APPENDIX G: HSC HISTOGRAM PLOTS

APPENDIX H: PERIODICITY TABLES

APPENDIX I: LOWER RIVER HYDRAULIC MODEL CALIBRATION

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fish and Aquatics Instream Flow Study (8.5)

Appendix G
HSC Histogram Plots

Initial Study Report

Prepared for

Alaska Energy Authority

Prepared by

R2 Resource Consultants, Inc.

February 2014 Draft

LIST OF FIGURES

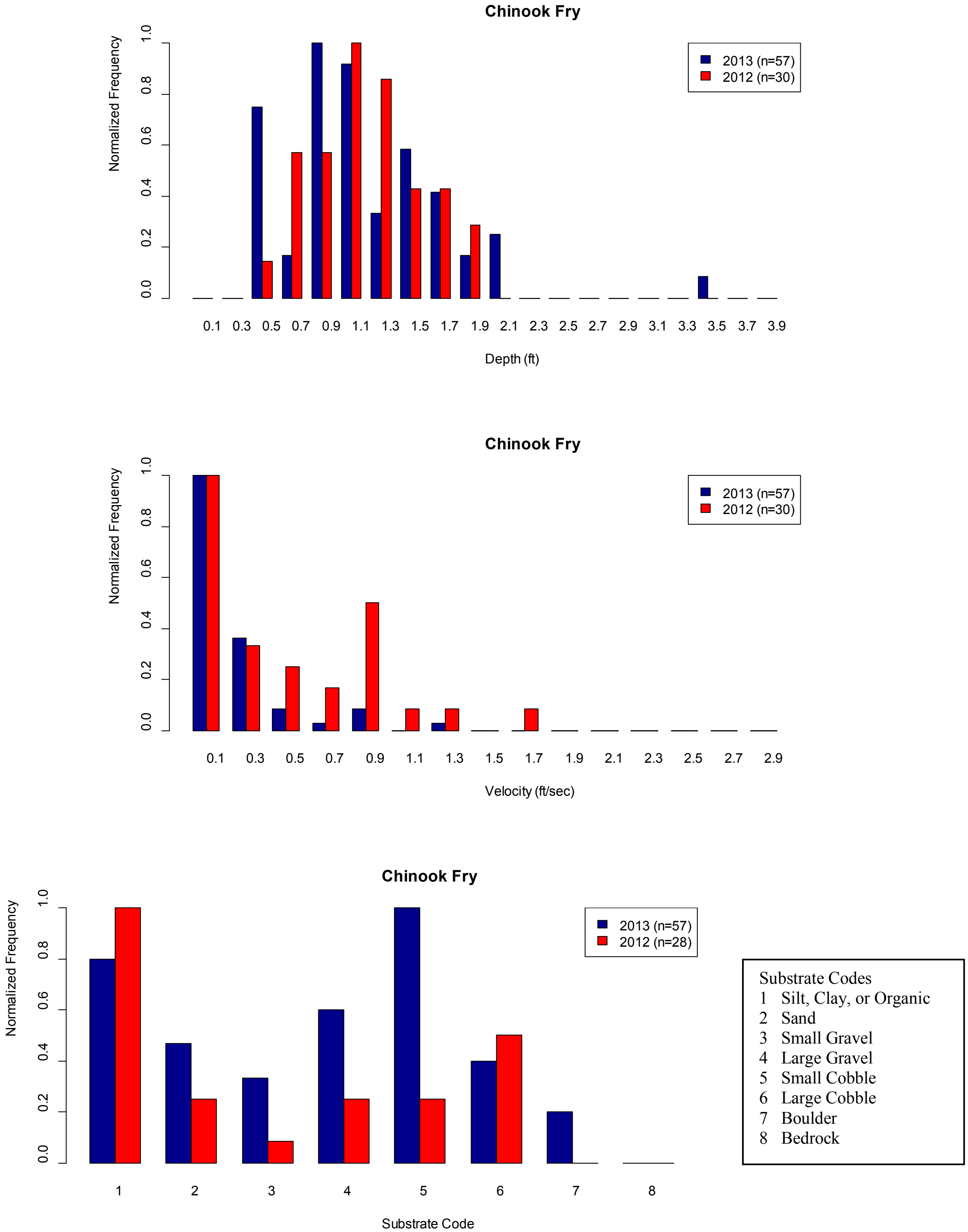


Figure 1. Histogram plots of 2012 and 2013 HSC observations for fry life stage of Chinook salmon normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

Notes:

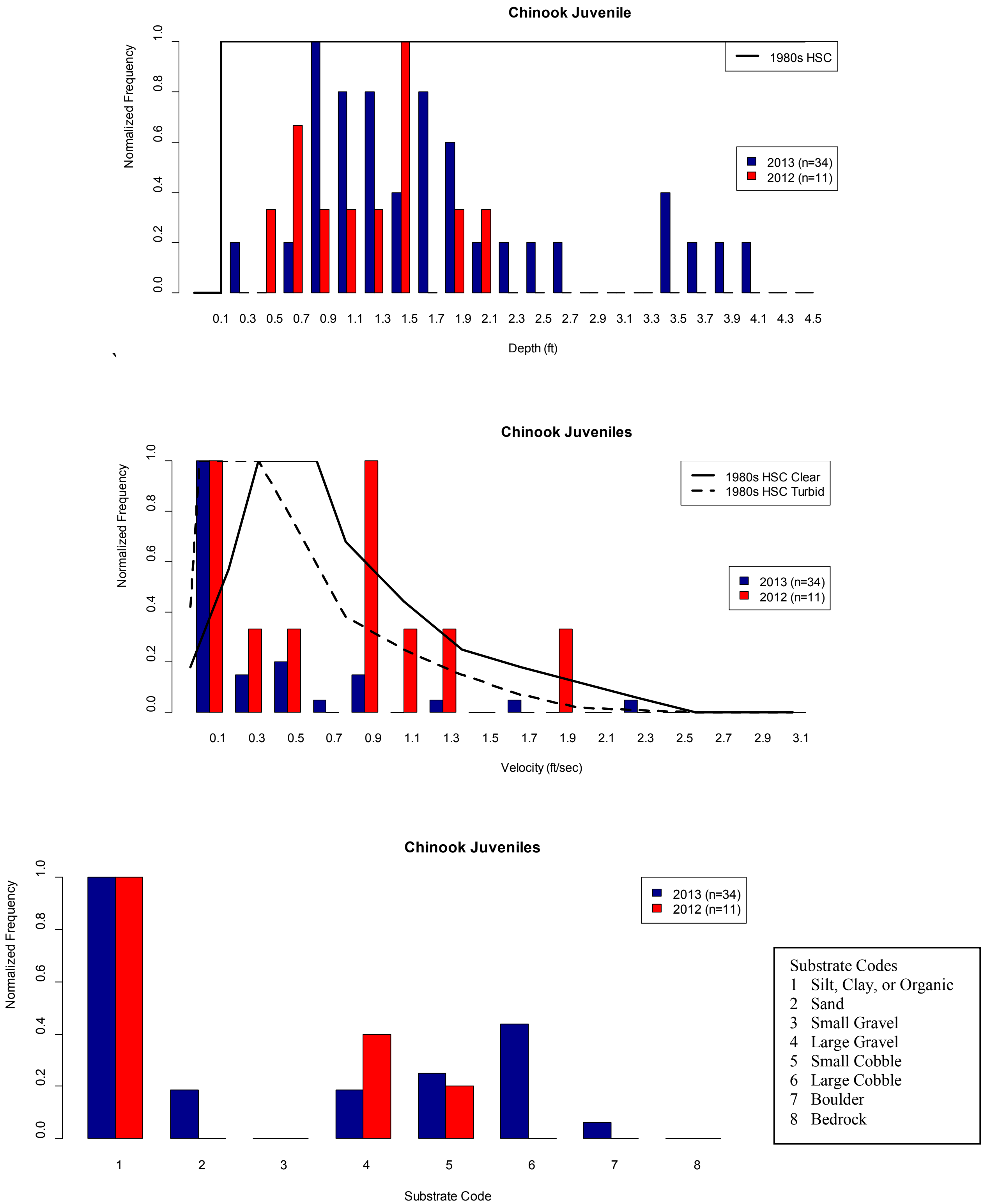


Figure 2. Histogram plots of 2012 and 2013 HSC observations for juvenile life stage of Chinook salmon normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

