geddes Brook 100% Design Report, Attachment A* (Anchor QEA, LLC [Anchor QEA] 2011). The analyses were performed using the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center – Statistical Software Package (HEC-SSP). This software package can perform several standard flood flow frequency analyses, including LP-III, and provides the 5% and 95% statistical confidence limits for each analysis.

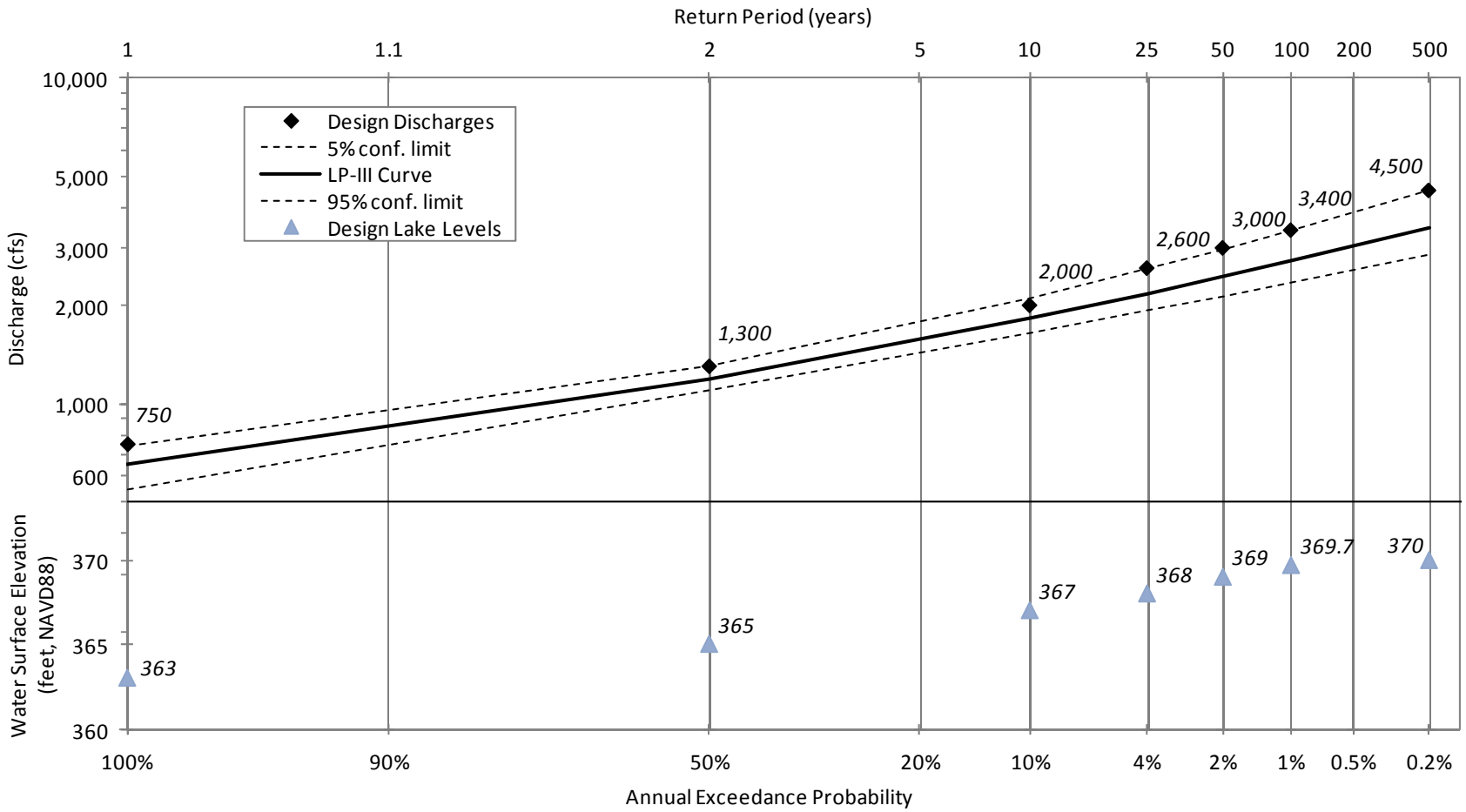
3.1.1 Flood Frequency Findings

The hydrologic design values reported in the *Geddes Brook 100% Design Report, Attachment A* (Anchor QEA 2011) are provided for reference in Table B-2.

Table B-2
Ninemile Creek, High-Flow Hydrology Design Values

Return Period (year)	Design Value (cfs)
1	750
2	1,300
10	2,000
25	2,600
50	3,000
100	3,400
500	4,500

The high flow hydrology analysis results are also shown in Figure B-7 along with the corresponding lake water surface elevations.



B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_95pct_Design\Evals-Calcs\Hydrology\Peak_Flow_Hydrology.xlsx Tab: Plots JRG 7/6/2011

Figure B-7

Ninemile Creek High Flow Hydrology

Notes: Lake water surface elevations are interpolated for the 10-year and 25-year return period events. The water surface elevation for the 500-year return period event is estimated.

3.2 Monthly Flow Exceedance Hydrology

To evaluate expected discharge ranges, the monthly discharge exceedance probability values were aggregated from the daily exceedance probability calculations (Anchor QEA 2011).

3.2.1 Monthly Flow Exceedance Hydrology Findings

The Ninemile Creek discharge values associated with the defined exceedance values and the minimum, average, and maximum for each month during the period of record are provided for reference in Table B-3.

The water year average during the period of record is also provided in the far right column for each exceedance probability. The minimum, average, and maximum values for each month during the period of record is provided in the lower three rows. The minimum and maximum values for the water year are the minimum and maximum values within the period of record, rather than the average.

Table B-3
Monthly Flow Exceedance Hydrology – Ninemile Creek

Ninemile Creek at Lakeland Gage, HSPF Model (WY 1997-2007)													
Exceedance Probability (%)	Discharge (cfs)												Water Year Average
	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	
5	155	230	307	434	492	690	586	406	322	281	137	176	351
10	110	183	254	339	375	566	493	328	223	194	104	103	273
20	87	141	206	286	288	465	426	211	168	128	80	71	213
30	75	108	161	245	233	376	373	183	145	99	69	57	177
40	64	83	126	201	209	322	309	153	125	89	58	49	149
50	52	69	106	162	184	286	273	143	110	81	53	43	130
60	44	60	93	124	166	259	256	127	93	75	49	40	115
70	40	52	81	108	145	235	236	120	88	71	46	37	105
80	36	45	70	88	123	210	220	110	81	64	41	33	94
90	33	41	64	60	101	188	207	102	72	58	36	30	83
95	30	37	54	53	88	164	182	95	64	53	32	27	73
Min.	23	28	32	39	60	103	121	69	47	38	19	17	17
Avg.	70	99	142	199	228	351	330	186	144	116	67	67	167
Max.	460	790	557	1,310	1,830	1,580	1,320	1,730	1,290	887	539	753	1,830

Note: The minimum and maximum values for the water year are the minimum and maximum values within the period of record, rather than the average.
Source: This table is a reproduction of the Ninemile Creek discharge values found in Table 2 of *Attachment A in the Geddes Brook 100% Design Report* (Anchor QEA 2011). WY is the water year starting October 1 and ending September 30.

3.3 Discharge Relationship for Ninemile Creek and Geddes Brook

To accurately model the confluence of Geddes Brook with Ninemile Creek, a discharge relationship was developed for use in the Geddes Brook floodplain restoration design (Anchor QEA 2011). A summary of the findings from this evaluation and the design values adopted for the Ninemile Creek project are presented herein.

3.3.1 Discharge Relationship Findings

Using the monthly discharge exceedance probability values for Ninemile Creek and Geddes Brook, a general relationship between Geddes Brook and Ninemile Creek discharge was developed. A linear regression applied to the data indicated that the discharge in Geddes Brook can be approximated as 12.2% of the discharge in Ninemile Creek (Figure B-8). This relationship shows excellent correlation at low discharges with increased scatter for higher discharges. For the purposes of design, this relationship was assumed to be valid for all discharges in Ninemile Creek, including the high flow hydrology design values.

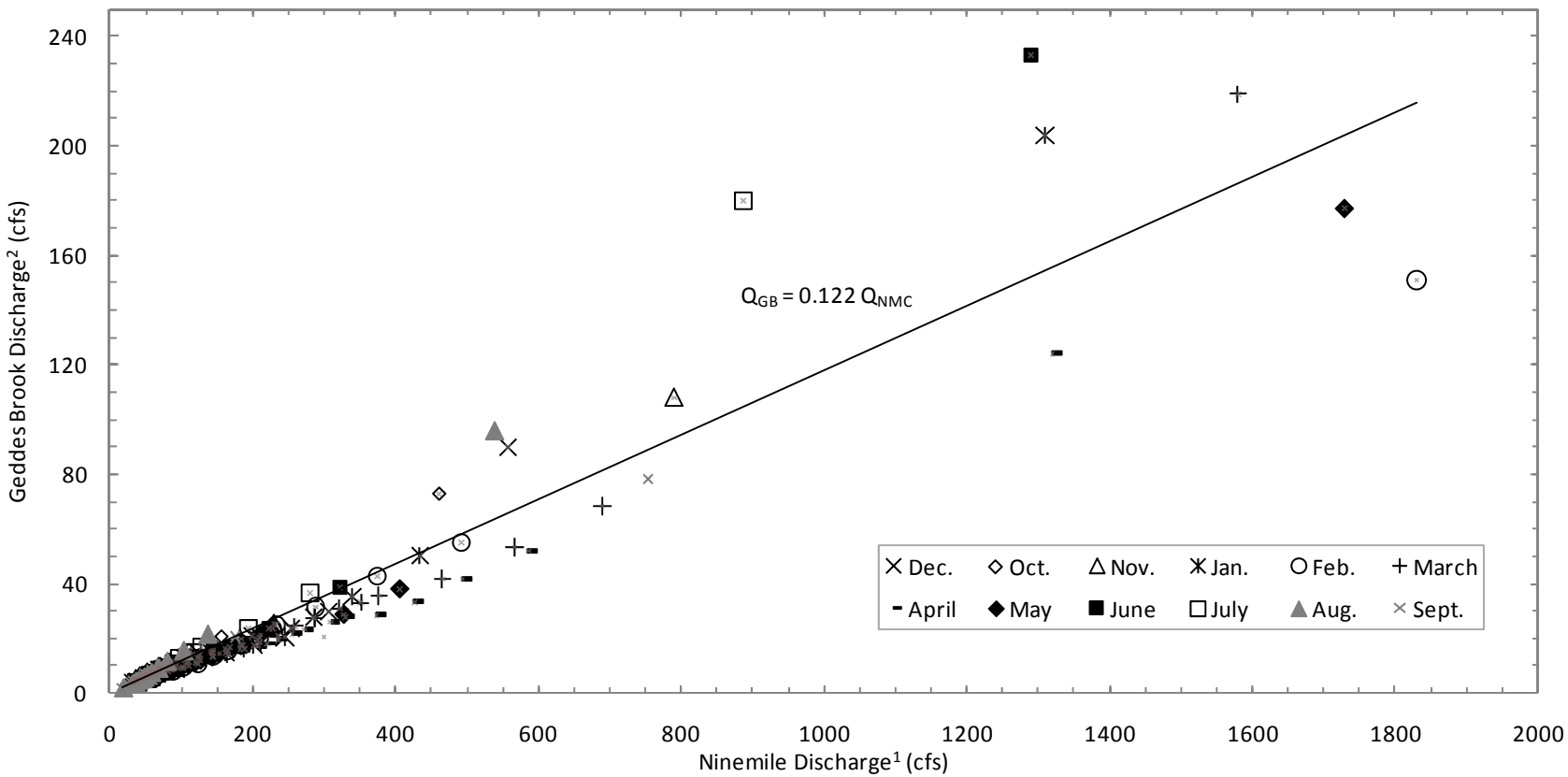


Figure B-8

Geddes Brook to Ninemile Creek Discharge Relationship

Notes:

1. Discharges are HSPF modeled monthly statistics at the Lakeland Gage
2. Discharges are HSPF modeled monthly statistics at the outlet of Geddes Brook
3. Q_{GB} is discharge in Geddes Brook, Q_{NMC} is discharge in Ninemile Creek

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_95pct_Design\Evals-Calcs\Hydrology\Summer_Flow_Analysis_Ninemile_Cr_HSPF.xlsx Tab: Plots JRG 8/11/2011

4 SUMMARY

The design hydrology and associated lake levels presented in this attachment are referenced throughout the remainder of the report. Please refer to the *Geddes Brook 100% Design Report* (Anchor QEA 2011) for additional details regarding Ninemile Creek hydrology.

5 REFERENCES

Anchor QEA (Anchor QEA, LLC), 2011. *Geddes Brook 100% Design Report, Attachment A – Hydrologic and Hydraulic Evaluation – Eastern Basin*. Prepared for Parsons, Liverpool, NY. February.

Federal Energy Regulatory Commission (FERC), 1996. *Phoenix Hydroelectric Project FERC No. 4113 Review of Project Operation and Local Flooding*. Washington, D.C. December.

Oswego Hydro Partners and NYSCC (Oswego Hydro Partners, L.P., and New York State Canal Corporation), 1997. *Phoenix Hydroelectric Project FERC No. 4113 High Flow Operating Procedures*. November 11, 1997.

ATTACHMENT C
HEC-RAS MODEL OF EXISTING AND PROPOSED CONDITIONS

TABLE OF CONTENTS

C.1 INTRODUCTION C-1

C.2 GENERAL HYDRAULIC MODEL UPDATES AND REVISIONS C-3

C.2.1 Model Geometry C-3

C.2.2 Boundary Conditions C-5

C.3 EXISTING CONDITIONS MODEL CALIBRATION AND VALIDATION C-6

C.3.1 Model Calibration C-6

C.3.2 Model Validation C-13

C.4 PROPOSED CONDITIONS MODEL C-16

C.4.1 Channel Bed Roughness C-16

C.4.2 Floodplain Roughness C-17

C.4.3 Habitat Feature Modeling C-18

C.5 NO-RISE ANALYSIS C-19

C.6 CHANNEL ROUGHNESS SENSITIVITY ANALYSIS C-22

C.7 FLOODPLAIN ROUGHNESS SENSITIVITY ANALYSIS C-33

C.8 SUMMARY C-42

C.9 REFERENCES C-43

List of Tables

Table C-1 Bridge Geometry in Existing and Proposed Condition HEC-RAS Models C-4
Table C-2 High-Flow Event Boundary Conditions C-5
Table C-3 HEC-RAS Calibration Results: Higher Flow Rates C-8
Table C-4 HEC-RAS Calibration Results: Median Range Flow Rates C-9
Table C-5 Manning's Roughness Coefficients Used in the Existing Conditions Model C-10
Table C-6 HEC-RAS Validation Results C-13
Table C-7 Manning's Roughness Coefficients Used in the Proposed Conditions Model C-17
Table C-8 Water Surface Elevation and Bridge Clearance at Ninemile Creek Bridges C-21
Table C-9 Channel Roughness Sensitivity Analysis Manning's n Values C-22
Table C-10 Floodplain Roughness Sensitivity Analysis Manning's n Values C-33

List of Figures

Figure C-1 Existing Conditions Model Calibration, All Flow Rates C-11
Figure C-2 Existing Conditions Model Calibration, Median Range Flow Rates C-12
Figure C-3 Existing Conditions Model Validation, Near Geddes Brook C-15
Figure C-4 No-rise Analysis C-20
Figure C-5 Channel Roughness Sensitivity Analysis, 100-year Flood, High Lake Level, Existing Conditions C-23
Figure C-6 Channel Roughness Sensitivity Analysis, 100-year Flood, High Lake Level, Proposed Conditions C-24
Figure C-7 Channel Roughness Sensitivity Analysis, 10-year Flood, Existing Conditions C-25
Figure C-8 Channel Roughness Sensitivity Analysis, 10-year Flood, Proposed Conditions C-26
Figure C-9 Channel Roughness Sensitivity Analysis, 2-year Flood, Existing Conditions C-27
Figure C-10 Channel Roughness Sensitivity Analysis, 2-year Flood, Proposed Conditions C-28

Figure C-11 Channel Roughness Sensitivity Analysis, 1-year Flood, Existing Conditions C-29
Figure C-12 Channel Roughness Sensitivity Analysis, 1-year Flood, Proposed Conditions C-30
Figure C-13 Channel Roughness Sensitivity Analysis, Long-term Median Flow Rate, Existing Conditions C-31
Figure C-14 Channel Roughness Sensitivity Analysis, Long-term Median Flow Rate, Proposed Conditions C-32
Figure C-15 Floodplain Roughness Sensitivity Analysis, 100-year Flood, High Lake Level, Existing Conditions C-34
Figure C-16 Floodplain Roughness Sensitivity Analysis, 100-year Flood, High Lake Level, Proposed Conditions C-35
Figure C-17 Floodplain Roughness Sensitivity Analysis, 10-year Flood, Existing Conditions C-36
Figure C-18 Floodplain Roughness Sensitivity Analysis, 10-year Flood, Proposed Conditions C-37
Figure C-19 Floodplain Roughness Sensitivity Analysis, 2-year Flood, Existing Conditions C-38
Figure C-20 Floodplain Roughness Sensitivity Analysis, 2-year Flood, Proposed Conditions C-39
Figure C-21 Floodplain Roughness Sensitivity Analysis, 1-year Flood, Existing Conditions C-40
Figure C-22 Floodplain Roughness Sensitivity Analysis, 1-year Flood, Proposed Conditions C-41

LIST OF ACRONYMS AND ABBREVIATIONS

Anchor QEA	Anchor QEA, LLC
BFE	base flood elevations
cfs	cubic feet per second
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FS	Feasibility Study
HEC-RAS	Hydraulic Engineering Center – River Analysis System
IRM	Interim Remedial Measures
LWD	large woody debris
n/a	not applicable
NAVD88	North American Vertical Datum of 1988
NYSDEC	New York State Department of Environmental Conservation
OUs	Operable Units
ROD	Record of Decision
SFS	Supplemental Feasibility Study
Site	Geddes Brook/Ninemile Creek site
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WSE	water surface elevation

C.1 INTRODUCTION

A previously developed hydraulic model was available for lower Ninemile Creek and lower Geddes Brook (Anchor QEA, LLC [Anchor QEA] 2009; Limno Tech 2005) for use in evaluating remedial alternatives in the Feasibility Study (FS) and in previous design phases for the Geddes Brook/Ninemile Creek site (Site; Parsons 2005; Anchor QEA 2009; Anchor QEA 2010; Anchor QEA 2011). The one-dimensional model was developed using the U.S. Army Corps of Engineers (USACE) Hydraulic Engineering Center – River Analysis System (HEC-RAS) hydraulic model (USACE 2008) and applied in steady-state mode.[1] HEC-RAS is a widely accepted tool for hydraulic modeling of channel systems that include structures such as weirs, culverts, and bridges, and is accepted by Federal Emergency Management Agency (FEMA) and New York State Department of Environmental Conservation (NYSDEC) for flood impact studies.

To organize the model, Ninemile Creek downstream of the area just above the mouth of Geddes Brook has been designated as "lower Ninemile Creek," and subdivided into three reaches (AB, BC, and CD). Subsequent to the submittal of the FS, the Site was organized into two Operable Units (OUs). The OU1 portion of the Site includes lower Geddes Brook and lower Ninemile Creek channel sediments, surface water, and floodplain soils associated with reaches BC and CD. OU2 includes the Reach AB portion of the Site, which extends approximately 3,000 feet upstream from the mouth of Ninemile Creek.

Based on the Record of Decision (ROD) for OU1 (NYSDEC and the U.S. Environmental Protection Agency [EPA] 2009a) and the ROD for OU2 (NYSDEC and EPA 2009b), the HEC-RAS model was updated during design, incoporating detailed bathymetric and topographic surveys conducted throughout the Site. Those surveys were completed in early 2009 and provided to the NYSDEC on May 14, 2009 (Thew Associates 2009). The survey and bathymetry data have been incorporated into the HEC-RAS models for existing and proposed conditions. The models presented here are used to evaluate high-flow (channel stability and no-rise) and low-flow conditions (habitat and recreation value) within Ninemile Creek

[1] Although it is a one-dimensional model, HEC-RAS incorporates three-dimensional bathymetric/topographic data, land coverage data (as represented by Manning's roughness coefficients), and structure geometries for calculating water surface profiles and velocities at points along the stream channel based on a one-dimensional conservation of energy equation.

under existing and proposed conditions, as discussed herein. This report describes the updates and calibration/verification of the existing conditions HEC-RAS hydraulic model for Ninemile Creek.

The substantive revisions to the model from the 50% design phase include the following:

- Revisions to cross-section extents to incorporate the 500-year floodplain or to extend to the ineffective flow area on the floodplain
- Addition of cross-sections to improve modeling of complex proposed hydraulic features
- Inclusion of the Geddes Brook floodplain proposed conditions topography from the Geddes Brook Interim Remedial Measure (IRM) final design in the proposed conditions model
- Indirect modeling of Geddes Brook as part of the Ninemile Creek floodplain to improve high-flow event modeling

The existing conditions HEC-RAS model described in this report is well calibrated based on existing data, provides a detailed representation of hydraulics within the system, and is suitable for use in the design process. The existing conditions model is used to define the base flood elevations (BFEs) for the 100-year high-flow event (see Section C.5).

C.2 GENERAL HYDRAULIC MODEL UPDATES AND REVISIONS

The HEC-RAS model initially applied in the OU1 Supplemental Feasibility Study [SFS] (Parsons 2008) and OU2 SFS (Parsons 2009) provides a tool that can be used to evaluate system hydraulics for both current conditions and proposed remedial design scenarios. Modifications to this model were made in this and previous design phases based on new data and evaluations conducted during design, as described below.

C.2.1 Model Geometry

Construction as-built drawings that provide bridge opening geometry detail and verification of low chord elevations were obtained. The construction as-built drawings were compared to existing survey data (Thew Associates 2009) and the more restrictive geometry (as-builts or survey) was incorporated into the model. The model incorporates the effects of bridges and abutments that are located within Reach BC. The geometry parameters for bridges included in the existing and proposed conditions models are provided in Table C-1. The locations of the bridges are shown on Figures 4 and 5 of Appendix E to the 100% Design Report. The piers associated with bridge numbers 2, 1a, and 1b were simulated as blocked obstructions because the deck height for these overpass bridges is significantly above the 100-year flood water surface elevation (WSE). This modeling approach allows the piers for these angled bridges to be placed in the proper location compared to a typical modeling approach where the bridge is assumed to be nearly perpendicular to flow in the channel.

Table C-1

Bridge Geometry in Existing and Proposed Condition HEC-RAS Models

Bridge Number	Location	Bridge Type	Material	Abutment Clear Span (feet)	Low Chord Elevation (feet, NAVD88)	Number of Piers in Floodplain	Pier Cross-Sectional Width (feet)
9	Access Road	Road Bridge	Steel/ Asphalt	88	372.6	--	n/a
11	Utility Crossing	Crossing	Steel	86.5	372.95	--	n/a
3	State Fair Boulevard	Road Bridge	Steel/ Asphalt	86.2	371.30	--	n/a
CSX RR	Railroad Bridge	Rail Bridge	Steel/ Gravel	72	371.35	--	n/a
2	To. S Hwy 695	Road Bridge	Steel/ Asphalt	140	397.7	2	3.5
1a	To. W. I-690	Road Bridge	Steel/ Concrete	156	398.9	2	3.5
1b	To. W. I-690	Road Bridge	Steel/ Concrete	107	400.50	2	3.5
6	East I-690	Road Bridge	Concrete	86.2	378.10	--	n/a
7	West I-690	Road Bridge	Concrete	86.6	377.0	--	n/a

Note:
n/a = not applicable
NAVD88 = North American Vertical Datum of 1988

C.2.2 Boundary Conditions

The boundary conditions that need to be specified in the existing and proposed condition models are: 1) incoming flow rates at upstream points along Ninemile Creek and Geddes Brook; and 2) water surface elevation of Onondaga Lake at the downstream boundary (see Attachment B of Appendix E). The models were used to evaluate high-flow events (e.g., 100- and 500-year floods), as well as low-flow conditions. The boundary condition values used for the high-flow event simulations are provided in Table C-2. Two downstream boundary conditions were used for the 50- and 100-year high-flow events, as indicated in Table C-2, with a (H) for the high lake level and a (L) for the low lake level. The lake levels for the 10- and 25-year high-flow events are interpolated between the 2- and 50-year lake levels provided in Attachment B.

Table C-2
High-Flow Event Boundary Conditions

Return Period (year)	Incoming Flow Rate (cfs)	Onondaga Lake Level (feet, NAVD88)
1	750	363.0
2	1,300	365.0
10	2,000	367.0
25	2,600	368.0
50	3,000	369.0 (H)/367.0 (L)
100	3,400	369.7 (H)/367.0 (L)
500	4,500	370.0

Notes:
cfs = cubic feet per second

C.3 EXISTING CONDITIONS MODEL CALIBRATION AND VALIDATION

Calibration of the existing conditions model was verified in this design phase given the updates to the model described above. Although the updates are relatively minor (i.e., largely refinements in bridge geometry), the veracity of the calibration was tested to identify if additional calibration was warranted. As part of this effort, predictions from the existing conditions model were compared to the same datasets used during calibration of models from previous design phases. In addition, the model was further verified using other existing data and newly collected data on water surface elevations, as described below.

C.3.1 Model Calibration

As part of this design phase, the calibration and verification procedure completed in previous design phases was repeated. As discussed in Anchor QEA (2009), instantaneous (e.g., 15-minute or hourly) flow rate and lake level data collected from 2000 to 2010 were reviewed and a series of dates where flow rate and lake elevations were relatively stable for a period of time was selected for model-data comparison. This screening of data for stable conditions was necessary since the model performs steady-state calculations. This procedure resulted in a set of 24 events representing higher flow conditions (in the range of 500 to 2,060 cubic feet per second [cfs]) and 17 events representing median range flow conditions (in the range of 100 to 436 cfs). It should be noted that the lake levels and flow rates during the largest events were not as stable as those from the other events included in this analysis. Because HEC-RAS was run as a steady-state model, uncertainty is introduced when its results are compared to data collected during dynamic events. Therefore, less weight should be given to data from dynamic (flashy) events used in model calibration.

For each of the stable flow events, the updated existing conditions model was run using flow rate data collected at the U.S. Geological Survey (USGS) Lakeland gage and daily average water surface elevation at Onondaga Lake as boundary conditions (Table C-3 and Table C-4). These simulations were conducted for the calibrated values of Manning's coefficients in both the channel and floodplain areas, as shown in Table C-5. The predicted water surface elevations at the USGS Lakeland gage did not significantly change from previous design phases for all events in the higher flow rate range (Table C-3). Therefore, the Manning's coefficient of 0.040 in the channel for reaches BC and AB is considered appropriate. This

Manning's coefficient value is well within the range of literature values associated with the bed type present in this area of Ninemile Creek (e.g., Chow 1959; USACE 2008). The predicted water surface elevation for the highest flow rate (April 2005; Table C-3) was higher than the Lakeland data (0.26 feet), although given the temporal variations in the flow rates and lake levels during that day, and the steady-state nature of the model calculations, such deviation is not unexpected. The calibration results for the median-range flow rates are presented in Table C-4; these results show that the Manning's coefficient used in the existing conditions model provides a good match to the data. The final values used for Manning's coefficient in the existing conditions model are listed in Table C-5. These values provide the best overall model calibration and are within generally accepted ranges for channel and floodplain roughness.

Table C-3
HEC-RAS Calibration Results: Higher Flow Rates

Date	USGS Lakeland Elevation NAVD88 (feet)	USGS Lakeland Flow Rate (cfs)	USGS Liverpool Elevation NAVD88 (feet)	Model Version			
				30% Design		100% Design	
				Predicted Lakeland Elevation NAVD88 (feet)	Error (feet)	Predicted Lakeland Elevation NAVD88 (feet)	Error (feet)
4/5/2001	364.25	504	363.20	364.16	-0.09	364.19	-0.06
4/9/2003	365.58	508	365.21	365.57	-0.01	365.57	-0.01
5/17/2002	364.86	517	364.21	364.82	-0.04	364.83	-0.03
5/18/2002	364.86	528	364.19	364.83	-0.03	364.84	-0.02
3/23/2010	364.47	530	364.02	n/a	-	364.73	0.26
4/6/2001	364.40	536	363.34	364.32	-0.08	364.35	-0.05
4/8/2003	365.72	544	365.34	365.73	0.01	365.72	0.00
3/14/2006	364.39	552	363.38	364.39	0.00	364.42	0.03
4/7/2001	364.59	573	363.53	364.53	-0.06	364.55	-0.04
5/19/2000	365.07	575	364.45	365.1	0.03	365.11	0.04
4/7/2003	365.85	607	365.39	365.85	0.00	365.84	-0.01
4/11/2001	365.48	622	364.84	365.47	-0.01	365.46	-0.02
4/13/2001	365.76	643	365.18	365.74	-0.02	365.74	-0.02
4/12/2001	365.71	670	365.02	365.67	-0.04	365.66	-0.05
3/13/2010	364.77	715	363.92	n/a	-	365.10	0.33
4/10/2001	365.51	716	364.68	365.53	0.02	365.53	0.02
3/23/2001	364.95	741	363.58	364.99	0.04	365.01	0.06
11/30/2005	365.45	864	364.03	365.50	0.05	365.50	0.05
1/26/2010	365.74	1,180	363.98	n/a	-	366.22	0.48
12/28/2009	366.38	1,470	363.27	n/a	-	366.74	0.36
4/5/1973	367.69	1,500	365.52	n/a	-	367.37	-0.32
9/29/1975	368.83	1,610	366.33	n/a	-	367.90	-0.93
4/3/2005	367.68	1,840	365.41	367.93	0.25	367.92	0.24
3/15/2007	368.62	2,060	363.42	n/a	-	368.02	-0.60

Note:
Calibration events not presented in the 30% design HEC-RAS Report (Anchor QEA 2009) are indicated with n/a.

Table C-4

HEC-RAS Calibration Results: Median Range Flow Rates

Date	USGS Lakeland Elevation NAVD88 (feet)	USGS Lakeland Flow (cfs)	USGS Liverpool Elevation NAVD88 (feet)	Model Version			
				30% Design		100% Design	
				Predicted Lakeland Elevation NAVD88 (feet)	Error (feet)	Predicted Lakeland Elevation NAVD88 (feet)	Error (feet)
1/19/2000	362.83	108	362.79	362.87	0.04	362.88	0.05
8/7/2004	362.79	110	362.78	362.87	0.08	362.88	0.09
1/29/2002	362.54	112	362.46	362.58	0.04	362.59	0.05
11/6/2009	363.02	116	363.02	na	-	363.11	0.09
1/13/2002	362.54	122	362.44	362.58	0.04	362.60	0.06
11/2/2000	362.63	126	362.49	362.63	0.00	362.65	0.02
11/12/2003	362.84	126	362.72	362.84	0.00	362.85	0.01
3/5/2001	362.81	127	362.67	362.80	-0.01	362.81	0.00
2/9/2002	363.10	128	363.02	363.12	0.02	363.13	0.03
2/12/2000	362.74	133	362.58	362.73	-0.01	362.74	0.00
10/26/2000	362.73	133	362.57	362.72	-0.01	362.74	0.01
10/27/2000	362.74	133	362.58	362.73	-0.01	362.74	0.00
2/10/2002	363.11	135	363.01	363.12	0.01	363.13	0.02
3/19/2002	362.85	139	362.66	362.81	-0.04	362.83	-0.02
2/24/2004	362.39	145	362.04	362.31	-0.08	362.34	-0.05
3/29/2010	363.77	301	363.63	na	-	363.96	0.19
10/28/2009	363.69	436	362.84	na	-	363.83	0.14

Note:
Calibration events not presented in the previous HEC-RAS Report (Anchor QEA 2009) are indicated with n/a.

Table C-5
Manning's Roughness Coefficients Used in the Existing Conditions Model

Section of Model	Manning's Coefficient			
	Main Channel[1]	Side Channels[2]	Left Overbank[3]	Right Overbank[3]
Ninemile Creek upstream of Geddes Brook	0.050	-	0.085	0.085
Ninemile Creek from mouth of Geddes Brook to the Access Rd. Bridge (Station 68+00 to 51+00)	0.050	0.06	0.085	0.125
Ninemile Creek from Access Rd. Bridge to 700 feet upstream of the last bend (Cross Sections 51+00 to 16+00)	0.040	-	0.050	0.050
Ninemile Creek from 700 feet upstream of the last bend to the last bend (Station 16+00 to 9+50)	0.040	-	0.050	0.085
Ninemile Creek from the last bend to Onondaga Lake (Station 9+50 to 0+00)	0.040	-	0.125	0.125

Notes:
[1] Main Channel is defined as the cross-section below the bank stations.
[2] Side Channels include the smaller channel through the large and small island area.
[3] Left and right overbanks refer to side of the stream facing downstream.

Figure C-1 shows the results of the calibration simulations for all flow rates (Table C-3 and Table C-4). The figure illustrates the reduced accuracy of the model, in terms of water surface elevation, for the higher flow conditions. The decreased accuracy for larger flow events can be attributed to limitations of a steady-state model as described in section C.3.1. For reference, the return period events from Table C-2 are identified along the horizontal axis. Figure C-2 shows the same model results as Figure C-1, but limits the flow rate to a maximum value of 500 cfs (i.e., median range flow rates).

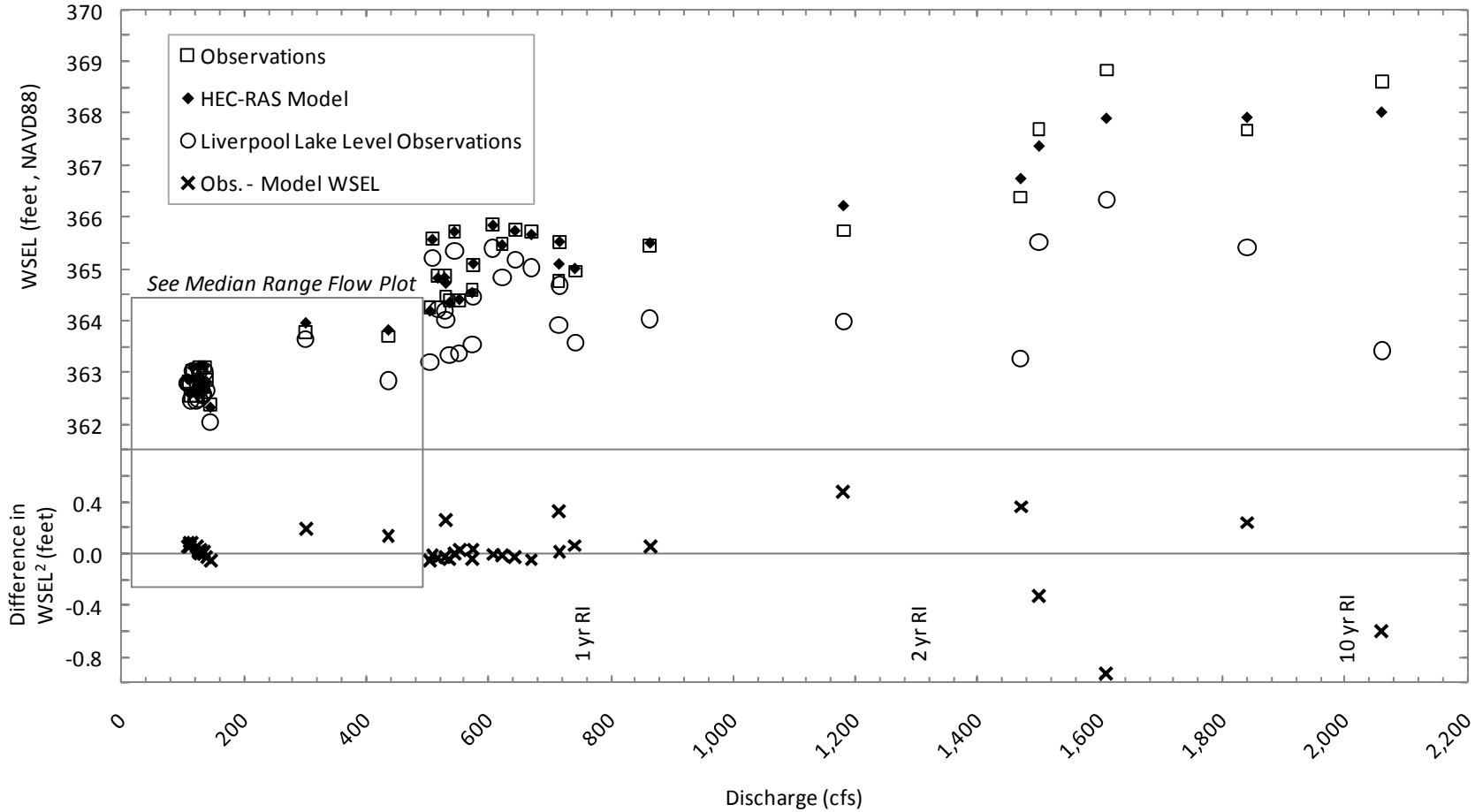


Figure C-1

Existing Conditions Model Calibration, All Flow Rates

Notes: WSE are at the USGS Lakeland Gage (HEC-RAS model station 39+82) Onondaga Lake WSE are from the Liverpool Gage for the specific calibration event date. Difference = HEC-RAS model WSE - Observed WSE.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Calibration_EG.xlsx Tab: Plots 3/14/2012 JRG

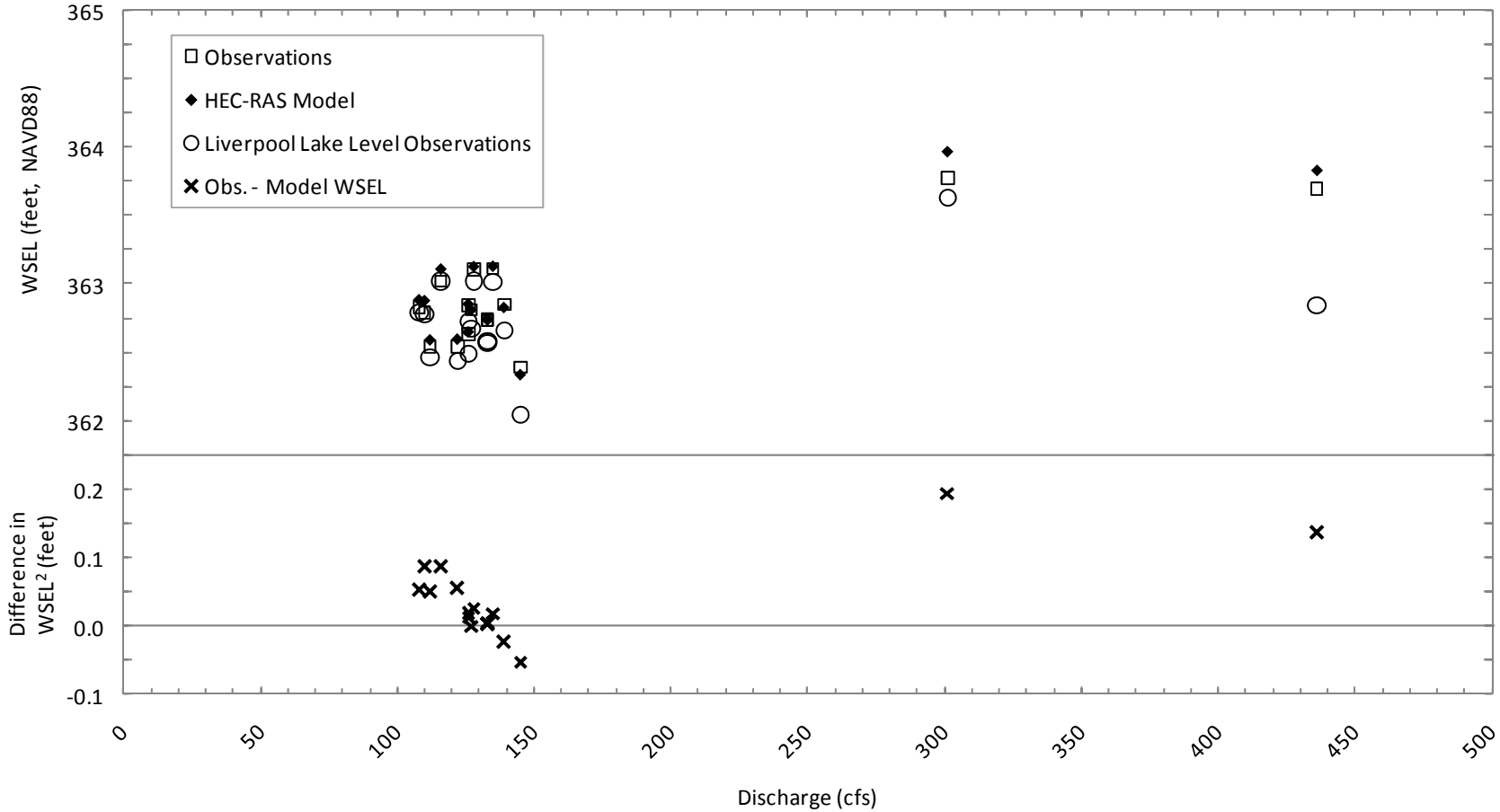


Figure C-2

Existing Conditions Model Calibration, Median Range Flow Rates

Notes: WSE are at the USGS Lakeland Gage (HEC-RAS model station 39+82) Onondaga Lake WSE are from the Liverpool Gage for the specific calibration event date. Difference = HEC-RAS model WSE - Observed WSE.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Calibration_EG.xlsx Tab: Plots 3/14/2012 JRG

C.3.2 Model Validation

Additional water surface elevation data were collected as part of the hydrogeological monitoring conducted at the site (Parsons 2010). As part of that study, water surface elevations (gage heights) were periodically measured at the following three locations in the modeling domain:

- Lower Geddes Brook: approximately 450 feet from its mouth
- Ninemile Creek: in the area just upstream of the mouth of Geddes Brook (Stilling Well NMC-SW-04 at approximately model station 69+50)
- Ninemile Creek: approximately 500 feet from its mouth

Selected readings taken at Stilling Well NMC-SW-04 between October 21, 2009, and March 31, 2010, were used for model validation. These data provide an independent dataset that were used to validate the existing conditions model. To perform such comparisons, boundary conditions for the model were established based on instantaneous flow rate data from Ninemile Creek (USGS Lakeland gage) and daily average water surface elevation data from Onondaga Lake (USGS Liverpool gage) that corresponded to the time of the staff gage readings. These boundary conditions, the water surface elevations calculated from the gage height readings, and the predicted water surface elevations are provided in Table C-6.

Table C-6
HEC-RAS Validation Results

Date	Stilling Well 04 NAVD88 (feet)	USGS Lakeland Flow (cfs)	USGS Liverpool Elevation NAVD88 (feet)	100% Design Model	
				Predicted Stilling Well Elevation NAVD88 (feet)	Error (feet)
11/6/2009	364.59	116	363.02	364.13	-0.46
3/29/2010	365.59	301	363.63	365.43	-0.16
10/28/2009	366.25	436	362.84	365.99	-0.26
3/23/2010	366.5	530	364.02	366.45	-0.05
3/13/201	367.15	715	363.92	367.08	-0.07
1/26/2010	368.43	1,180	363.98	368.46	0.03

Figure C-3 shows comparisons of predicted and observed water surface elevations for the validation simulations presented in Table C-6. The validation results indicate that the HEC-

RAS model predicts water surface elevation in Reach CD and the area adjacent to the Geddes Brook floodplain with adequate accuracy. The overall comparisons of the existing conditions model predictions to observed water surface elevations indicate that the model is representative of system hydraulics.