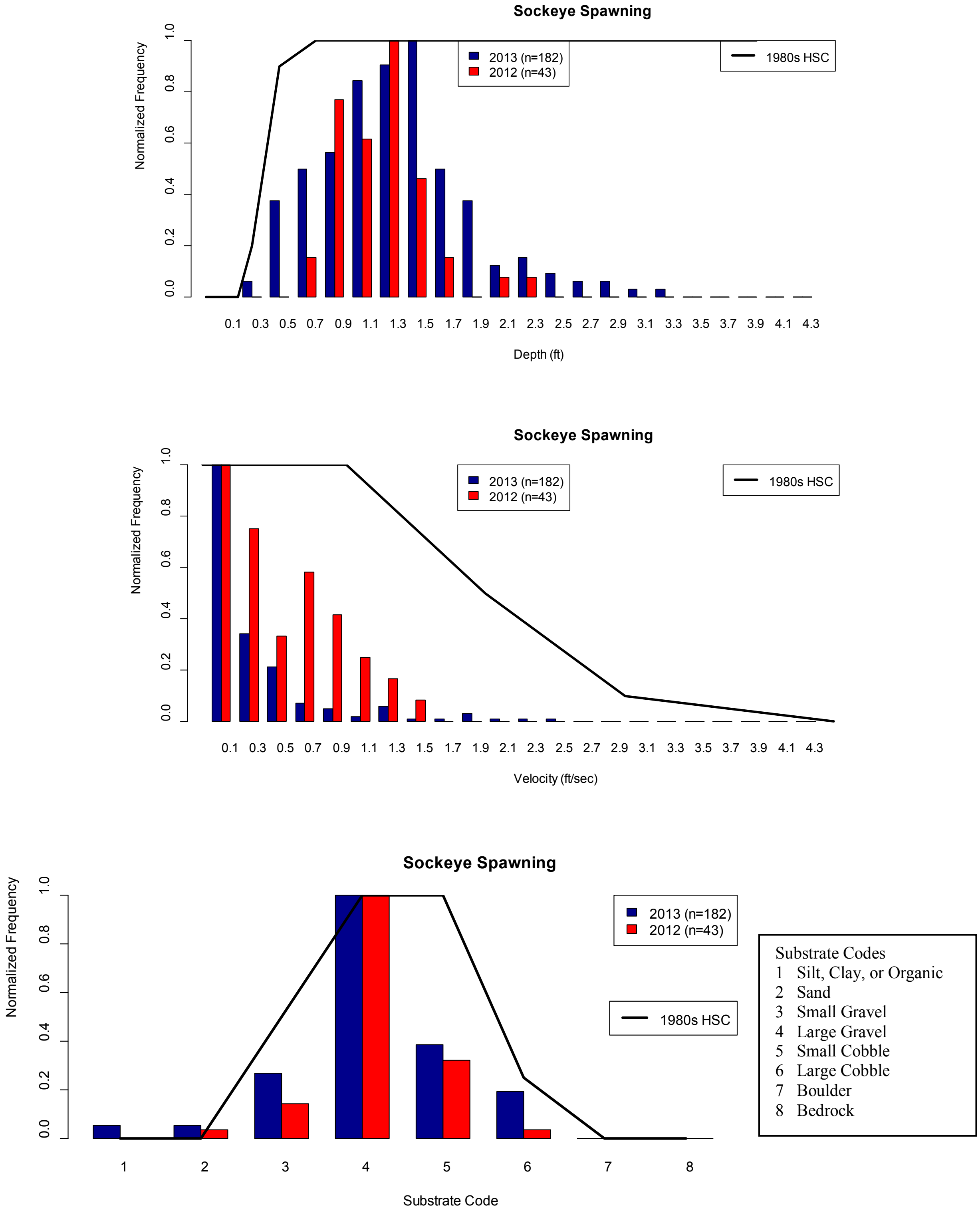


Figure 3. Histogram plots of 2012 and 2013 HSC observations for spawning life stage of sockeye salmon normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

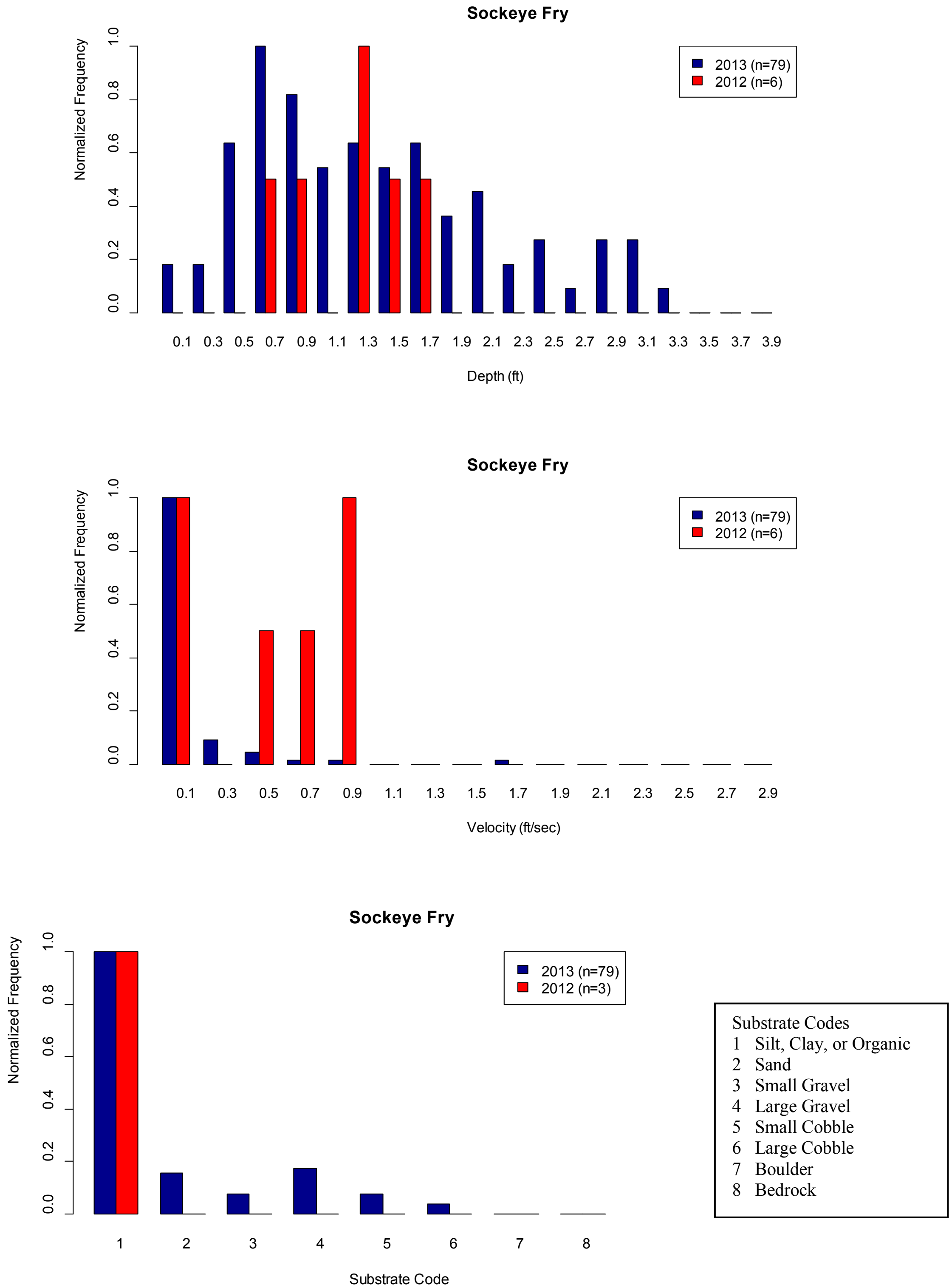


Figure 4. Histogram plots of 2012 and 2013 HSC observations for fry life stage of sockeye salmon normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