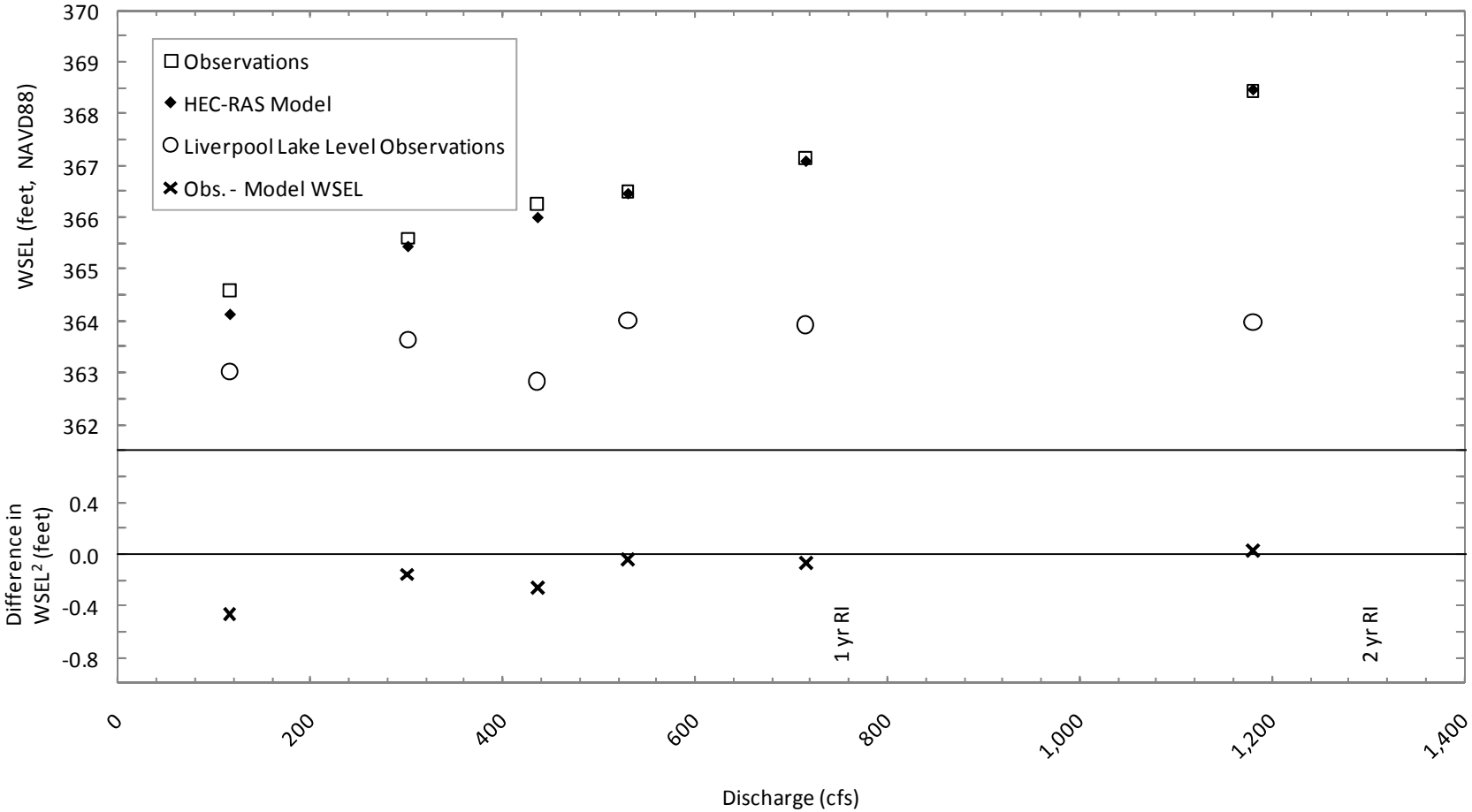


Figure C-3

Existing Conditions Model Validation, Near Geddes Brook

Notes: Water surface elevations (WSEL) are at the Stilling Well NMC-SW-04 at the Geddes Brook outlook. (HEC-RAS model station 68+90) Onondaga Lake WSEL are from the Liverpool Gage for the specific calibration event date. Difference = HEC-RAS model WSEL - Observed WSEL.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Calibration_EG.xlsx Tab: Plots 3/14/2012 JRG

C.4 PROPOSED CONDITIONS MODEL

The existing conditions model was revised and amended in the following ways to simulate proposed conditions:

- Cross-section locations and orientation were modified from the existing conditions model where necessary to reflect changes in channel alignment or model specific habitat features.
- The design finished grade surface created in AutoCAD Civil3D was used for cross-section elevation data.
- The main channel roughness values were revised to be representative of the proposed bed material composition and allowable placement tolerances.
- The floodplain roughness values were revised to be representative of the proposed planting plan.
- Specific habitat features were incorporated into the model using additional cross-sections and obstructions representing the habitat feature (i.e. large woody debris [LWD] and live cribs)

The proposed conditions model provided hydraulic data for channel design analysis, evaluation of habitat features, and assessment of recreational conditions. Hydraulic data included predicted water surface elevations, current velocities, and bed shear stress over a range of flow conditions. A sensitivity analysis was performed on the main channel and floodplain roughness values for proposed conditions (see Section C.6 and Section C.7). The proposed conditions model was used to evaluate whether the proposed condition would result in an increase in the base flood elevation (see Section C.5 for further details).

C.4.1 Channel Bed Roughness

The existing conditions channel bed material is predominantly sand whereas as the proposed conditions channel bed material will be a well-graded mixture of cobble, gravel, and sand. This change in channel bed material type may potentially change the channel roughness values. To evaluate whether a change in channel roughness values was warranted, the main channel bed roughness for the proposed bed material was estimated using several empirical methods. These methods use the material grain size distribution to estimate the roughness height and then translate that value to an equivalent Manning's n value for given hydraulic conditions. The three methods selected (Limerinos [1970], Hey [1979] and Bathurst [1985])

use the grain size that 84% of the material (by weight) is finer than (D_{84}) to estimate the roughness height. Using the average D_{84} for the proposed channel bed material, the methods estimate Manning's n values ranging from 0.035 to 0.038 for the 100-year high-flow event. These values are less than the existing conditions Manning's n values used for the main channel; however, given the variation in D_{84} allowed by the material specification, the estimated channel Manning's n values could match those used in the existing conditions model. In order to exceed the Manning's n value used in the existing conditions model, the D_{84} would need to be 10 inches or greater, which is prohibited based on the material specification. The values for main channel roughness are shown in Table C-7.

Table C-7
Manning's Roughness Coefficients Used in the Proposed Conditions Model

Section of Model	Manning's Coefficient			
	Main Channel[1]	Left Overbank[2]	Right Overbank[2]	Wooded Wetland[3]
Ninemile Creek upstream of Geddes Brook	0.050	0.085	0.125	-
Ninemile Creek from mouth of Geddes Brook to the Access Rd. Bridge (Station 68+00 to 51+00)	0.050	0.085	0.125	-
Ninemile Creek from Access Rd. Bridge to 700 feet upstream of the last bend (Cross Sections 51+00 to 16+00)	0.040	0.050	0.050	-
Ninemile Creek from 700 feet upstream of the last bend to the last bend (Station 16+00 to 9+50)	0.040	0.050	0.085	-
Ninemile Creek from the last bend to Onondaga Lake (Station 9+50 to 0+00)	0.040	0.125	0.125	0.085

Notes:
[1] Main Channel is defined as the cross-section below the bank stations.
[2] Left and right overbanks refer to side of the stream facing downstream.
[3] Area planted with species suitable for low stem density at ground level, such as a wooded wetland.

To examine the influence of variation in bed roughness, a sensitivity analysis was performed on the main channel roughness value for proposed conditions (see Section C.6).

C.4.2 Floodplain Roughness

Changes in floodplain roughness from the existing conditions were made in the model where significant changes in vegetation hydraulic resistance could arise from the planting plan. These changes include the floodplain in Reach AB downstream of Station 9+50 and the

Geddes Brook floodplain being restored as emergent wetland as part of the Geddes Brook IRMs. The values for floodplain roughness in the proposed conditions model are shown in Table C-7.

To examine the influence of variation in floodplain roughness, a sensitivity analysis was performed on the main channel roughness value for proposed conditions (see Section C.7).

The selected floodplain roughness values are representative of the average overbank conditions that will be created by the designed plantings. The selected Manning's coefficient values are well within the range of literature values associated with the type of floodplain vegetation proposed along Ninemile Creek (e.g., Chow 1959; USACE 2008).

C.4.3 Habitat Feature Modeling

In the proposed conditions model, habitat features were incorporated into the model as blocked obstructions or high roughness areas. The LWD are modeled using obstructions and an increase in the local roughness value. For the LWD, additional cross-sections were included in the model to more accurately reflect the feature geometry and its influence on the local hydraulic conditions. The live cribs are modeled using obstructions and an increase in the local roughness value. The pools associated with LWD and live crib were included in the finished grade surface; these pools provide additional cross-sectional area, which offsets the flow obstruction and roughness increase created by the LWD and rootwads in the live cribs. The stone with joint plantings are designed to present a negligible flow obstruction and are represented in the model as a local increase in the roughness value.

C.5 NO-RISE ANALYSIS

A no-rise analysis was performed to evaluate potential changes in water surface elevation associated with work in the channel and floodway. The analysis of the proposed conditions model indicated that there would be no increase (0.00 feet) in the BFEs at all modeled cross-sections for the 100-year high-flow event (see Figure C-4). The freeboard from the no-rise condition ranges from 0.01 to 0.25 feet. In addition to resulting in no-rise in water surface elevation, the predicted clearance at all bridges was increased for both the 50- and 100-year high-flow events. The bridge clearance data are presented in Table C-8 for existing and proposed conditions.

For more information on the design flood condition flow rates and Onondaga Lake levels, see the discussion in Section C.2.2 and values provided in Table C-2. For additional details on the development of flow rates and Onondaga Lake levels used for flood predictions see Attachment B of Appendix E.

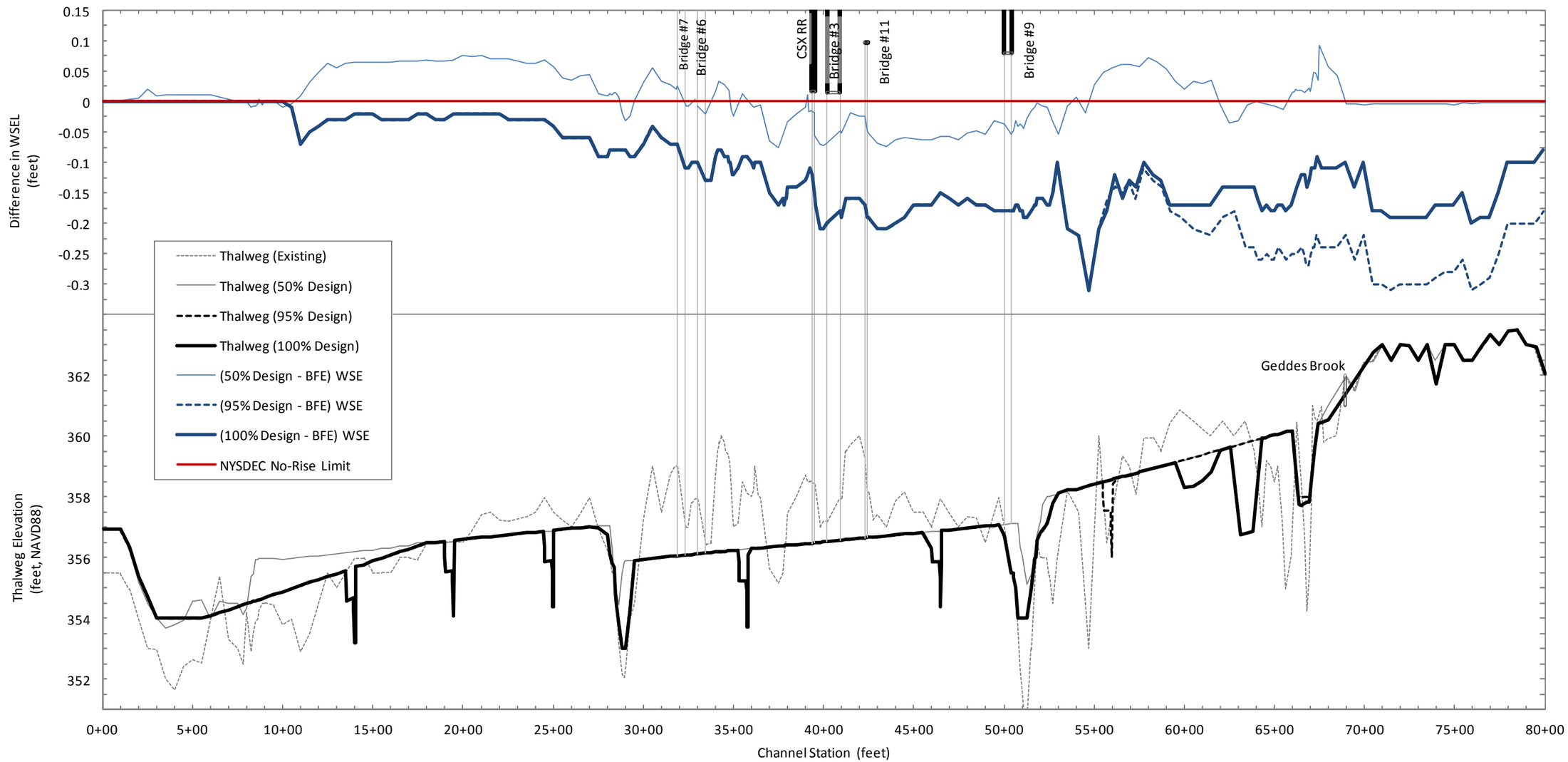


Figure C-4

No-rise Analysis

Notes: Difference in WSEL profiles are from HEC-RAS model results for the 100-year return period event. Discharge of 3,400 cfs with an Onondaga Lake WSEL of 369.7 feet NAVD88. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately station 68+90.
Base Flood Elevation (BFE), Water Surface Elevation (WSE).

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\100yr_RI_Profiles_100pct.xlsx Tab: Plots 3/14/2012 JRG

Table C-8

Water Surface Elevation and Bridge Clearance at Ninemile Creek Bridges

Bridge Description	Station	Lower Chord Elevation (feet)	Existing Conditions				Proposed Conditions			
			WSE (feet)		Clearance (feet)		WSE (feet)		Clearance (feet)	
			50-year Flood	100-year Flood	50-year Flood	100-year FLood	50-year Flood	100-year Flood	50-year Flood	100-year Flood
West I-690 (#7)	31+20	377	370.38	371.11	6.62	5.89	370.27	370.99	6.73	6.01
East I-690 (#6)	32+20	378.1	370.45	371.18	7.65	6.92	370.32	371.05	7.78	7.05
Railroad (CSX RR)	38+25	371.35	370.87	371.65	0.48	-0.30	370.72	371.47	0.63	-0.12
State Fair (#3)	39+64	371.3	370.97	371.82	0.33	-0.52	370.80	371.62	0.50	-0.32
Utility (#11)	41+20	372.95	371.03	371.87	1.92	1.08	370.87	371.69	2.08	1.26
Access Rd. (#9)	49+14	372.6	371.41	372.25	1.19	0.35	371.25	372.07	1.35	0.53

Notes:
50-year flood of 3,000 cfs, 369 feet NAVD88 Lake WSEL; 100-year flood of 3,400 cfs, 369.7 feet NAVD88 lake WSE.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Bridge_Clearances.xlsx Tab: Bridge_Clearnaces_100pct 3/14/2012 JRG

C.6 CHANNEL ROUGHNESS SENSITIVITY ANALYSIS

To examine the influence of channel roughness on water surface elevations, a sensitivity analysis was conducted for both the existing and proposed conditions models. The sensitivity analysis examined variation in the channel Manning's n value (coefficient of roughness) by a factor of +/- 20% in increments of 10%. The channel Manning's n values used for the sensitivity analysis are provided in Table C-9.

Table C-9
Channel Roughness Sensitivity Analysis Manning's n Values

Adjustment Factor	Manning's n Value: Station 0+00 to 51+00	Manning's n Value: Station 51+00 to 80+00
0.8	0.032	0.040
0.9	0.036	0.045
1.0	0.040	0.050
1.1	0.044	0.050
1.2	0.048	0.055

The results of the sensitivity analysis for a range of flow rates under existing and proposed conditions are presented in Figure C-5 through Figure C-14. Because of the influence of Onondaga Lake levels at lower flow rates (i.e., 180 cfs), the variation in channel roughness has a negligible impact on water surface elevations until approximately model station 56+00. The maximum predicted variation in WSE is less than +/-0.2 feet for a variation in Manning's n of +/-20% from the calibrated values. For the 100-year high-flow event, a variation in roughness of +/-20% from the calibrated values results in a maximum predicted variation in WSE of less than 0.8 feet at station 80+00. A variation in roughness of +20% for the 100-year high-flow event, for both the existing and proposed conditions models, does not show overtopping of any bridges in Reach BC, although the WSE is approximately at the height of the bridge deck at several bridge locations under existing and proposed conditions.

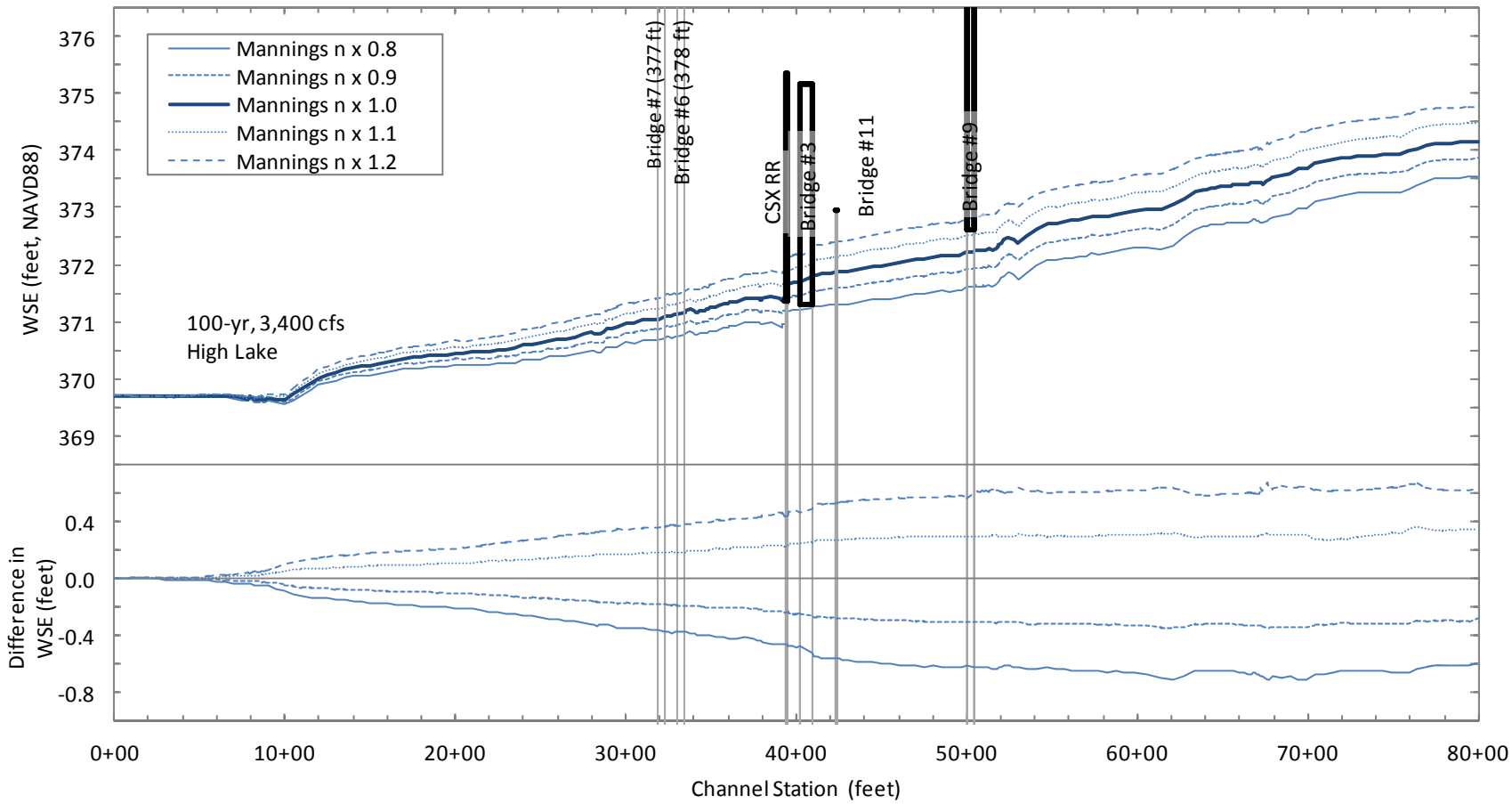


Figure C-5

Channel Roughness Sensitivity Analysis, 100-year Flood, High Lake Level, Existing Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in main channel Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_EG.xlsx Tab: Plots 3/14/2012 JRG

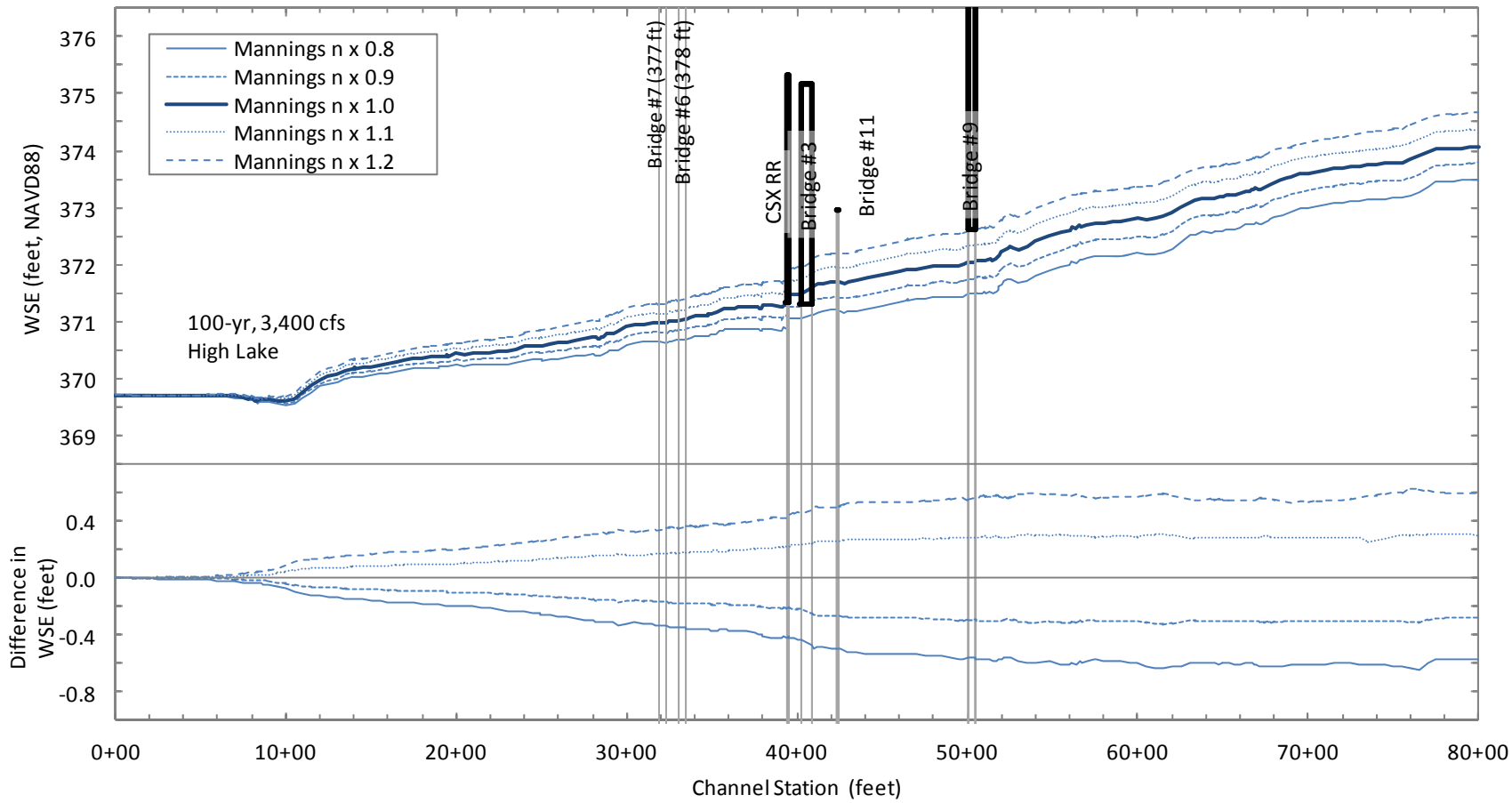


Figure C-6

Channel Roughness Sensitivity Analysis, 100-year Flood, High Lake Level, Proposed Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in main channel Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_PG.xlsx Tab: Plots 3/14/2012 JRG