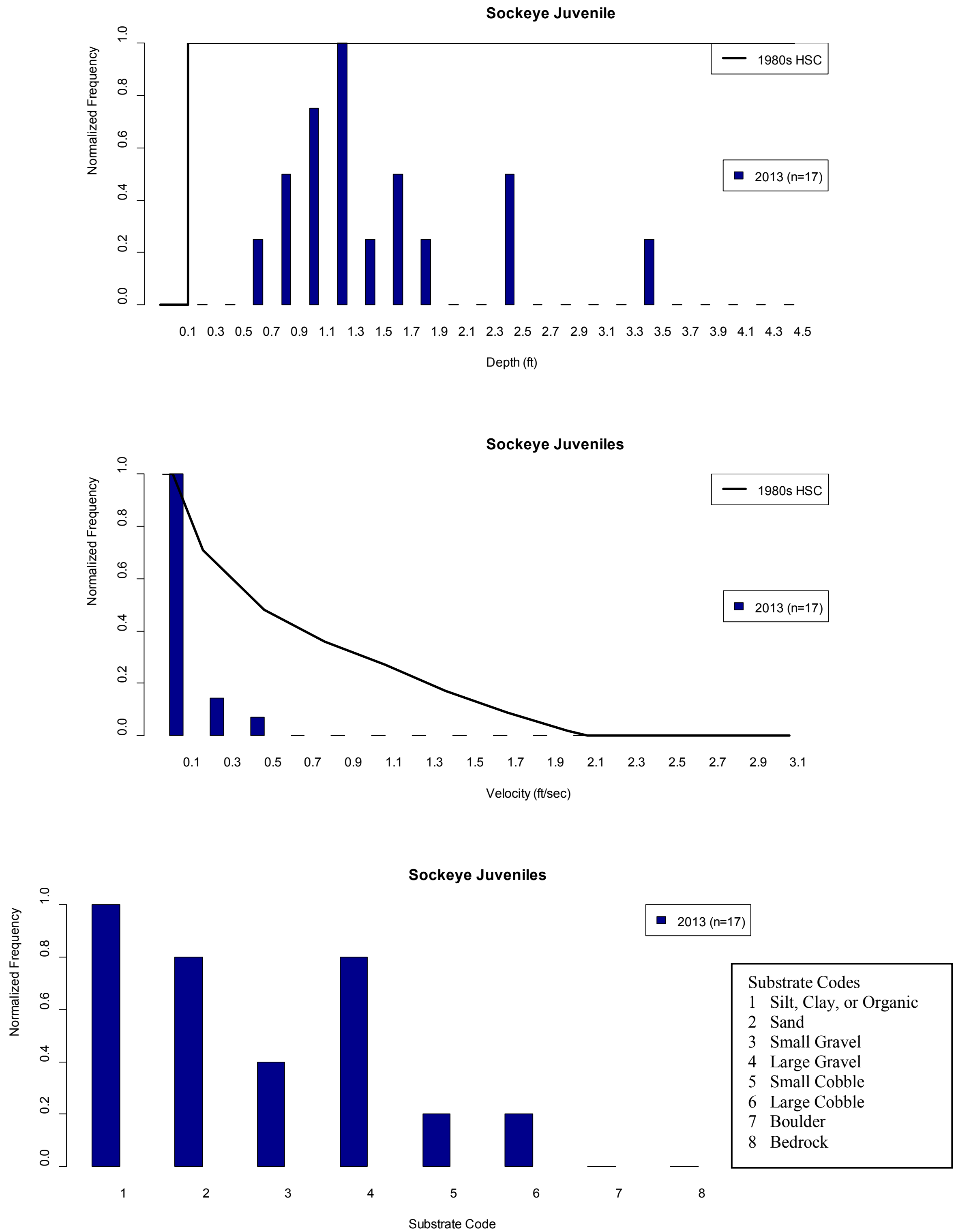


Figure 5. Histogram plots of 2012 and 2013 HSC observations for juvenile life stage of sockeye salmon normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

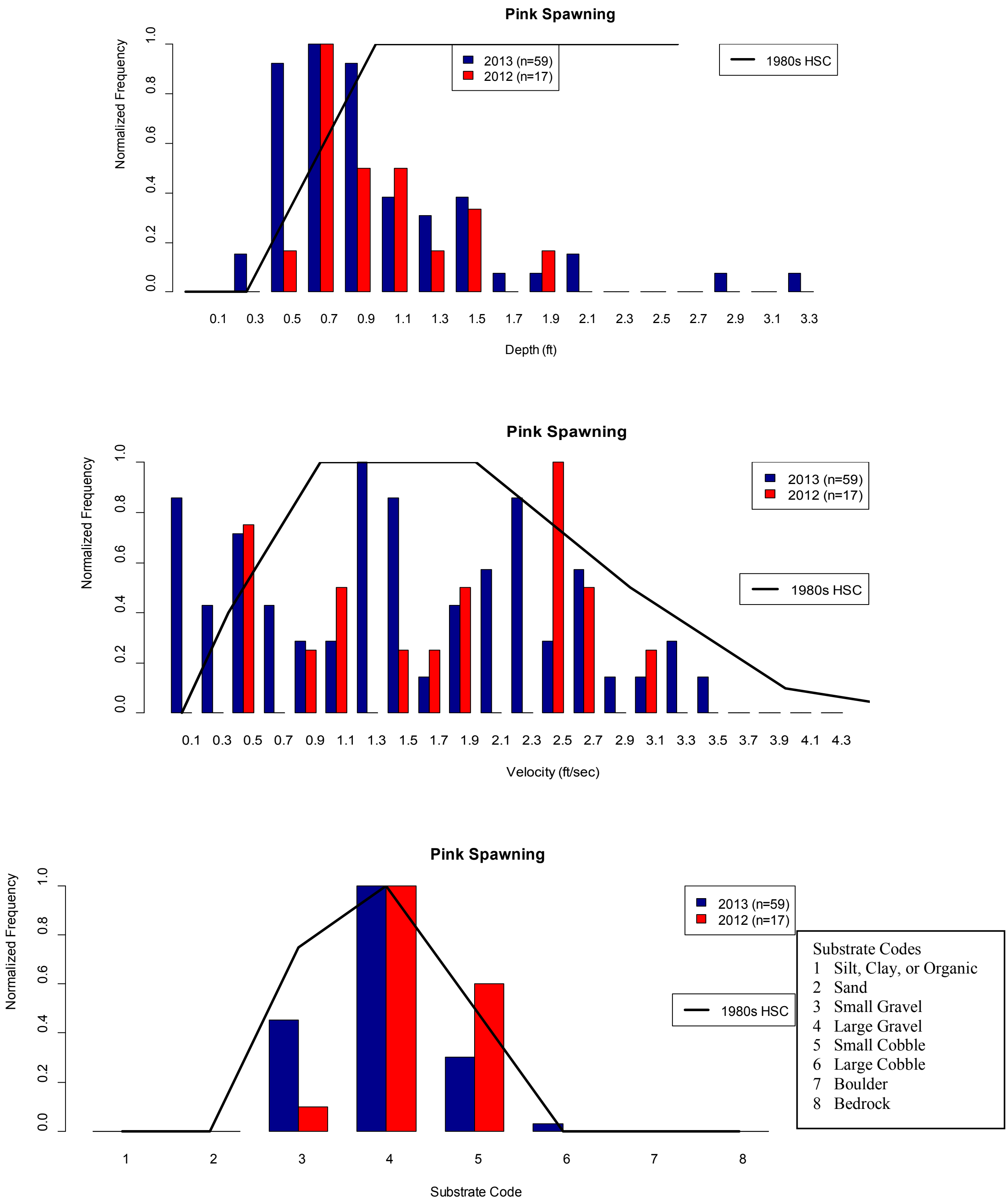


Figure 6. Histogram plots of 2012 and 2013 HSC observations for spawning life stage of pink salmon normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