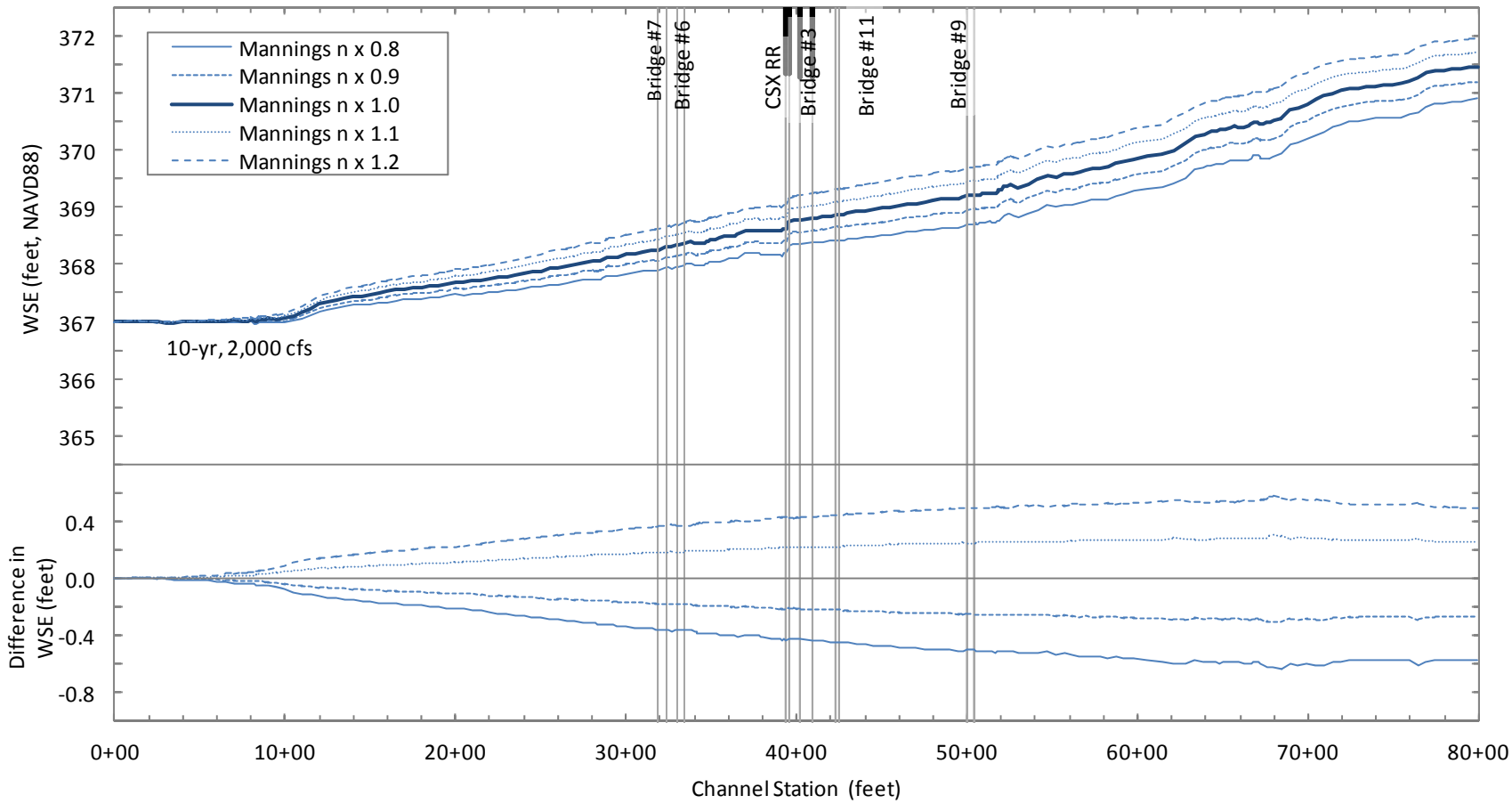


Figure C-7

Channel Roughness Sensitivity Analysis, 10-year Flood, Existing Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in main channel Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_EG.xlsx Tab: Plots 3/14/2012 JRG

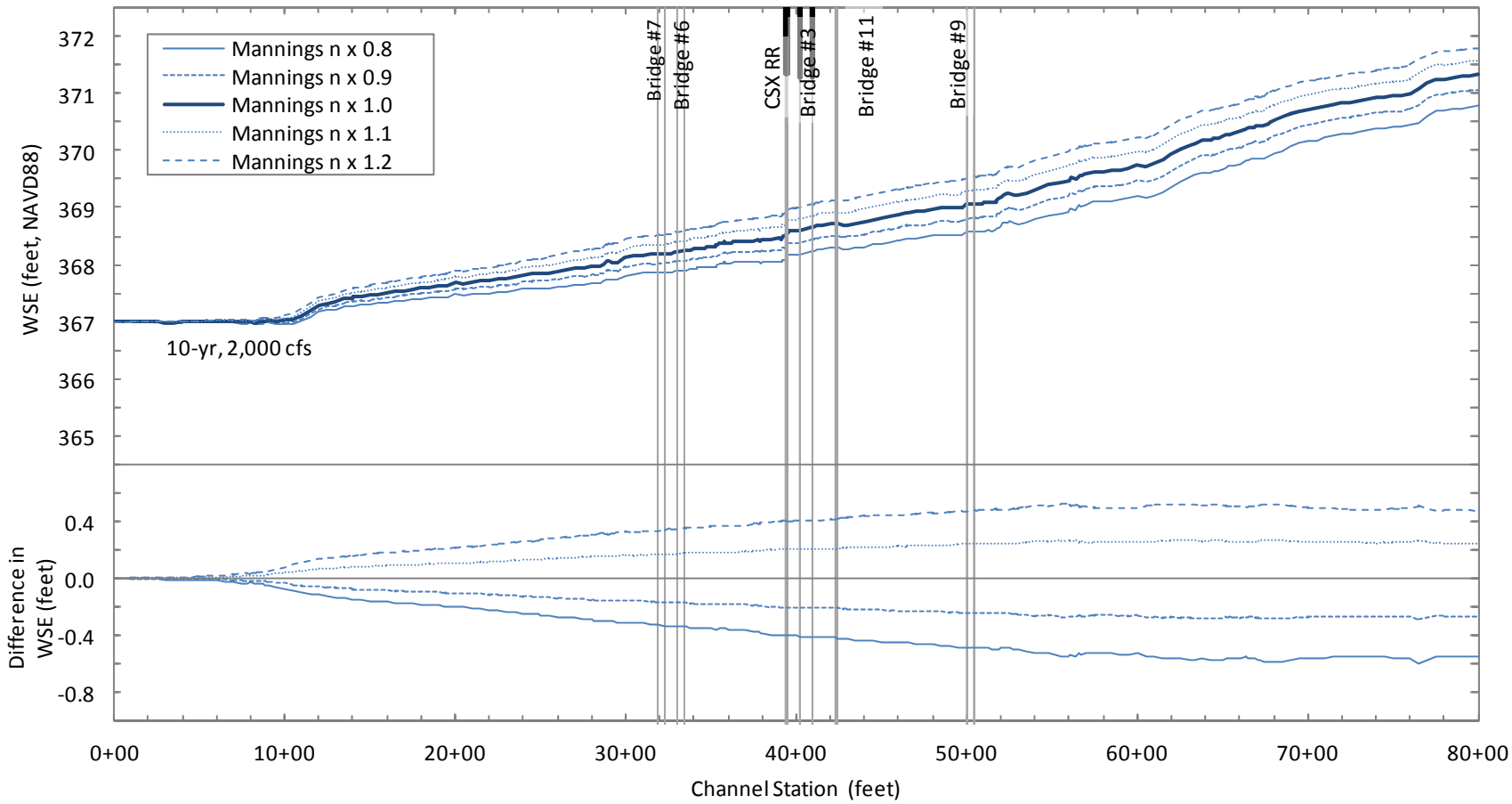


Figure C-8

Channel Roughness Sensitivity Analysis, 10-year Flood, Proposed Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in main channel Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_PG.xlsx Tab: Plots 3/14/2012 JRG

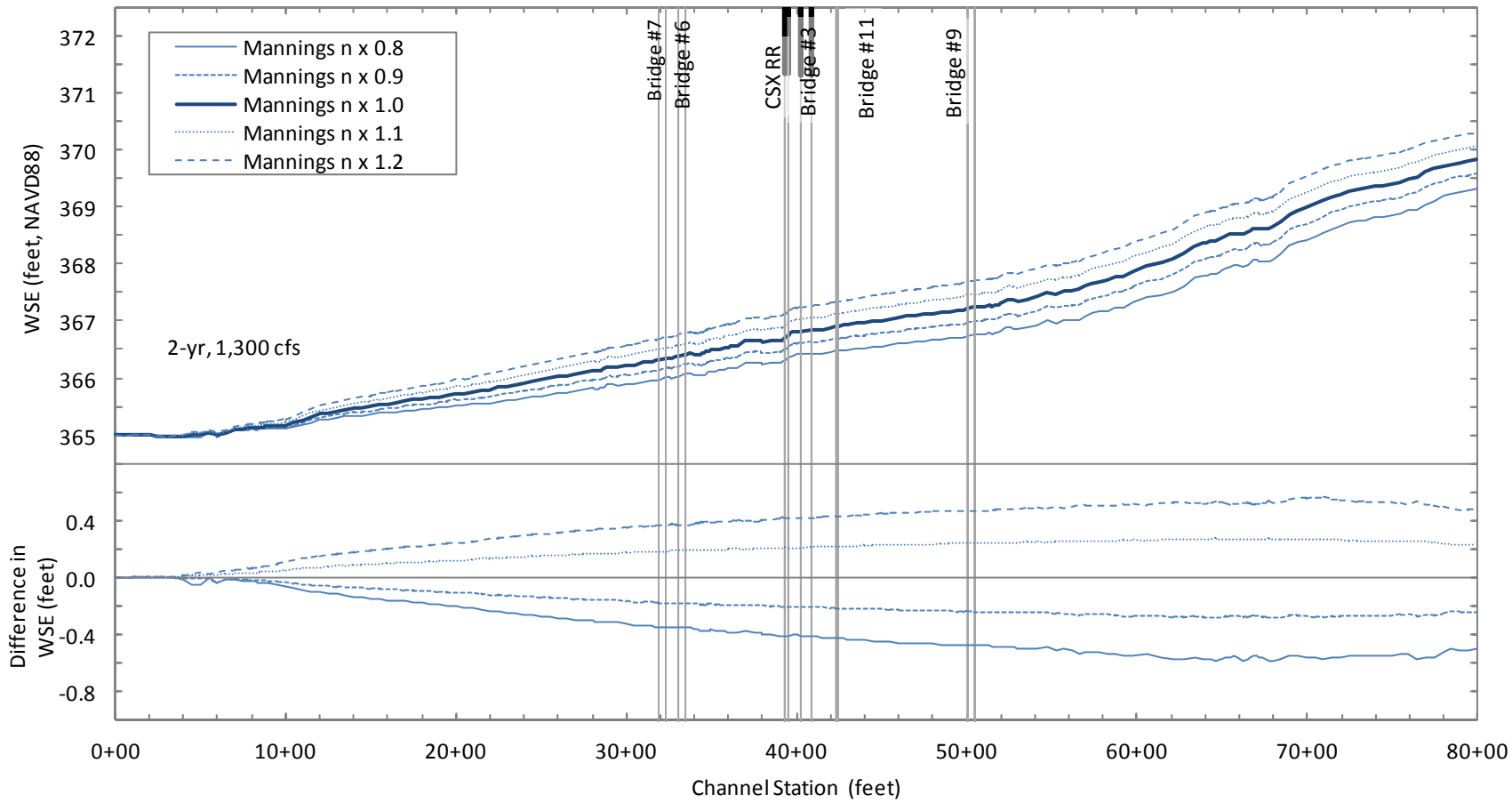


Figure C-9

Channel Roughness Sensitivity Analysis, 2-year Flood, Existing Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in main channel Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_EG.xlsx Tab: Plots 3/14/2012 JRG

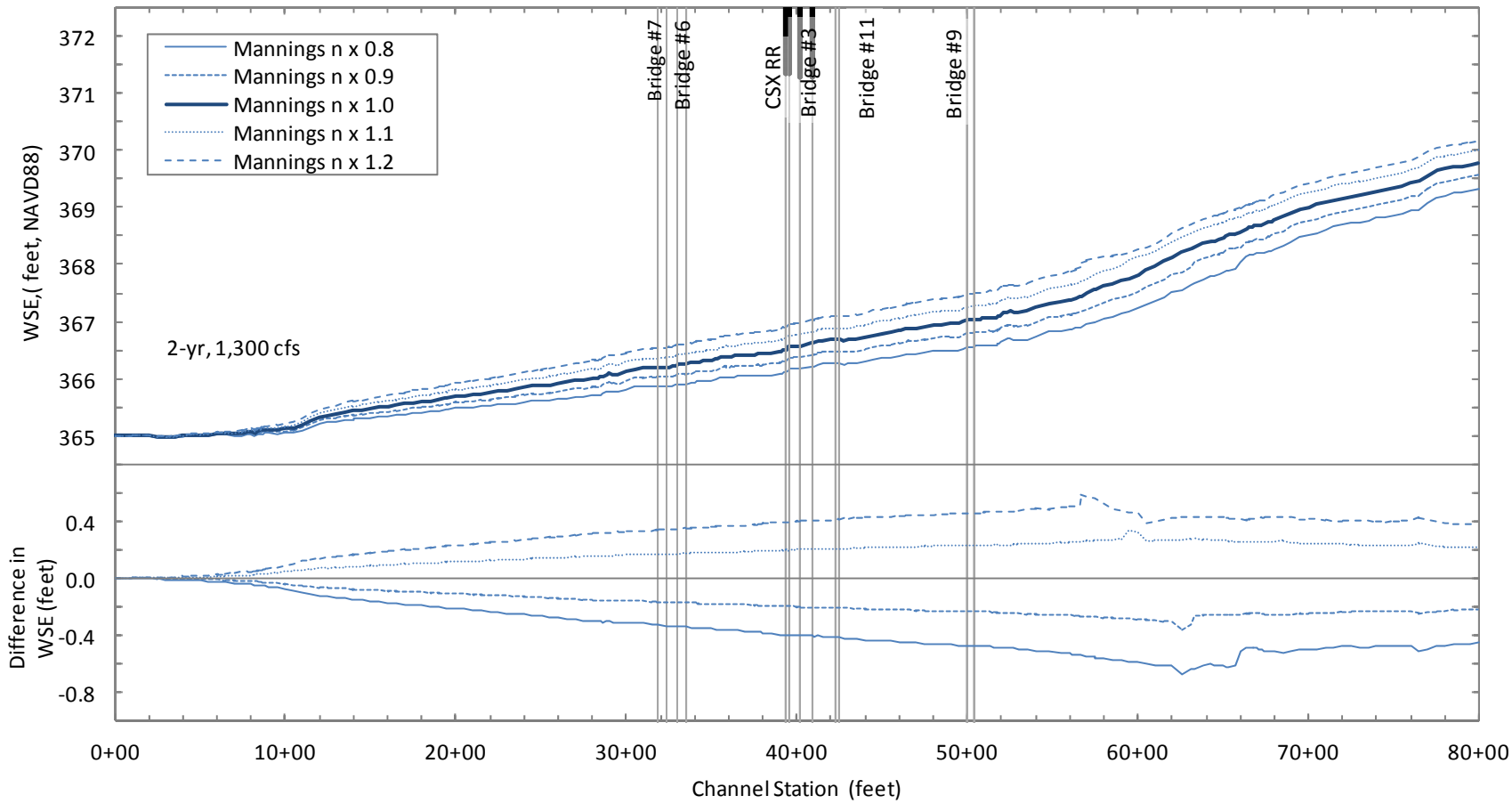


Figure C-10

Channel Roughness Sensitivity Analysis, 2-year Flood, Proposed Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in main channel Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_PG.xlsx Tab: Plots 3/14/2012 JRG

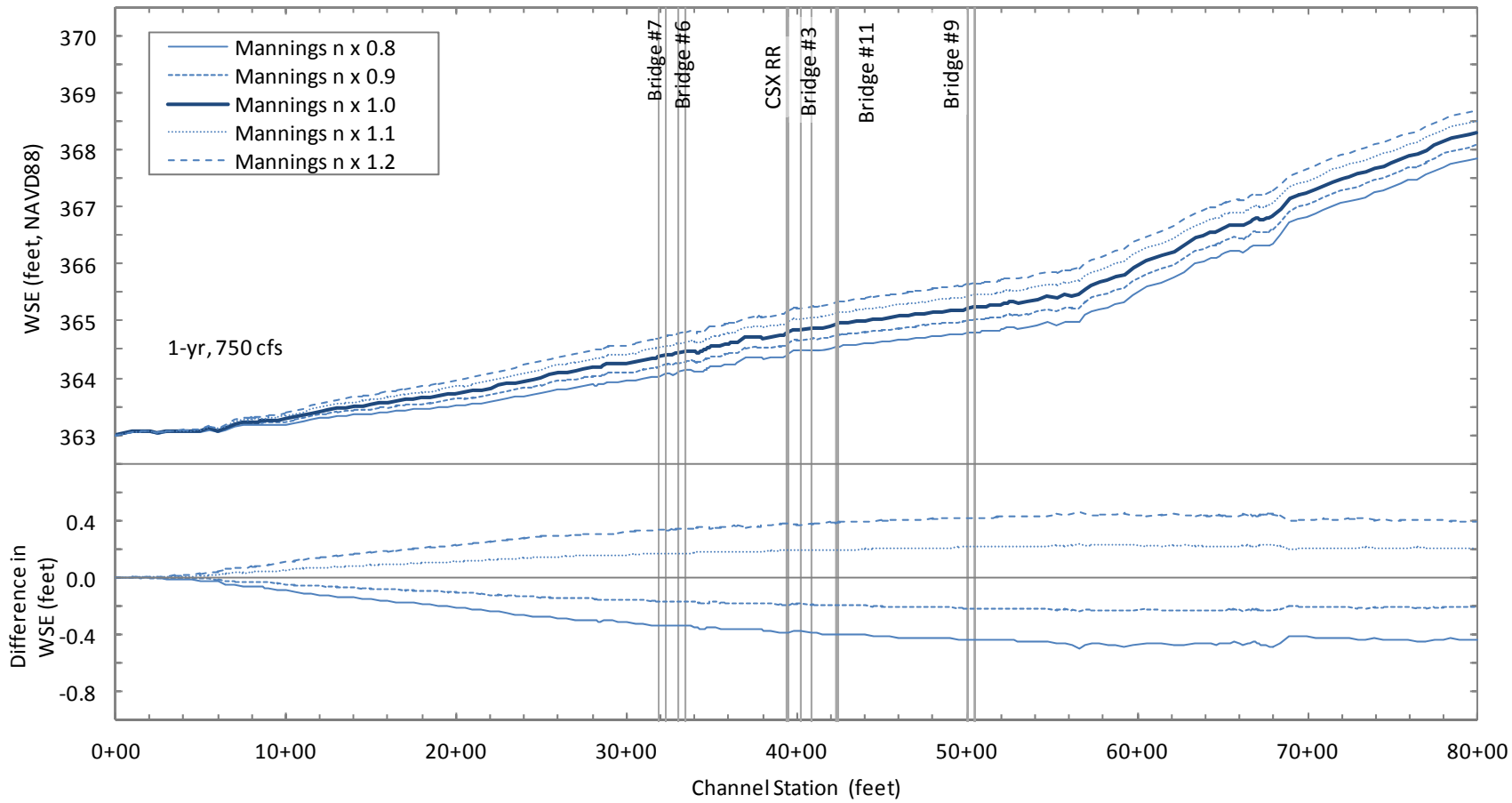


Figure C-11

Channel Roughness Sensitivity Analysis, 1-year Flood, Existing Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in main channel Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_EG.xlsx Tab: Plots 3/14/2012 JRG