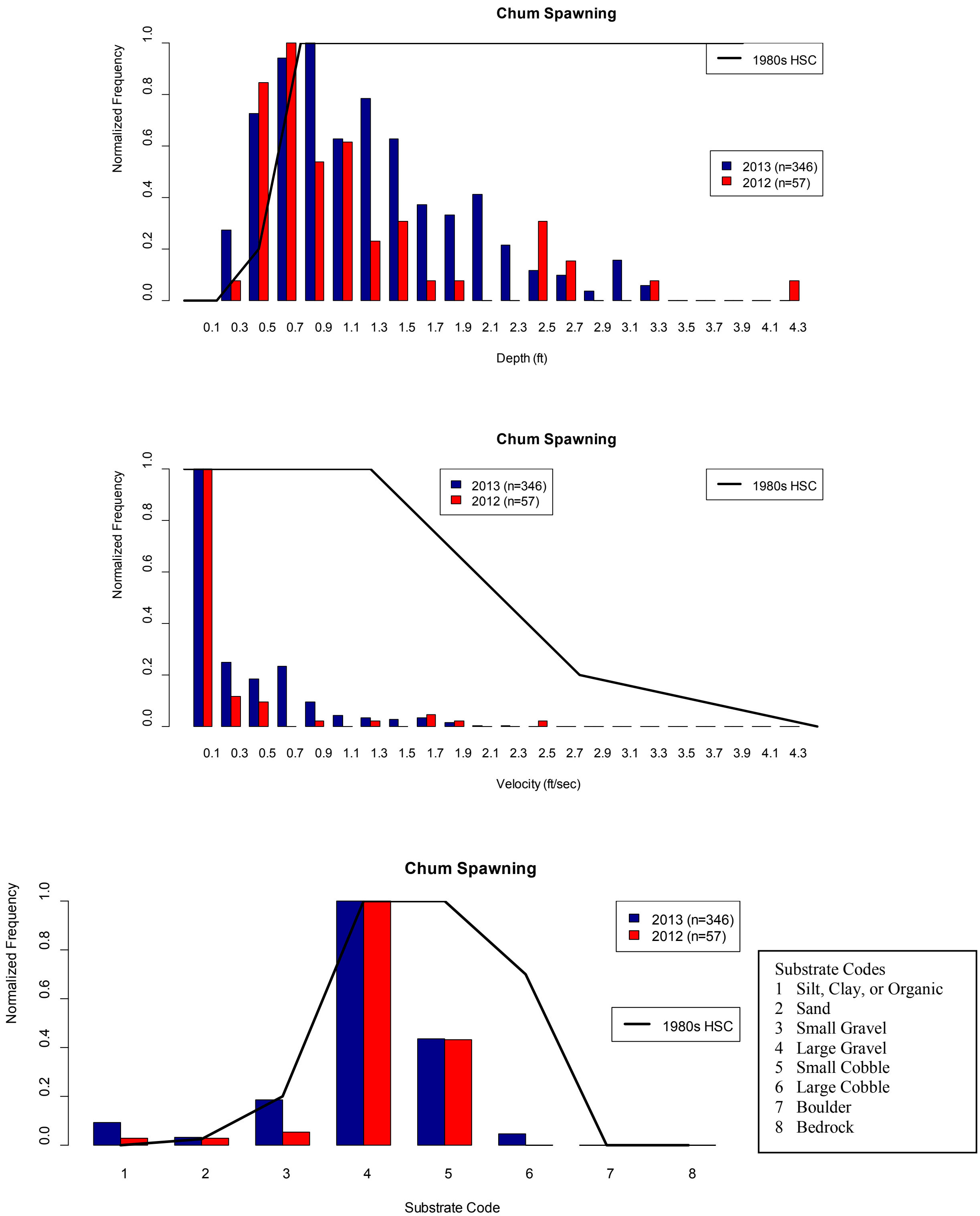


Figure 7. Histogram plots of 2012 and 2013 HSC observations for spawning life stage of chum salmon normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

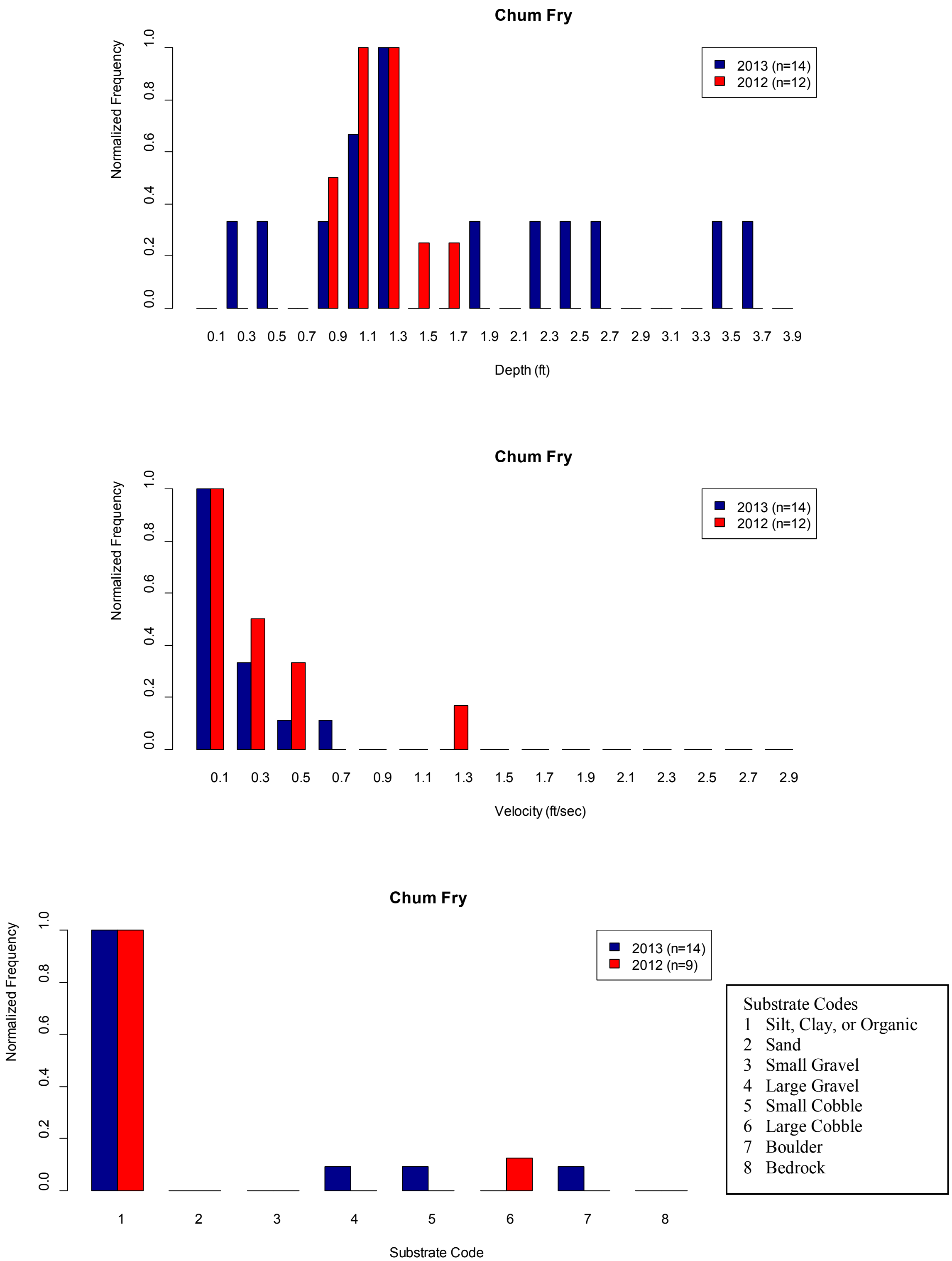


Figure 8. Histogram plots of 2012 and 2013 HSC observations for fry life stage of chum salmon normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