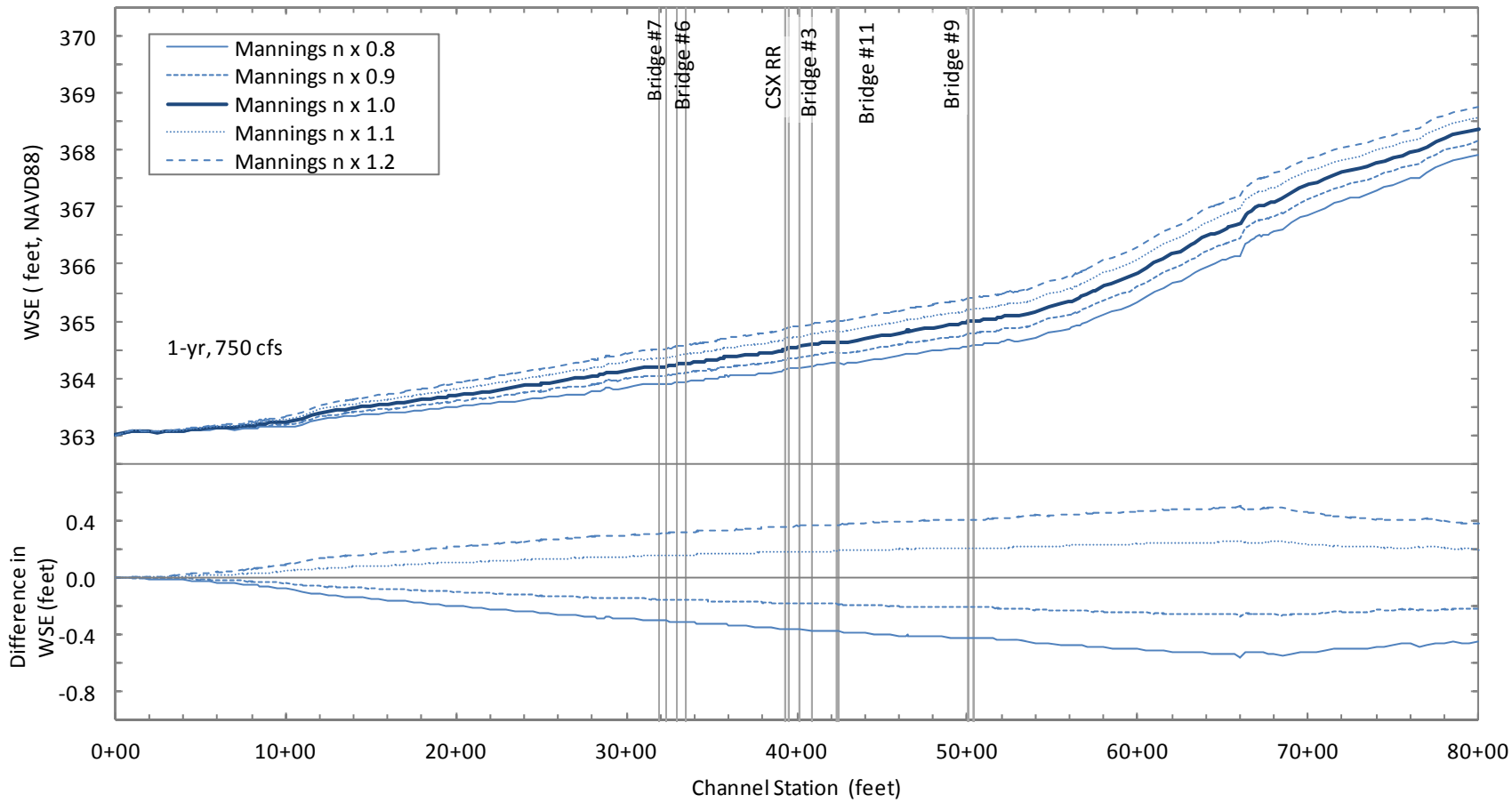


Figure C-12

Channel Roughness Sensitivity Analysis, 1-year Flood, Proposed Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in main channel Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_PG.xlsx Tab: Plots 3/14/2012 JRG

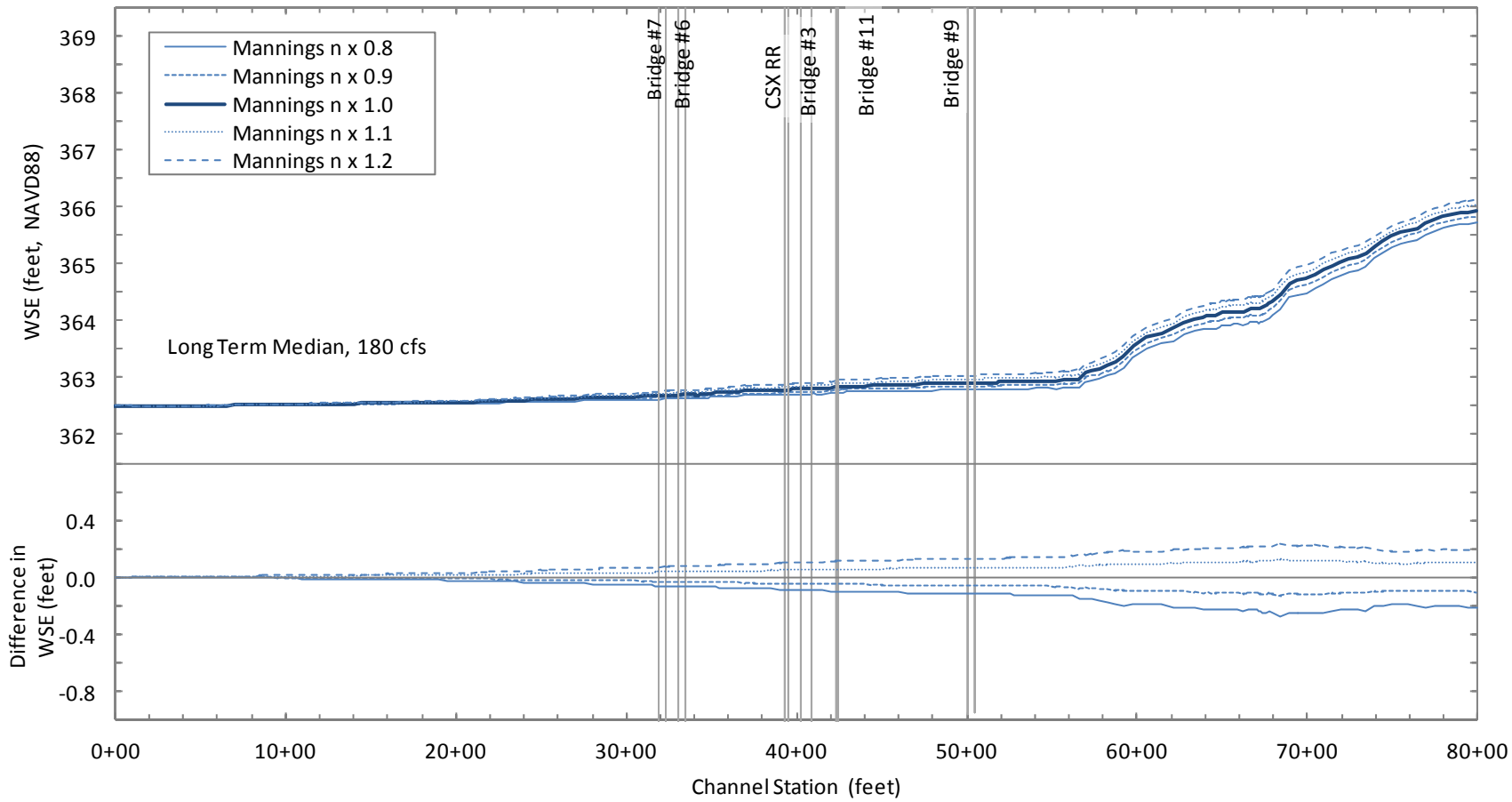


Figure C-13

Channel Roughness Sensitivity Analysis, Long-term Median Flow Rate, Existing Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in main channel Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_EG.xlsx Tab: Plots 3/14/2012 JRG

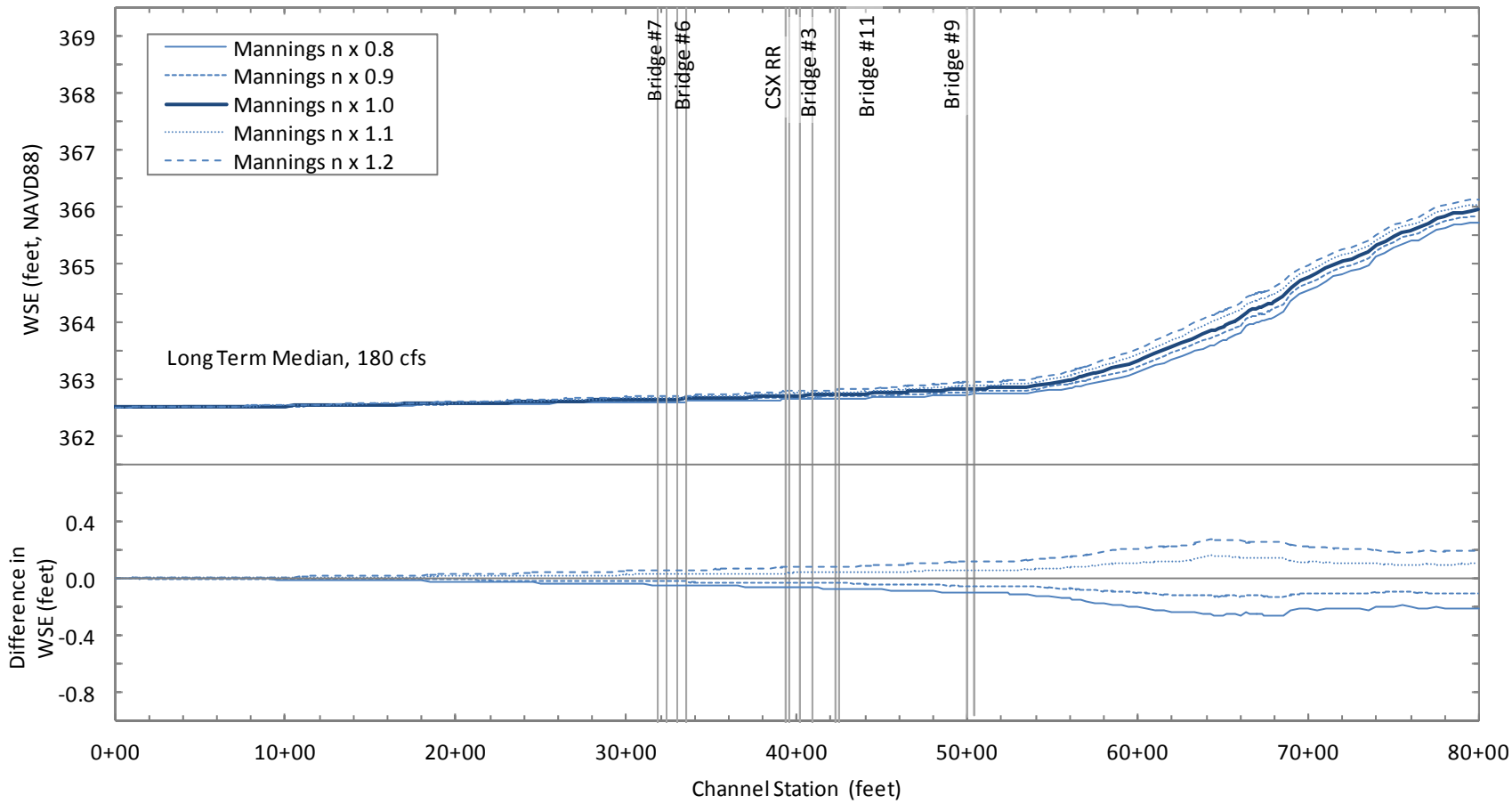


Figure C-14

Channel Roughness Sensitivity Analysis, Long-term Median Flow Rate, Proposed Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in main channel Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_PG.xlsx Tab: Plots 3/14/2012 JRG

C.7 FLOODPLAIN ROUGHNESS SENSITIVITY ANALYSIS

To examine the influence of floodplain roughness on predicted water surface elevations, a sensitivity analysis was conducted for both the existing and proposed conditions models. The sensitivity analysis examined variation in the floodplain Manning's n value (coefficient of roughness) by a factor of +/- 20% in increments of 10%. The floodplain Manning's n values used for the sensitivity analysis are provided in Table C-10. The results of the sensitivity analysis for a range of flow rates under existing and proposed conditions are presented in Figure C-15 through Figure C-22.

Table C-10
Floodplain Roughness Sensitivity Analysis Manning's n Values

Adjustment Factor	Manning's n Value: Dense Woody Vegetation	Manning's n Value: Shrub/Srub Vegetation	Manning's n Value: Dense Flexible Vegetation
0.8	0.100	0.068	0.040
0.9	0.113	0.076	0.045
1.0	0.125	0.085	0.050
1.1	0.138	0.094	0.055
1.2	0.150	0.102	0.060

At lower flow rates (i.e., 180), the variation in floodplain roughness has no impact on water surface elevations because of the lack of floodplain inundation. The 1-year flood is minimally influenced by variation in floodplain roughness because a large majority of the flow is influenced by the channel roughness value, with a maximum predicted variation in WSE of less than +/-0.01 feet for a variation in roughness of +/-20% from the calibrated values. For the 100-year flood, a variation in roughness of +/-20% results in a maximum predicted variation in WSE of less than 0.15 feet at station 80+00. A variation in roughness of +20% from the calibrated values for the 100-year flood, for both the existing and proposed conditions models, does not show overtopping of any bridges in Reach BC, although the predicted WSE is at the height of the bridge deck. Overall variations in floodplain roughness values have considerably less influence compared to channel roughness values on predicted WSE (see Section C.6).

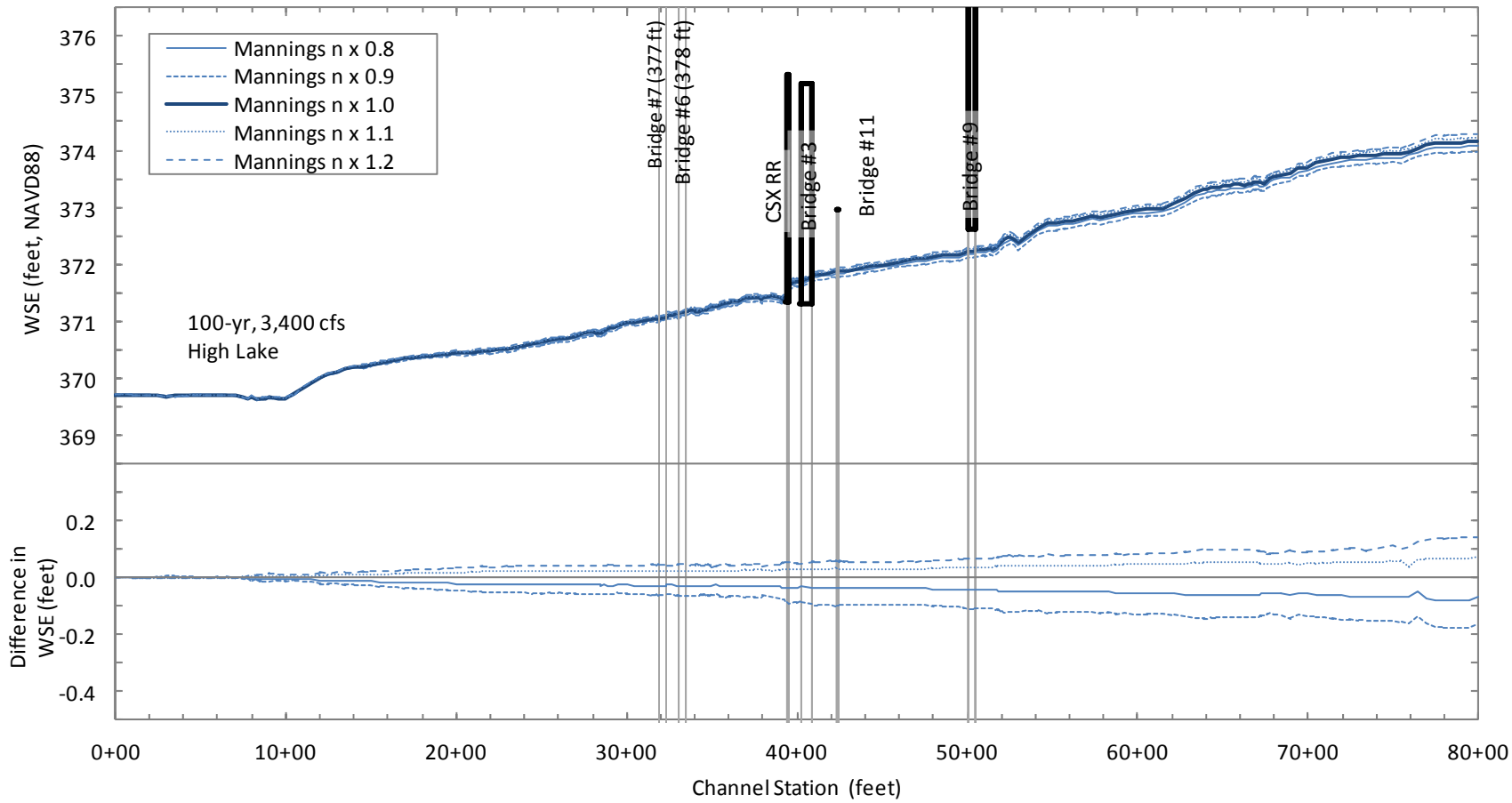


Figure C-15

Floodplain Roughness Sensitivity Analysis, 100-year Flood, High Lake Level, Existing Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in floodplain Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_EG_FP.xlsx Tab: Plots 3/14/2012 JRG

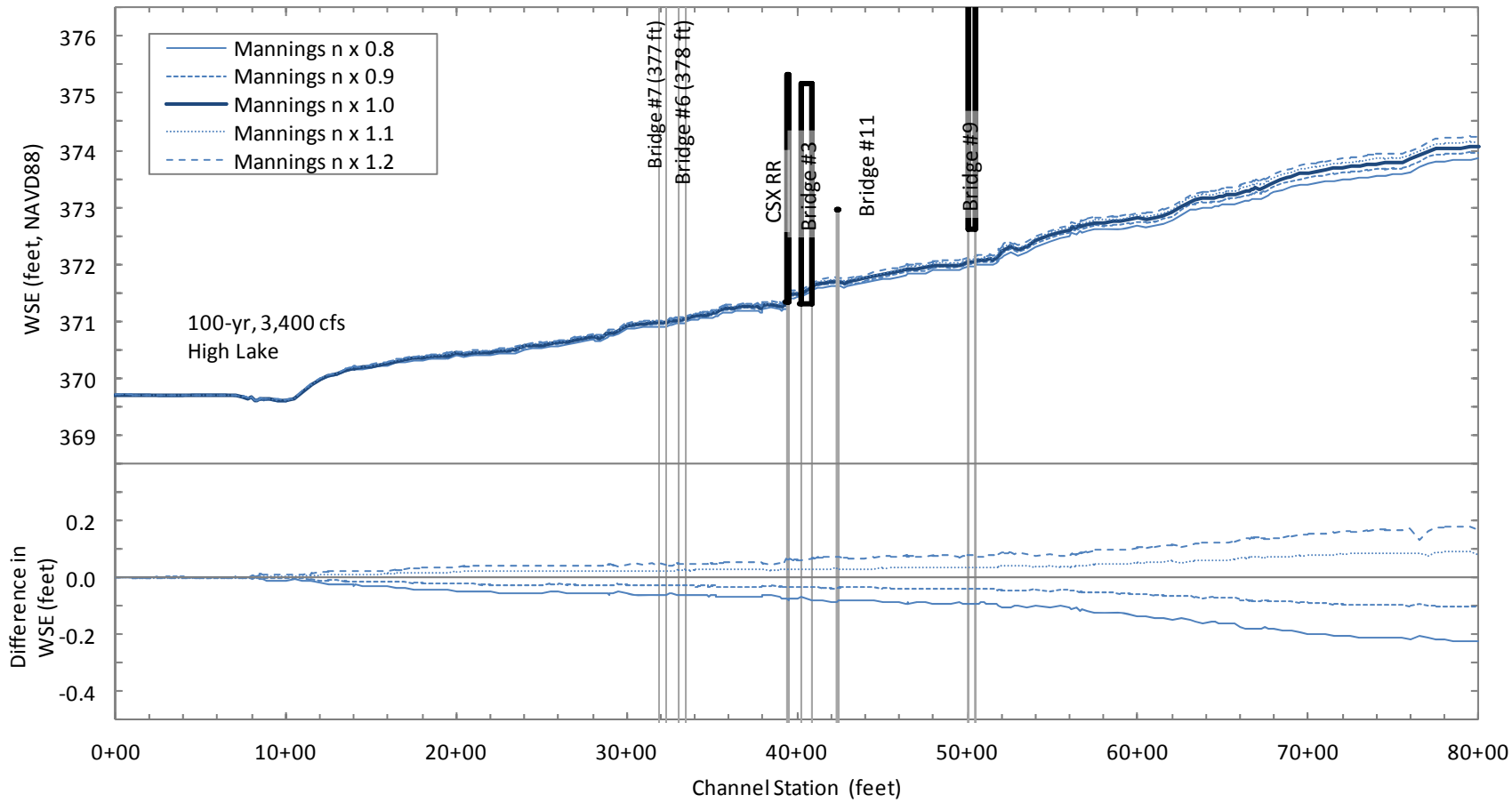


Figure C-16

Floodplain Roughness Sensitivity Analysis, 100-year Flood, High Lake Level, Proposed Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in floodplain Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_PG_FP.xlsx Tab: Plots 3/14/2012 JRG

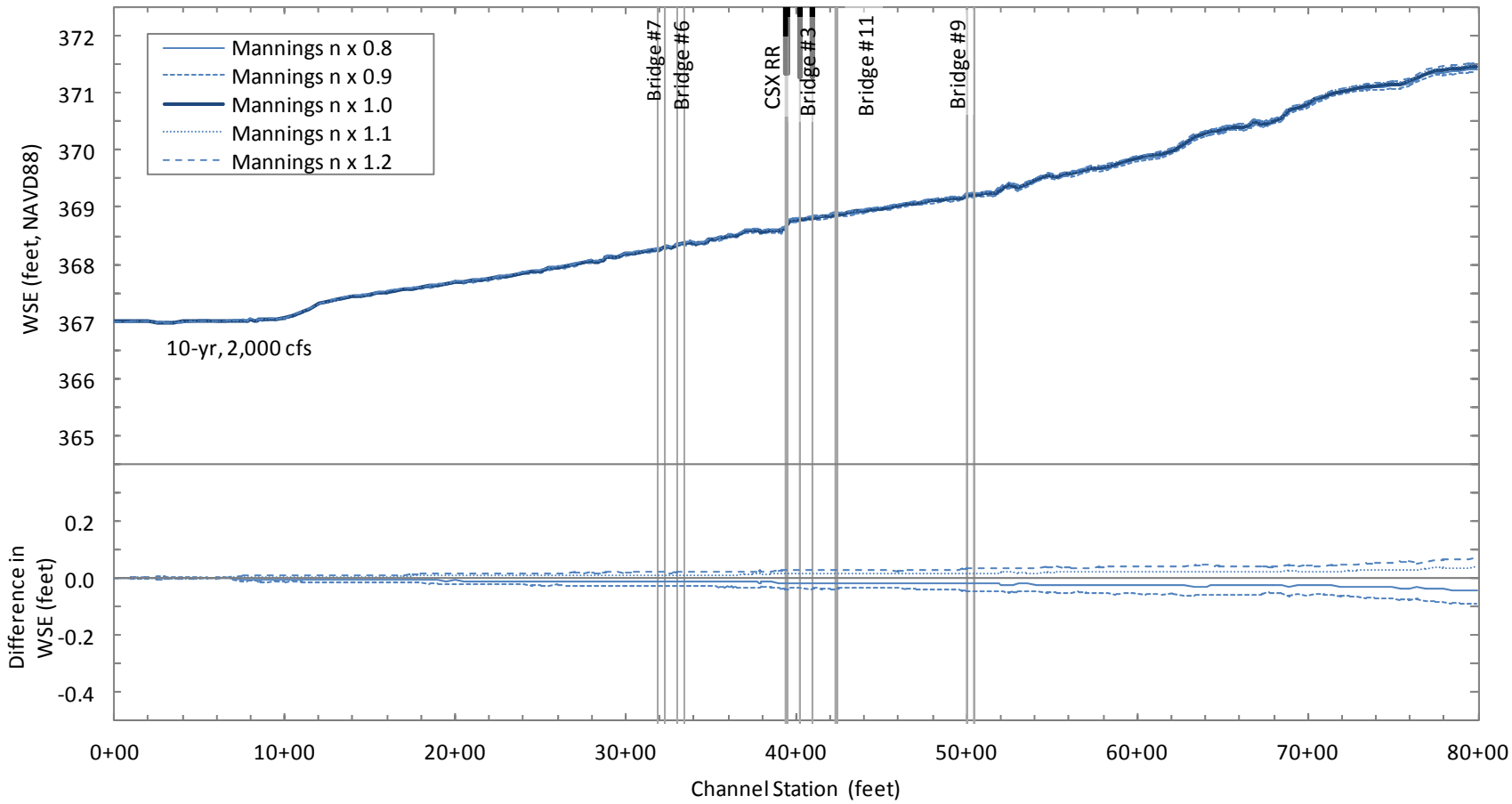


Figure C-17

Floodplain Roughness Sensitivity Analysis, 10-year Flood, Existing Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in floodplain Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_EG_FP.xlsx Tab: Plots 3/14/2012 JRG

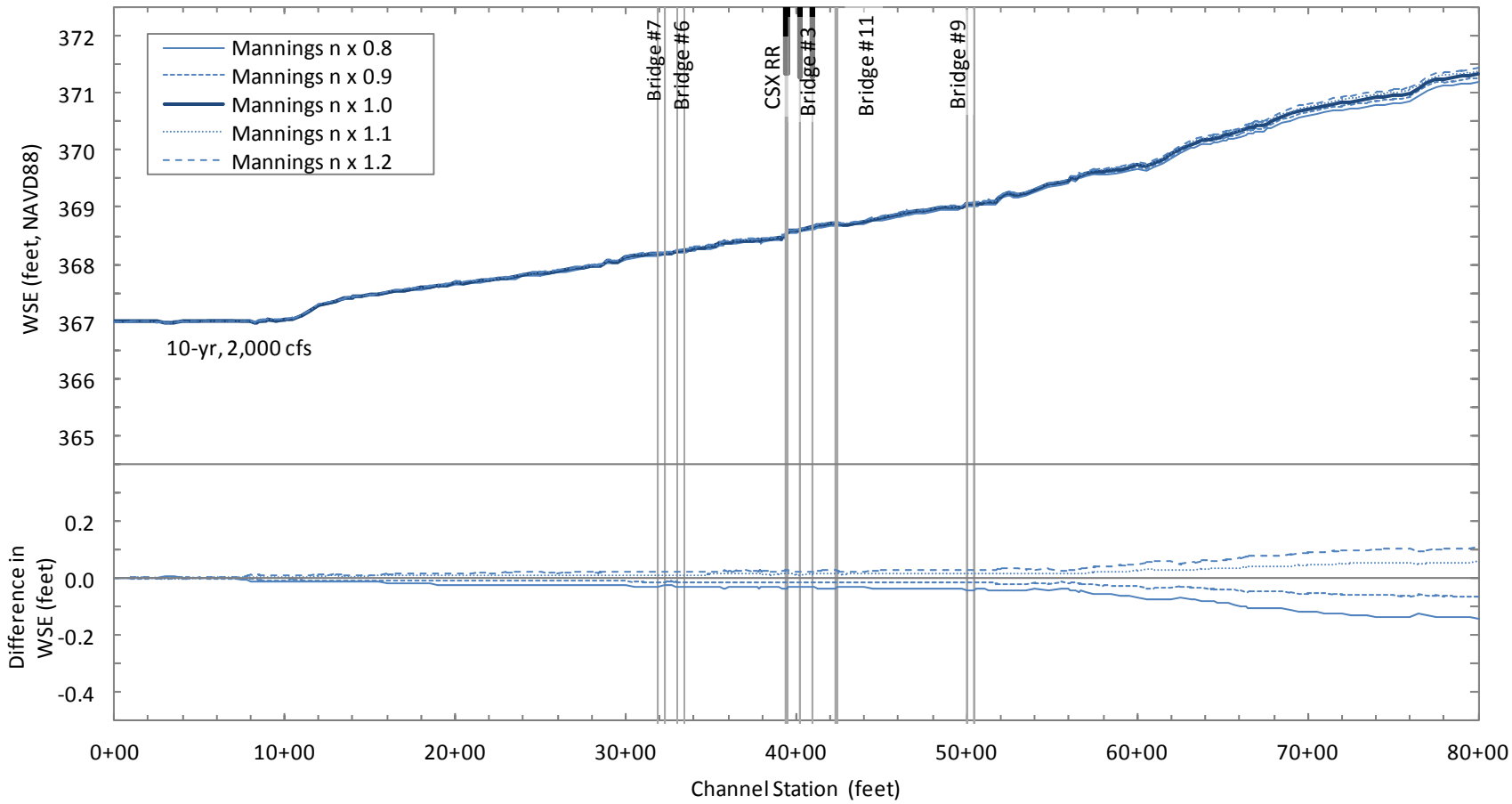


Figure C-18

Floodplain Roughness Sensitivity Analysis, 10-year Flood, Proposed Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in floodplain Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_PG_FP.xlsx Tab: Plots 3/14/2012 JRG

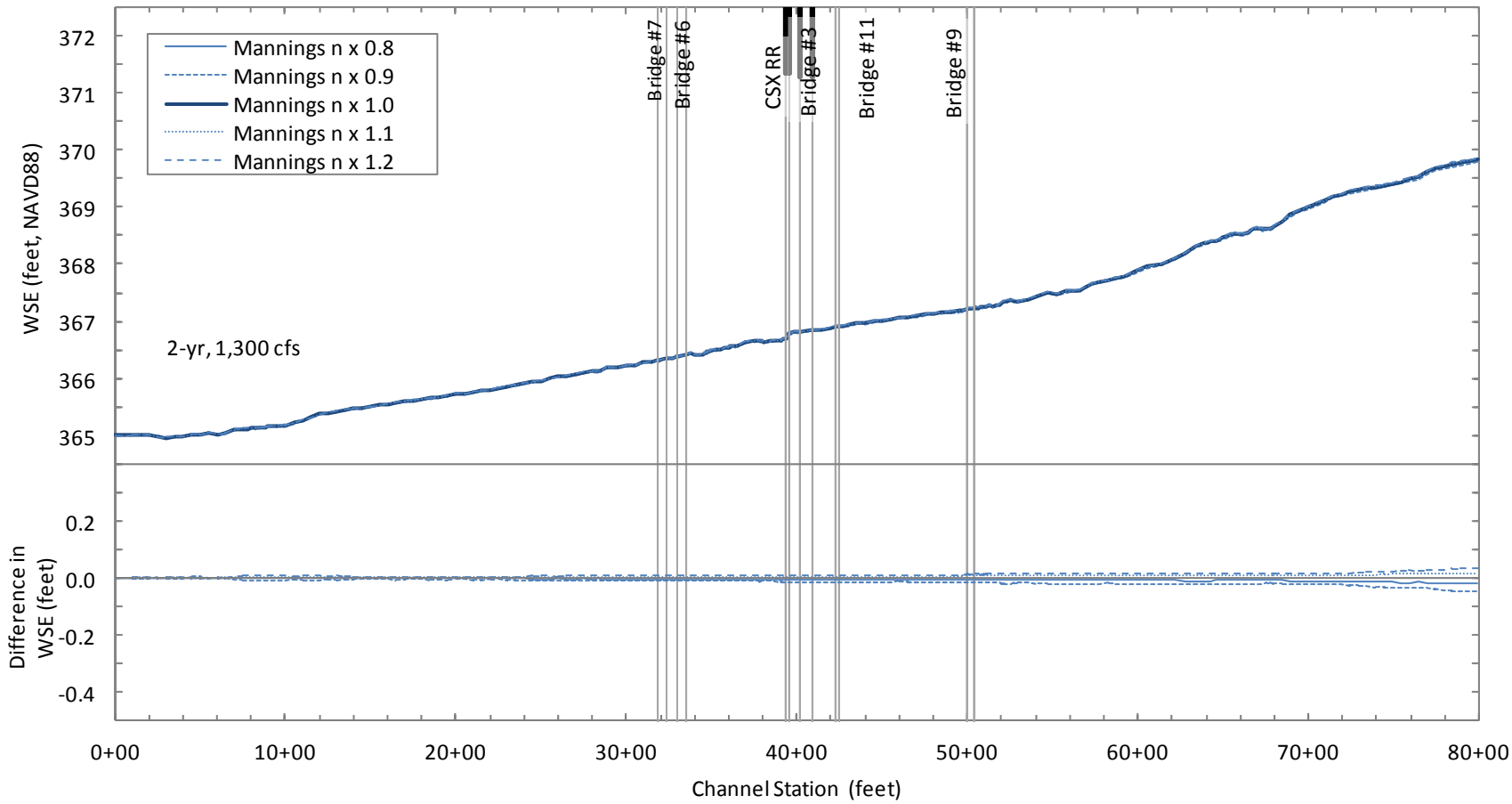


Figure C-19

Floodplain Roughness Sensitivity Analysis, 2-year Flood, Existing Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in floodplain Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_EG_FP.xlsx Tab: Plots 3/14/2012 JRG

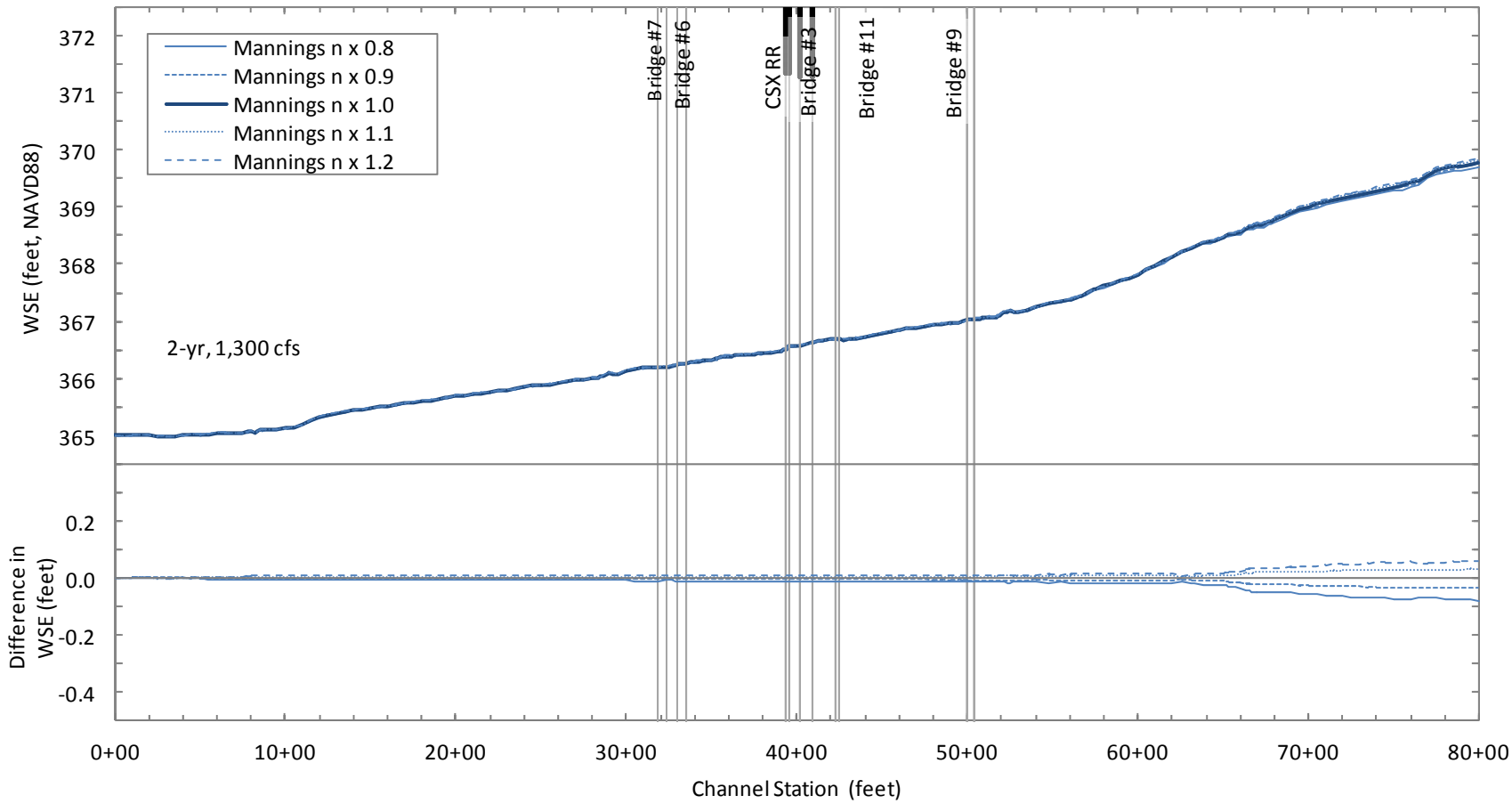


Figure C-20

Floodplain Roughness Sensitivity Analysis, 2-year Flood, Proposed Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in floodplain Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_PG_FP.xlsx Tab: Plots 3/14/2012 JRG

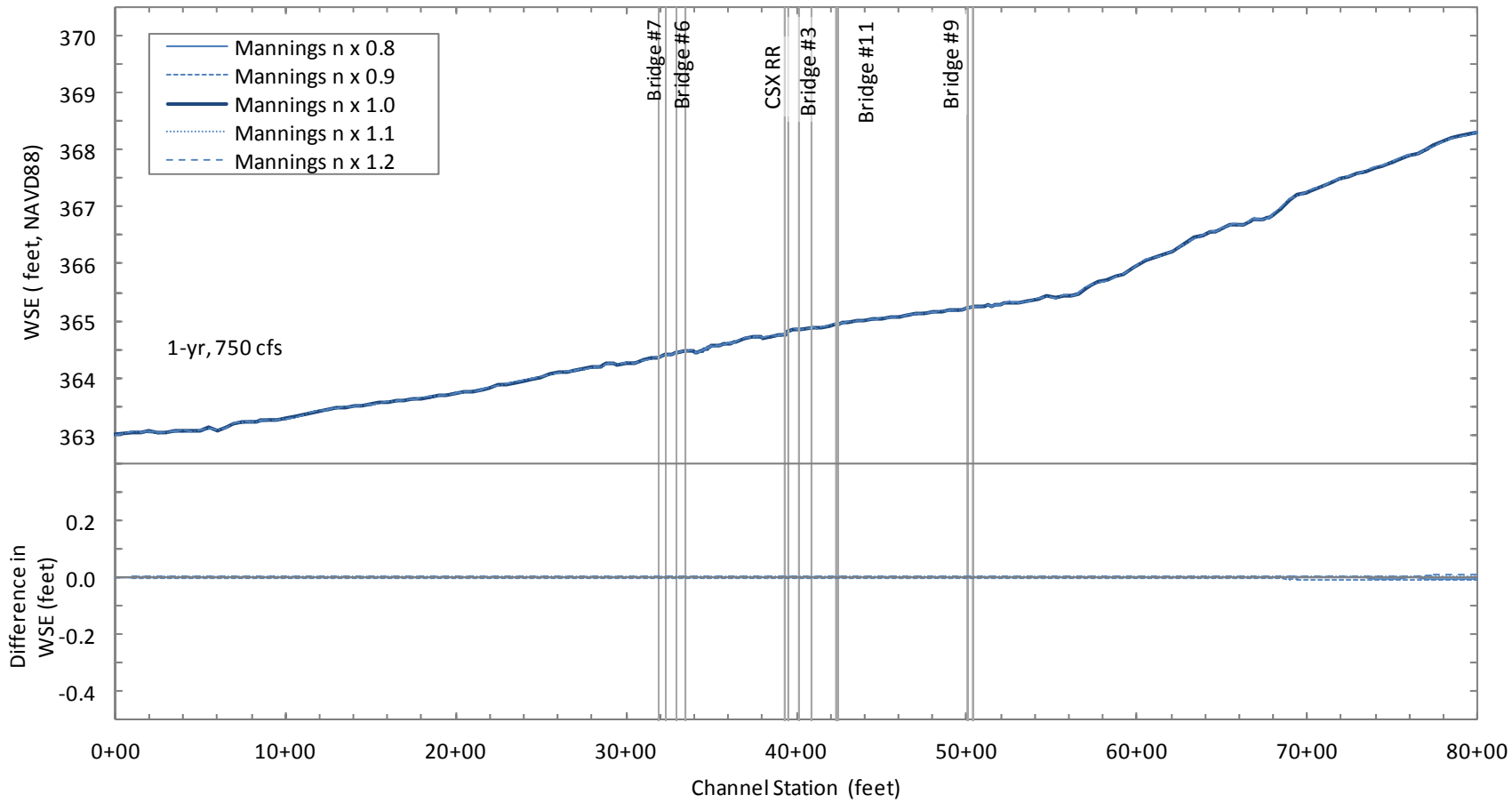


Figure C-21

Floodplain Roughness Sensitivity Analysis, 1-year Flood, Existing Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in floodplain Manning,s n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_EG_FP.xlsx Tab: Plots 3/14/2012 JRG

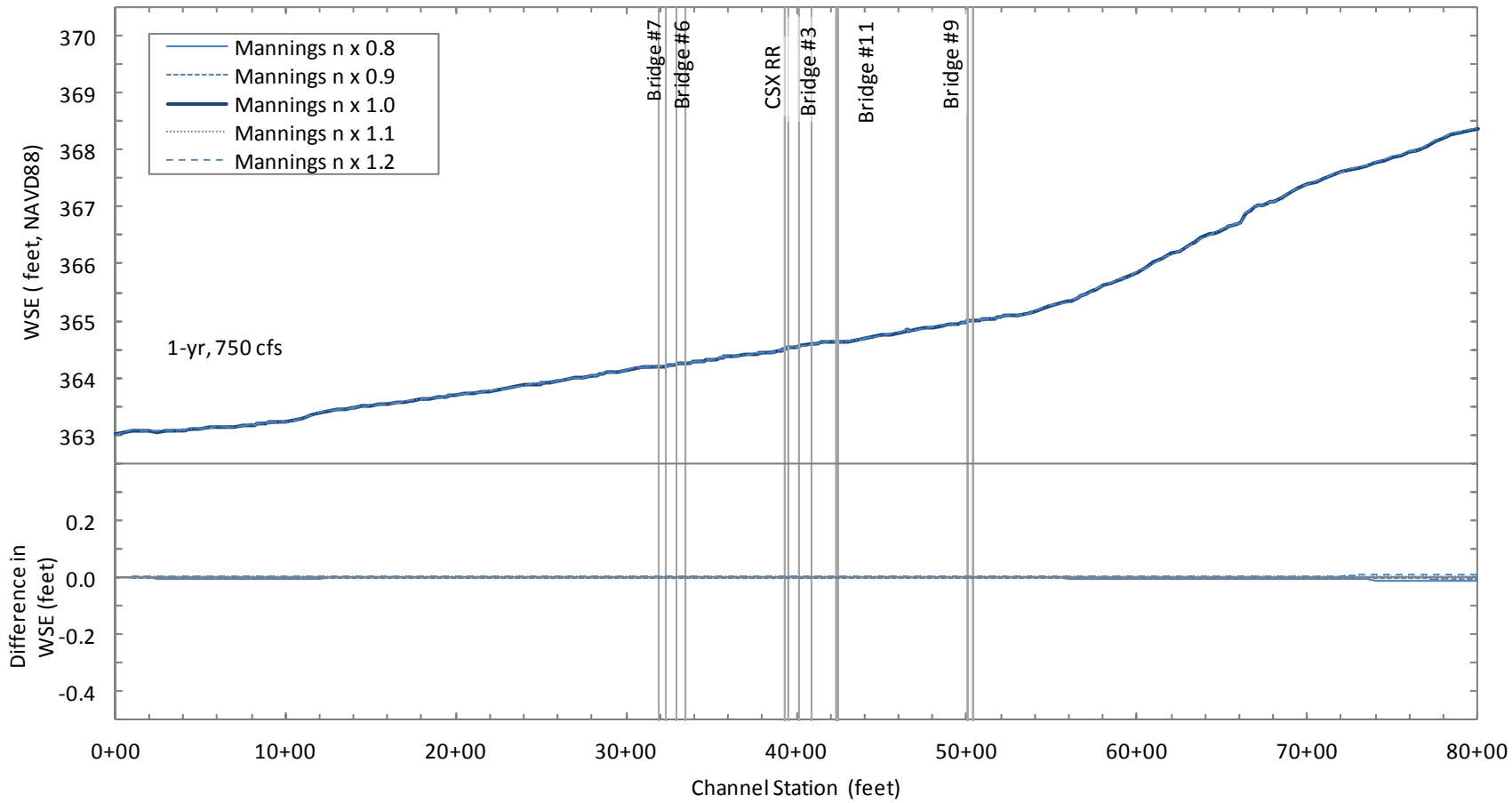


Figure C-22

Floodplain Roughness Sensitivity Analysis, 1-year Flood, Proposed Conditions

Notes: WSE profiles are HEC-RAS model results for the indicated variation in floodplain Manning's n roughness value. See report for boundary conditions. Difference = adjusted n WSE - design n WSE. Bridge #7, West I-690. Bridge #6, East I-690. CSX RR, CSX Railroad Bridge. Bridge #3, State Fair Blvd. Bridge #11, Utility Crossing. Bridge #9, Access Road. Geddes Brook enters Ninemile Creek at approximately Station 68+90.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Model\Output\Manning's_n_Sensitivity_PG_FP.xlsx Tab: Plots 3/14/2012 JRG

C.8 SUMMARY

The updated HEC-RAS models described in this document have been shown to provide a good representation of hydraulics within the system and are suitable for use in the design process. Design evaluations that utilize the model include the following:

- Habitat feature hydraulics
- Low-flow water depths
- No-rise for the 100-year high-flow event
- Bridge clearances
- Channel roughness sensitivity for existing and proposed conditions
- Floodplain roughness sensitivity for existing and proposed conditions
- Channel bed material design
- Bank protection design (see Appendix E of the 100% Design Report)

C.9 REFERENCES

Anchor QEA (Anchor QEA LLC), 2009. HEC-RAS Model Geddes Brook/Ninemile Creek. Prepared for Parsons, Syracuse, New York. July.

Anchor QEA, 2010. *Ninemile Creek Intermediate Channel Design Analysis Report, Attachment C – Existing Conditions HEC-RAS Model Geddes Brook/Ninemile Creek*. Prepared for Parsons, Liverpool, NY. October.

Anchor QEA, 2011. *Geddes Brook 100% Design Report, Attachment C – Existing Conditions HEC-RAS Model Geddes Brook/Ninemile Creek*. Prepared for Parsons, Liverpool, NY. February.

Bathurst, J.C., 1985. Flow resistance estimation in mountain rivers. Proc ASCE, *Journal of Hydraulic Engineering* 111(4):625-643.

Chow, V.T., 1959. *Open Channel Hydraulics*, published by McGraw-Hill, 1959.

Hey, R.D., 1979. *Flow resistance in gravel bed rivers*. Proc ASCE, *Journal of Hydraulic Division*, 105(4):365-379

Limerinos, J.T., 1970. *Determination of the Manning coefficient from measured bed roughness in natural channels*. Water Supply Paper 1898-B, US Geological Survey, Washington, 1970.

Limno Tech, Inc., 2005. *HEC-RAS Model Calibration for Current Conditions and Remedial Scenario Forecasts for Ninemile Creek*. Prepared for Parsons. April 12, 2005.

New York State Department of Environmental Conservation (NYSDEC) and United States Environmental Protection Agency (EPA), 2009a. *Record of Decision for Operable Unit 1 of the Geddes Brook/Ninemile Creek Site*. NYSDEC, Albany, NY and EPA Region 2, New York, NY. April.

NYSDEC and EPA, 2009b. *Record of Decision for Operable Unit 2 of the Geddes Brook/Ninemile Creek Site*. NYSDEC, Albany, NY and EPA Region 2, New York, NY. May.

Parsons, 2005. *Geddes Brook/Ninemile Creek Feasibility Study Report. Draft Final*. Prepared by Parsons, Liverpool, NY in association with Exponent, Albany, NY for Honeywell, Morristown, NJ. May.

Parsons, 2008. *Geddes Brook/Ninemile Creek Operable Unit 1 Supplemental Feasibility Study Report. Draft Final.* Prepared by Parsons, Liverpool, NY in association with Exponent and QEA for Honeywell, East Syracuse, NY. November.

Parsons, 2009. *Geddes Brook/Ninemile Creek Operable Unit 2 Supplemental Feasibility Study Report. Draft Final*. Prepared by Parsons, Liverpool, NY in association with Exponent and QEA for Honeywell, East Syracuse, NY. May.

Parsons, 2010. Ninemile Creek Pre-Design Investigation Data Summary Report. Prepared for Honeywell. October.

Thew Associates, 2009. Topographic and Bathymetric Survey.

U.S. Army Corps of Engineers (USACE), 2008. *HEC-RAS River Analysis System, Hydraulic Reference Manual,* Version 4.0, March 2008.

ATTACHMENT D
SEDIMENT GRAIN SIZE DISTRIBUTION DESIGN AND STABLE GRAIN SIZE/TRANSPORT EVALUATION

TABLE OF CONTENTS

D.1 INTRODUCTION D-1

D.2 HABITAT AND EROSION PROTECTION MATERIAL DESIGN D-2

D.2.1 Material Type and Gradation D-2

D.2.2 Material Thickness D-3

D.3 STABLE GRAIN SIZES D-8

D.3.1 Maynord's Equation D-9

D.3.2 Cao's Modified Shields Diagram for Critical Grain Size D-10

D.3.3 Findings D-11

D.4 SEDIMENT TRANSPORT D-12

D.4.1 Sediment Transport Capacity D-12

D.4.2 Fractional Sediment Transport D-15

D.4.3 Findings D-17

D.5 REFERENCES D-19

List of Tables

Table D-1 Proposed Sediment Grain Size Distribution Range D-3

List of Figures

Figure D-1 Proposed Conditions Critical Grain Size, 10-year Return Period Flow, Design Lake Level D-5

Figure D-2 Proposed Conditions Critical Grain Size, 100-year Return Period Flow, Low Lake Level D-6

Figure D-3 Proposed Conditions Sediment Transport Rate, 1-year Return Period Flow, Design Lake Level D-14

Figure D-4 Fractional Sediment Transport Grain Size Distributions and Proposed Grain Size Distribution Range D-16

LIST OF ACRONYMS AND ABBREVIATIONS

cfs	cubic feet per second
HEC-RAS	Hydraulic Engineering Center – River Analysis System
ft/s^2	feet per square second
HSI	Habitat Suitability Index
lbs/ft^3	pounds per cubic foot
lb/ft/s	pound per foot per second
mm	Millimeters
NAVD88	North American Vertical Datum of 1988
SOW	Statement of Work
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency

D.1 INTRODUCTION

Performance objectives for the channel bed material include the following:

- Protecting infrastructure
- Protecting chemical isolation layer, where present
- Providing substrate habitat for fish and benthic macroinvertebrates
- Maintaining surface sediment variability through natural sediment transport and deposition patterns
- Preclude the need for any additional grade control features beyond the intrinsic grade control provided by the channel bed material.

This attachment identifies and evaluates channel substrate material that meets these objectives. The material is described in terms of grain size gradation (i.e., different sizes of material) and thickness of that material.

The erosion protection function of the material, needed to protect infrastructure and the chemical isolation layer, where present, was evaluated using industry standard methods published by the U.S. Army Corps of Engineers (USACE; 1994) and the U.S. Environmental Protection Agency (USEPA; 2005) for constructing and maintaining channels. In addition to these standard methods, other peer-reviewed methods for calculating sediment stability and transport were used to further evaluate the design (see specific references throughout the document). Findings from the analyses are applicable to erosion protection of a chemical isolation layer, scour protection of infrastructure and utilities, and general channel stability.

The habitat function of the material was evaluated by reviewing habitat suitability index (HSI) models developed by the U.S. Fish and Wildlife Service and other literature reviewed as part of developing the Draft Lakewide Habitat Plan (Parsons 2009; Voshell 2002).

D.2 HABITAT AND EROSION PROTECTION MATERIAL DESIGN

The channel bed material will serve two different functions: 1) habitat for aquatic organisms; and 2) stability to resist erosion where required. The types of bed material suitable for the aquatic organisms were identified through review of relevant literature and guidance documents and from work on Onondaga Lake. The types of material that will be needed to provide the required stability were evaluated using multiple bed stability calculation methods as further described herein.

D.2.1 Material Type and Gradation

A material sourcing evaluation has been ongoing as part of the design work for Ninemile Creek and Onondaga Lake to identify potential sources of backfill and erosion protection material. Based on the habitat and stability requirements for the material to be used in Ninemile Creek, as described in Sections D.3 and D.4, a bank-run material has been identified as part of that sourcing evaluation, which meets both requirements. The bank-run material is a glacio-fluvial deposit consisting of rounded and sub-angular material with a wide range of grain sizes.

The grain size envelope of the material is discussed in Section D.4.2and a gradation specification range is provided in Table D-1. Glacio-fluvial material was moved by glaciers and subsequently sorted and deposited by streams flowing from the melting ice and, as such, provides a suitable stream substrate. This material provides the range of sizes required to reconcile stability and habitat functions. Additionally, this material has the benefit of being relatively local and would require little to no processing before being used, factors that support USEPA Region 2's Clean and Green policy.

Table D-1
Proposed Sediment Grain Size Distribution Range

U.S. Sieve Classification	Upper Bound Percent Passing	Lower Bound Percent Passing
12 inches	100	100
6 inches	50	92
2 inches	40	76
#4 (0.19 inches)	10	33
#40 (0.017 inches)	3	13
#200 (0.0030 inches)	0	7

Compared to the existing condition grain size distribution (see Appendix B, Attachment B-2 Material Handling Properties of the draft 100% Design Report for Ninemile Creek) for the channel, the proposed grain size distribution is considerably coarser. The average existing condition channel bed median grain size range is approximately 0.1 to 1 millimeters (mm; 0.004 to 0.04 inches). In contrast, the proposed median grain size in the channel, based on the locally available glacio-fluvial source, may range from approximately 15 to 152 mm (0.6 to 6 inches). As stated above, the coarser grain size distribution will reconcile both stability and habitat function requirements.

D.2.2 Material Thickness

A minimum habitat and erosion protection layer thickness is required to accommodate the maximum grain size, provide sufficient depth for grain interlocking, limit the penetration of high-flow current velocities into the erosion protection stone voids, and provide habitat function. The layer design requires a balance between erosion protection and habitat functions. The design presented herein achieves that balance through the use of a glacio-fluvial material consisting of rounded and sub-angular material with a wide range of grain sizes.

Palermo et al. (1998) recommends different thicknesses of the erosion protection layer based on whether the material will be subject to flood flows or turbulence associated with propeller wash. For turbulent flow associated with propeller wash, Palermo et al. (1998) recommends that the minimum layer thickness be $2D_{50}$; however, propeller wash is not anticipated to be a factor within the Ninemile Creek channel as water depths are relatively

shallow, limiting the use and speed of motor boats on Ninemile Creek. For flood flows, Palermo et al. (1998) recommends using the maximum grain diameter (D_{100}), or one and a half times the median grain diameter ($1.5D_{50}$), whichever is greater. If the minimum habitat and erosion protection layer thickness is based on two times the predicted stable D_{50}, the habitat and erosion protection layer would be approximately 3 to 6 inches for the majority of the creek, with some locations requiring a thickness of 12 inches. If the thickness is based on the specified grain size distribution given in Table D-1 (D_{50} = 1.2 inches, D_{100} = 12 inches), the required thickness of channel substrate in Ninemile Creek ranges from 2.4 to 18 inches.

The Statement of Work (SOW; Parsons 2010) requires a minimum thickness of 24 inches for the habitat material. The SOW states that if an erosion protection layer is required, the erosion protection layer can be part of the 24-inch-thick habitat layer, to the extent inclusion of the erosion protection layer material is compatible with habitat layer requirements. The grain size requirements for both erosion protection and fish use are similar, as shown in Figure D-1 and Figure D-2; therefore, a single material can provide both functions.

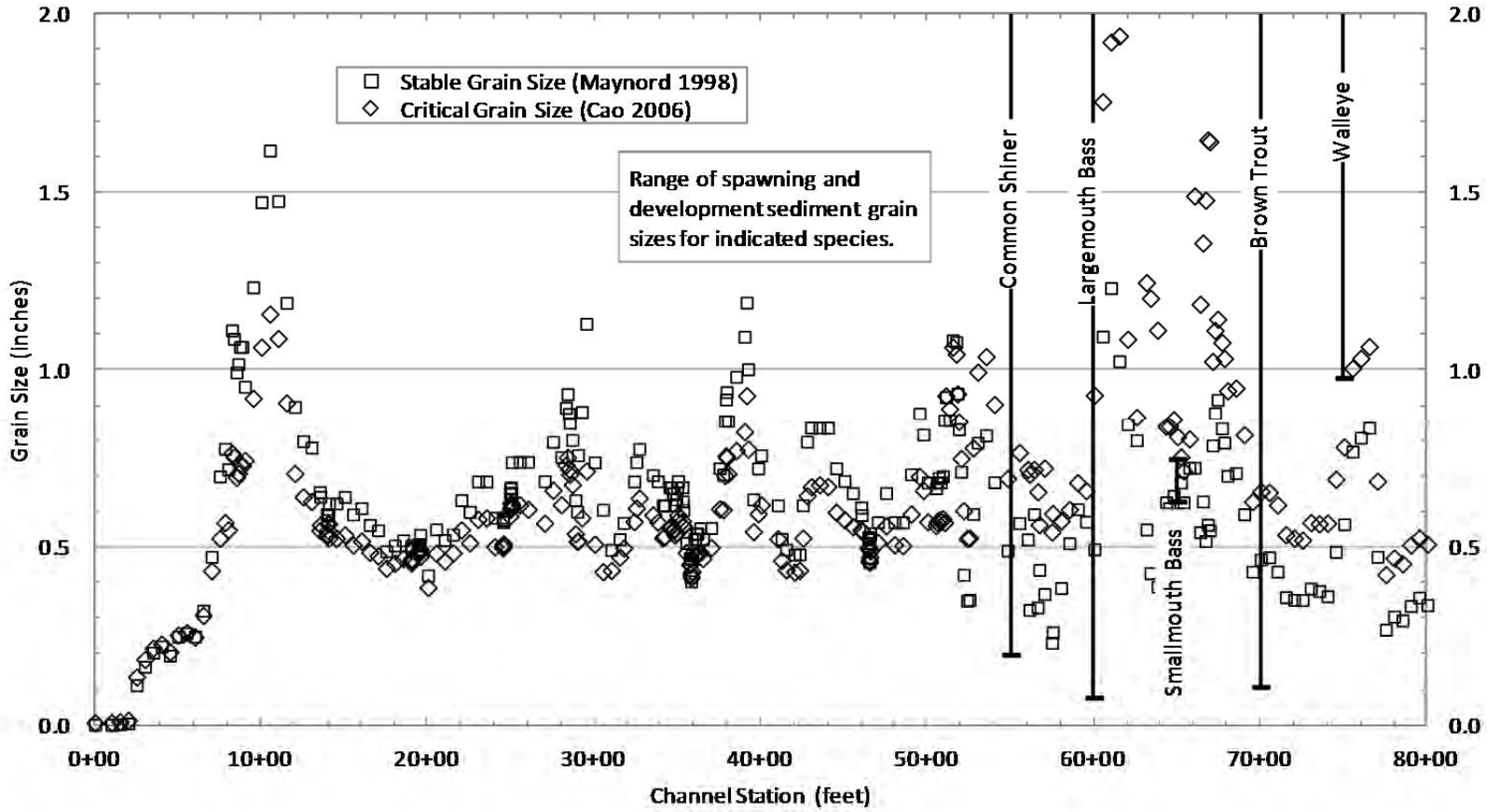


Figure D-1

Proposed Conditions Critical Grain Size, 10-year Return Period Flow, Design Lake Level

Notes:
Ten-year return period flow is 2000 cubic feet per second (cfs), design lake level is 367 feet North American Vertical Datum of 1988 (NAVD88). For Cao et al. (2006), critical grain size was determined using a critical dimensionless shear stress of 0.045. A factor of safety of 1.1 was applied to Maynord's stable grain size calculations (Palermo et al. 1998).

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Design-Analysis\Sediment_Transport\Stable_Sed_Size-Transport_Rate_Calc_10yr_DL.xlsx Tab: Plots_BG 3/14/2012 JRG

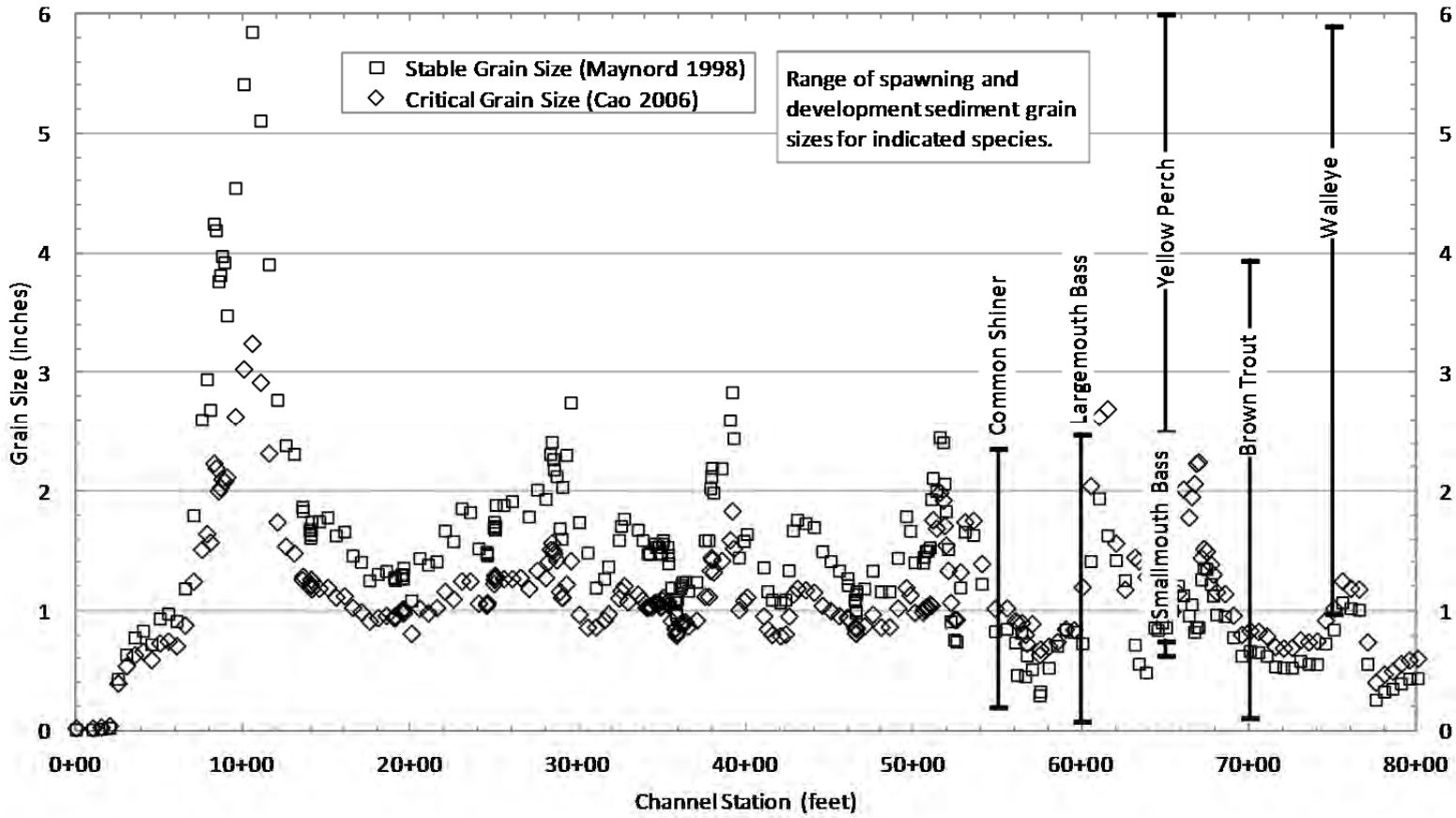


Figure D-2

Proposed Conditions Critical Grain Size, 100-year Return Period Flow, Low Lake Level

Notes:
One-hundred-year return period flow is 3400 cfs, low lake level is 367 feet NAVD88. For Cao et al. (2006) critical grain size was determined using a critical dimensionless shear stress of 0.045. A factor of safety of 1.1 was applied to Maynord's stable grain size calculations (Palermo et al. 1998).

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Design-Analysis\Sediment_Transport\Stable_Sed_Size-Transport_Rate_Calc_100yr_LL.xlsx **Tab: Plots_BG 3/14/2012 JRG**

Based on data evaluated as part of the Remedial Design Elements for Habitat Restoration[1] (Parsons 2009), the depth of biological activity will likely be limited to the top 6 inches of the sediment for the organisms anticipated to use the creek channel (i.e., fish and benthic macroinvertebrates). Submerged aquatic vegetation, while not currently planned for the channel, is also limited to the top 6 to 12 inches of the sediment. As such, 24 inches (placed minimum thickness) of suitable habitat and erosion protection material will be appropriate to support organisms using the creek and provide erosion protection.

[1] A document prepared to support the Onondaga Lake remedy.

D.3 STABLE GRAIN SIZES

The stability of the proposed habitat and erosion protection material was evaluated to satisfy the USEPA's *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA 2005) that states the following:

> *"[t]he design of the erosion protection features of an in-situ cap (i.e., armor layers) should be based on the magnitude and probability of occurrence of relatively extreme erosive forces estimated at the capping site. Generally, in situ caps should be designed to withstand forces with a probability of 0.01 per year, for example, the 100-year storm."*

Based on this guidance, the Hydraulic Engineering Center – River Analysis System (HEC-RAS) hydraulic model for the proposed channel (see Attachment C of the main report) was used to compute the spatial distributions of current velocities, bed shear stresses and water depths in the channel for 100-year flood events[2]. Specifically, these parameters were computed at all transects representing the restored channel conditions. Stable grain sizes were computed at each transect location using the following two methods:

- Maynord's equation from USEPA's *Guidance for In-Situ Subaqueous Capping of Contaminated Sediment* (Palermo et al. 1998), which uses current velocity and water depth for flood conditions and was modified from method EM 1110-2-1601 (USACE 1994)
- The dimensionless Shields diagram (i.e., critical shear stress) as presented by Cao et al. (2006)

These two methods were used to evaluate stable grain sizes and are described in Sections D.3.1 and D.3.2, respectively. Findings from the analyses are presented in Section D.3.3.

[2] The 10-year flood event was also simulated for comparative purposes.

D.3.1 Maynord's Equation

Maynord's equation is presented in Palermo et al. (1998) and is based on the USACE's "Hydraulic Design of Flood Control Channels" (USACE 1994). The following method uses current velocity and water depth to determine the median grain size (D_{50}) of the erosion protection layer (Palermo et al. 1998):

$$D_{50} = S_f C_s C_v C_T C_G d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{1/2} \frac{V}{\sqrt{K_1 g d}} \right]^{2.5} \quad (1)$$

where:

D_{50}	=	median grain size in feet
S_f	=	safety factor = 1.1 (page A-6 from Palermo et al. 1998, and page 3-6 from USACE 1994)
C_s	=	stability coefficient for incipient failure = 0.375 for rounded rock (page A-6 from Palermo et al. 1998). A value of 0.375 representing rounded rock was selected. This value provides a conservative estimate of the median grain size compared with angular rock (a value of 0.30).
C_V	=	velocity distribution coefficient = 1.0 for straight channel, inside of bends and = 1.283-.2$log(R/W)$ for outside of bends (1 for $R/W > 26$) (page A-6 from Palermo et al. 1998)
C_T	=	blanket thickness coefficient (typically 1 for flood conditions; page A-6 of Palermo et al. 1998)
C_G	=	gradation coefficient = $(D_{85}/D_{15})^{1/3}$
D_{85}/D_{15}	=	gradation uniformity coefficient (typical range = 1.8 to 3.5) = 3.5 (page A-6 from Palermo et al. 1998). A value of 3.5 was selected for this analysis. This value is the closest to representing a wide grain size distribution suitable for habitat while staying within the limitations of the equation.
R	=	centerline radius of bend
W	=	water surface width at upstream end of bend
d	=	water depth in feet

γ_s	=	unit weight of stone = 165 pounds per cubic foot (lbs/ft^3; page A-6 of Palermo et al. 1998)
γ_w	=	unit weight of water = 62.4 lbs/ft^3
V	=	maximum depth-averaged velocity in feet per second
K_1	=	side slope correction factor = computed to be 0.801 using page 3-7 from USACE 1994
g	=	acceleration due to gravity = 32.2 feet per square second (ft/s^2)

Maynord's equation was developed for the reasonably uniform grain size gradations that are typical of armor stone. The typical range for the gradation uniformity coefficient (D_{85}/D_{15}) of well-graded (i.e., wide grain size distribution) sediment is considerably larger than the range of values for which Maynord's equation is applicable. A gradation coefficient larger than the range of values for which Maynord's equation is applicable will over-predict the stable median grain size, providing overly conservative findings. Therefore, a second method was used to evaluate the stable grain sizes independent of a gradation uniformity coefficient.

D.3.2 Cao's Modified Shields Diagram for Critical Grain Size

This method uses the Shields diagram presented in Vanoni (1975) as modified by Cao et al. (2006). The Cao et al. (2006) approach uses the following relationship between critical grain size (D_c) and critical dimensionless shear stress (τ^*_c):

$$\tau^*{}_c = \frac{\tau}{(\rho_s - \rho) g D_c} \tag{2}$$

where:

τ	=	bed shear stress
ρ_s	=	sediment grain density
ρ	=	water density

For this evaluation, a critical dimensionless shear stress (τ^*_c) value of 0.045 was used (Cao et al. 2006). This value is valid for critical grain sizes in the gravel size range and is conservative for larger critical sediment grain sizes. No factor of safety is implicit in these

calculations; therefore, compared to Maynord's equation, this method provides a lower bound for the stable grain size.

D.3.3 Findings

Findings of the stable and critical grain size evaluations are presented in Figure D-1 and Figure D-2. Generally, the stable grain sizes predicted using the Maynord and Cao equations range from medium sand to coarse gravel for the majority of Ninemile Creek (i.e., D_{50} of less than 0.1 to 1 inch). The maximum predicted stable grain sizes occur in localized areas, such as creek banks on the outside of channel bends or near bridge abutments or footings (e.g., D_{50} of 2 to 6 inches). Therefore, larger material or other stabilization methods are required in some locations. However, Maynord's method tends to over-predict the stable grain size for a well-graded sediment grain size distribution, and the actual maximum stable grain size shown in Figure D-2 is more closely predicted by Cao's equations. The stable grain sizes predicted using Cao's equations are consistent with the habitat and erosion protection material gradation shown in Table D-1. Additionally, the stable grain sizes predicted using Maynord's equation are consistent in a majority of the channel, given the range allowed for the habitat and erosion protection material gradation. Based on findings presented herein, the proposed habitat and erosion protection layer material satisfies the USEPA's guidance for erosion protection layers used as an in-situ cap. To further support the design of the habitat/erosion protection layer, a detailed analysis of the sediment transport characteristics of the material gradation is presented in Section 4. Overall, these results support the performance objectives of the channel bed material listed in section D.1.

D.4 SEDIMENT TRANSPORT

The ability of the stream to transport various grain sizes was evaluated using two approaches. These analyses provide an estimate of the sediment transport capacity in Ninemile Creek for grain sizes smaller than the stable grain size. Findings from these analyses provide an indication of the creek's ability to suspend and transport fine grained sediment that could otherwise lead to siltation, and the degree of self-sorting that can be expected.

The 1-year high-flow event was used for this analysis because it is often similar to the effective discharge and demonstrates the types of material that would be routinely transported through the system. Over time, discharges similar to the 1-year high-flow event (750 cubic feet per second [cfs]) are likely to be the most effective in influencing channel morphology. This concept of effective discharge was first presented by Wolman and Miller (1960) and has become generally accepted in channel morphology. This concept asserts that the moderate sediment transport rates during relatively frequent high-flow events move more total sediment over time than the high sediment transport rates during the relatively rare high-flow events (e.g., 10- or 100-year floods).

D.4.1 Sediment Transport Capacity

The sediment transport capacity in Ninemile Creek was analyzed for the 1–year high-flow event using representative grain sizes that are assumed to currently be present in the sediment bed. Four sediment transport models were used in this analysis: 1) Wilcock and Crowe (2003); 2) Wilcock (2001); 3) Meyer-Peter and Müller (1948, as modified by Wong and Parker 2006); and 4) Cui (2007). See the references for a presentation and explanation of each sediment transport model. These models are most appropriate for coarse sediment systems, with median grain sizes (D_{50}) larger than 2 mm (0.08 inches).

The sediment transport models were used to calculate the spatial distribution of dimensionless transport rate (W^*) in Ninemile Creek during the 1-year flow event. This information was used to calculate to the sediment mass transport rate (Q_b) as follows:

$$Q_b = \frac{W^* B {u^*}^3 \rho_s}{(s-1)g} \tag{3}$$

where:

W^*	=	dimensionless transport rate
B	=	transport width
u^*	=	shear velocity ($u^* = \sqrt{\tau/\rho_w}$)
τ	=	shear stress
ρ_w	=	fluid density
ρ_s	=	sediment grain density
s	=	sediment specific gravity
g	=	gravitational acceleration

Findings from this analysis are presented in Figure D-3, which shows the amount of sediment of different grain sizes (pound per foot per second [lb/ft/s]) that could be transported during the 1–year flow event.[3] For comparative purposes, the sediment mass transport rate was separated into three categories:

- Significant transport: 1 to 10 lb/ft/s
- Moderate transport: 0.1 to 1 lb/ft/s
- Minor transport: 0.01 to 0.1 lb/ft/s

[3] The estimates are generally conservative in terms of over-predicting transport rate for sediment grain sizes smaller than 2 millimeters (mm). As such, the transport rate calculated for the 0.04 inch material may be slightly overestimated.

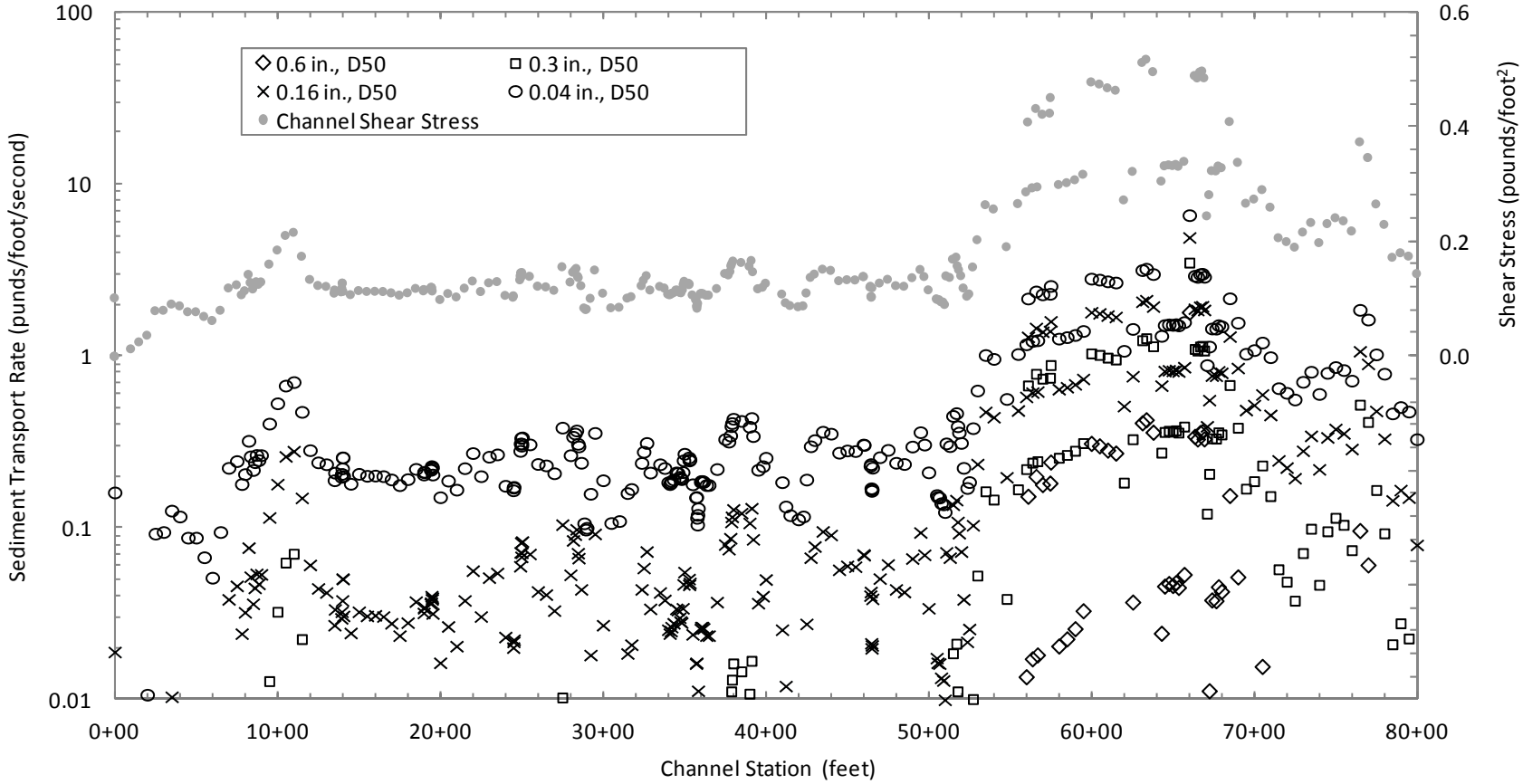


Figure D-3

Proposed Conditions Sediment Transport Rate, 1-year Return Period Flow, Design Lake Level

Notes:
One-year return period flow is 750 cfs, design lake level is 362.5 feet NAVD88. Transport rate is the average of several well established transport models for coarse sediments. The model provides conservative estimates for sediments finer than 2 mm (0.08 inches).

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Design-Analysis\Sediment_Transport\Stable_Sed_Size-Transport_Rate_Calc_1yr_DL.xlsx Tab: Plots_BG 3/14/2012 JRG

A significant transport rate is representative a highly mobile bed condition where bed scour and subsequent sediment deposition is very likely. A moderate transport rate is representative of a visibly mobile bed condition where selective transport and deposition of finer grain size fractions is likely. A minor sediment transport rate is repetitive of an intermittently mobile bed with larger grain size fractions likely remaining immobile.

D.4.2 Fractional Sediment Transport

The sediment grain size distribution used for this analysis is based on material available from a local glacio-fluvial source (see Section 4) with a wide grain size distribution that meets the stability requirements established in this document. The fractional bed load sediment transport model developed by Wilcock and Crowe (2003) was applied to a specific sediment grain size distribution to determine the fraction of that material that would be transported during the 1-year flow event. The anticipated surface grain size distribution range, based on the values shown in Table D-1 along with additional intermediate grain size classification points, was used as input for the transport analysis.

The Wilcock and Crowe (2003) model uses a transport rate formulation that is similar to the approach described in the previous section, but it calculates the transport rate for each specified grain size class. The model accounts for the interaction between different grain size classes. The model uses the entire size distribution of the bed surface to incorporate the nonlinear effect of sand content on gravel transport rate.

Findings from this analysis are presented in Figure D-4. This figure shows the proposed surface grain size distribution range (shaded area), as well as the grain size distribution of the material that would be transported as bed load during 1-, 10-, and 100-year high-flow events. The grain size distribution of material transported during the 100-year high-flow event corresponds to an upper-bound limit. The hydraulic conditions for each profile are averaged over the entire channel length for presentation clarity.

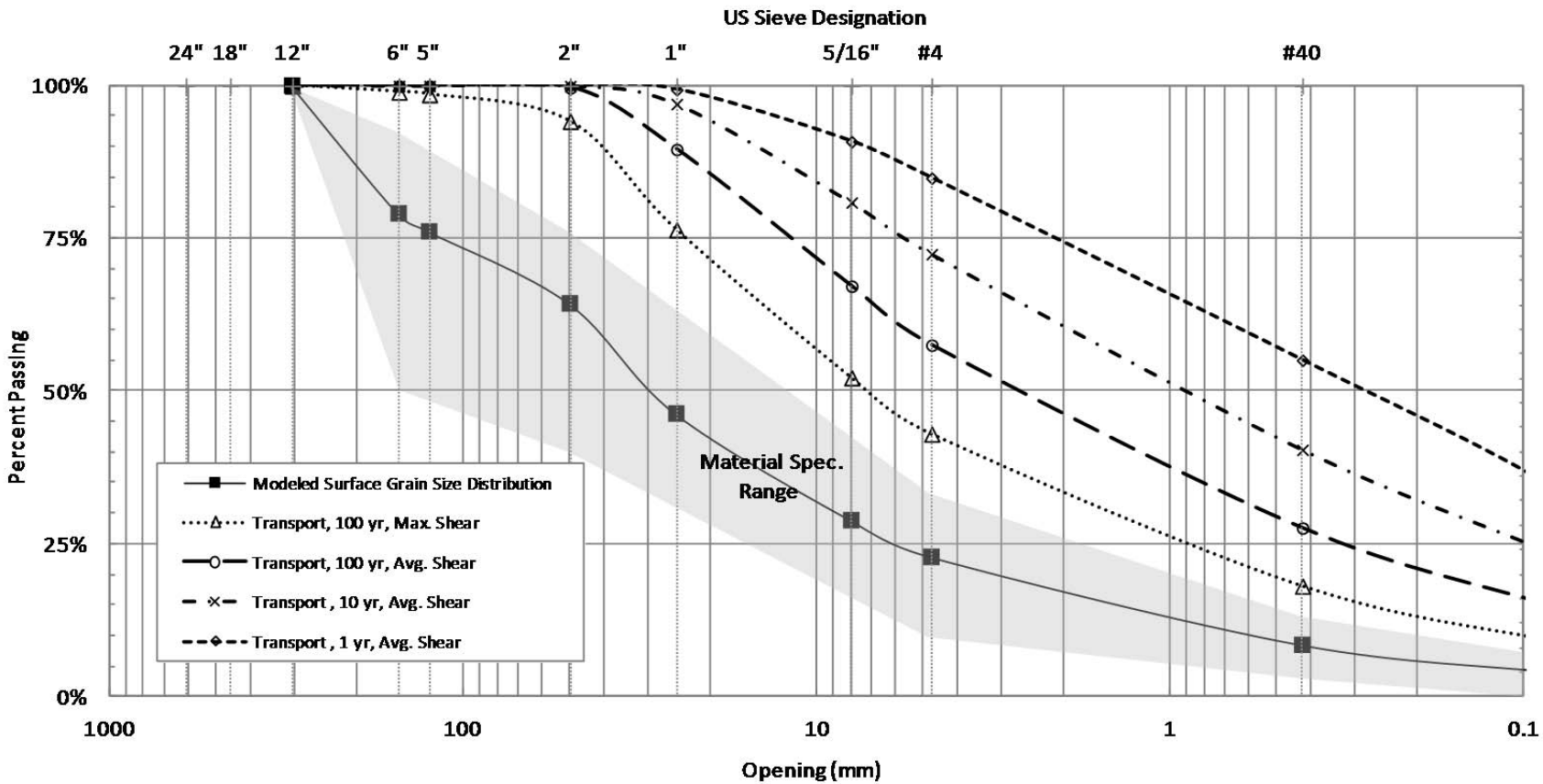


Figure D-4

Fractional Sediment Transport Grain Size Distributions and Proposed Grain Size Distribution Range

Notes:

Bed load sediment transport rates calculated using Wilcock and Crowe's (2003) mixed grain size coarse sediment transport model.

Shaded zone is the material gradation range for the proposed erosion protection and habitat layer shown in Table D-1. Surface sediment grain size distribution used in transport calculations is the anticipated grain size distribution. Transport is modeled for the indicated return period flow and the average or maximum channel shear stress as indicated. The 100-year flow uses the low lake level for a more conservative estimate of channel shear stress.

B:\Projects\Honeywell\Nine Mile Creek (090139-01)\NMC_100pct_Design\Design-Analysis\Sediment_Transport\iSURF\iSURF_v2.0alpha.xls Tab: SBTM 3/14/2012 JRG

D.4.3 Findings

Findings from the sediment transport analysis shown on Figure D-3 indicate that the creek is capable of transporting a significant amount of sediment (on the order of 1 lb/ft/s) finer than 0.04 inches (representative of medium sand) along the entire channel length during a 1-year flow event. This result indicates that finer grained material that deposits on the creek bed during low-flow periods will be resuspended and transport during the 1-year flow event (i.e., annually), which will reduce the potential for silt buildup and increase sediment surface heterogeneity.

Findings from the sediment transport analysis also indicate that the creek will do the following:

- Transport a moderate amount (on the order of 0.1 to 1 lb/ft/s) of sediment with a median grain size of 0.16 inches (representative of very fine gravel) along the entire channel length (i.e., the channel will erode and transport material finer than 0.16 inches once a year, removing silts and fine sand)
- Transport a moderate amount (on the order of 0.1 to 1 lb/ft/s) of sediment with a median grain size of 0.3 inches (representative of fine gravel) in the upper portion of the channel and other isolated locations

These transport rates and grain sizes give an indication of how sediment from upstream may be transported and deposited in the channel during a 1-year high-flow event. Sediment smaller than the stable grain size deposited in the system during 1-year high-flow events is anticipated to be transported through the system during larger high-flow events.

Findings from the fractional sediment transport model indicate that the surface will self sort as smaller grain sizes (typically sand-sized material) are transported away, without significant loss of layer thickness, leaving an armor layer of gravel and cobble-sized material. As shown on Figure D-4, approximately 55% of the material transported as bed load during a 1-year flow event is smaller than the #40 sieve (0.0165 inches), indicating that the majority of finer grained sediment will move through the system. This analysis demonstrates that the system

will be capable of selectively transporting, and later depositing[4] in other locations, various grain sizes to create a diverse surface sediment grain size distribution, while maintaining a stable channel bed over a wide range of flow events. This self sorting will increase surface heterogeneity, thereby improving habitat value and creating a more stable surface layer. During the 1- and 10-year high-flow events, the findings indicate minimal transport of material larger than the median grain size and no transport of material larger than 2 inches (Figure D-4). Findings also indicated that, during the 100-year high-flow event, locations with the highest bed shear stress may transport some material larger than the median grain size (Figure D-4). Therefore, these areas will be protected with the placement of large stone to preclude the possibility of erosion. Additionally, this analysis conservatively assumes that the surface grain size distribution is the same as the bulk grain size distribution, representative of post-construction conditions. Given that the channel surface is expected to generally self armor during 1- to 10-year high-flow events that may occur prior to a 100-year high-flow event, the sediment transport rate may be reduced during that larger flow. Overall, these results are consistent with the maximum stable grain size of approximately 6 inches (Figure D-2) and show that there is a significant factor of safety against erosion and transport of the coarser fraction of the habitat and erosion protection layer. Overall, these results support the performance objectives of the channel bed material listed in section D.1.

[4] Deposition will likely occur as sediment grains are transported into areas where shear stresses are lower than that required for transport.

D.5 REFERENCES

Cao, Z., G. Pender, J. Meng, 2006. Explicit Formulation of the Shields Diagram for Incipient Motion of Sediment. *Journal of Hydraulic Engineering* 132(10):1097-1099.

Cui, Y., 2007. The Unified Gravel-Sand (TUGS) Model: simulating sediment transport and gravel/sand grain size distributions in gravel-bedded rivers. Water Resources Research 43, W10436.

Meyer-Peter, E. and R. Müller, 1948. *Formulas for bed-load transport*. Proceedings, 2nd Congress International Association for Hydraulic Research. Stockholm, Sweden: 39-64.

Palermo, M., S. Maynord, J. Miller, and D. Reible, 1998. *Guidance for In-Situ Subaqueous Capping of Contaminated Sediments.* EPA 905-B96-004, Great Lakes National Program Office, Chicago, Illinois.

Parsons, 2009. *Remedial Design Elements for Habitat Restoration*. Prepared by Parsons, Liverpool, New York, in association with Anchor QEA, Exponent, O'Brien and Gere, and SUNY-ESF, for Honeywell, East Syracuse, New York. December.

Parsons, 2010. Statement of Work. Ninemile Creek Remedial Design. Prepared for Honeywell. September.

United States Army Corps of Engineers (USACE), 1994. *Hydraulic Design of Flood Control Channels. Engineering Manual EM 1110-2-1601.* U.S. Army Corps of Engineers. Washington, D.C.

United States Environmental Protection Agency (USEPA), 2005. *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites.* EPA-540-R-05-012, Office of Solid Waste and Emergency Response.

Vanoni, V.A., 1975. *Sedimentation Engineering.* ASCE Manuals and Reports on Engineering Practice – No. 54, 730 pp.

Voshell, J.R., Jr., 2002. *A guide to common freshwater invertebrates of North America*. The McDonald & Woodward Publishing Company. Blacksburg, Virginia. 442 pp.

Wilcock, P.R., 2001. Toward a practical method for estimating sediment-transport rates in gravel-bed rivers. *Earth Surface Processes and Landforms* 26(13):1395-1408.

Wilcock, P.R. and J.C. Crowe, 2003. Surface-based transport model for mixed-size sediment. *Journal of Hydraulic Engineering* 129(2):120-128.

Wolman, M.G., and J.P. Miller, 1960. Magnitude and frequency of forces in geomorphic processes. *Journal of Geology* 68:54-74.

Wong, M. and G. Parker, 2006. Reanalysis and correction of bed-load relation of Meyer-Peter and Müller using their own database. *J. Hydr. Engrg.* 132(11):1159-1168.