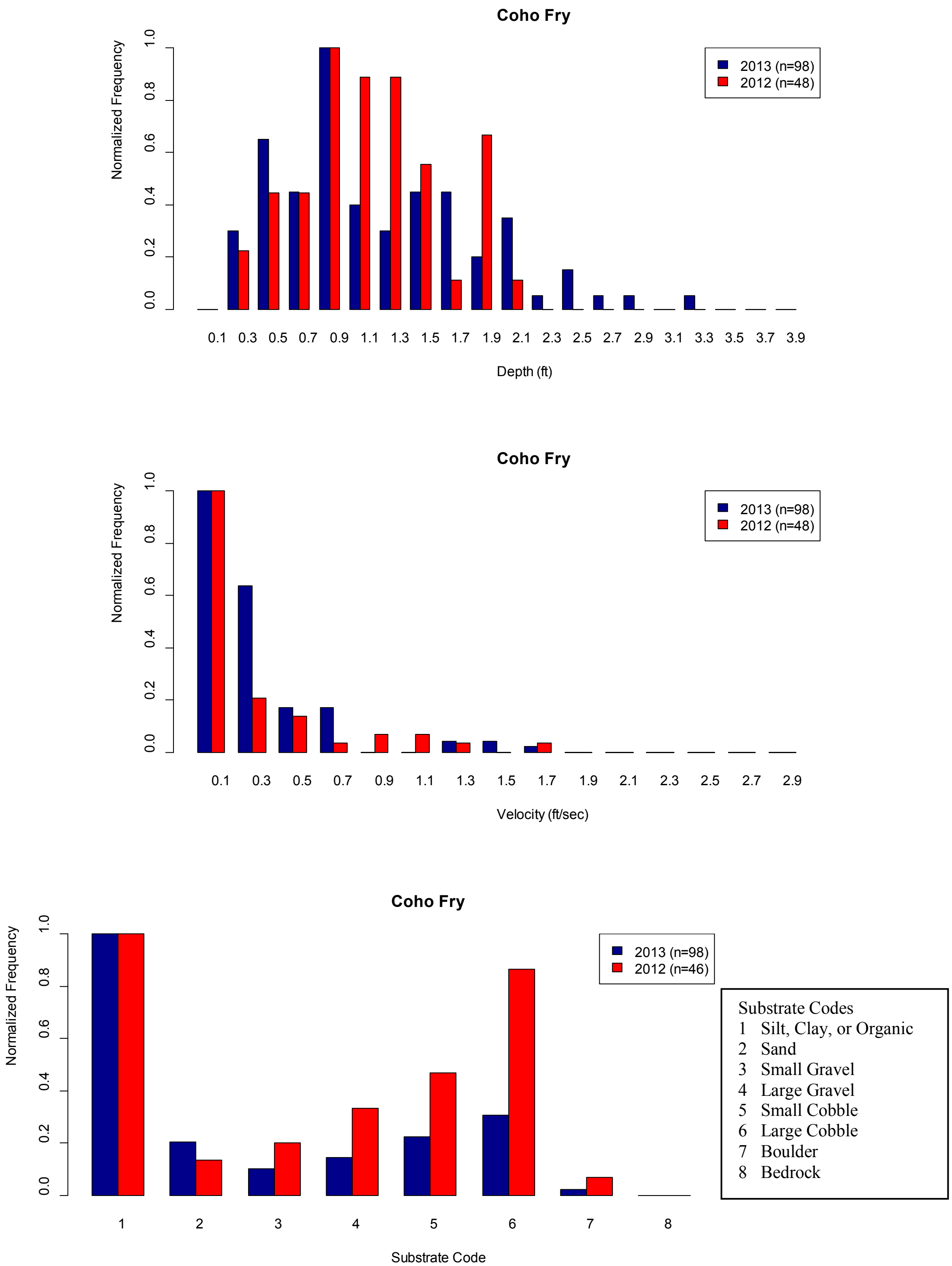


Figure 9. Histogram plots of 2012 and 2013 HSC observations for fry life stage of coho salmon normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

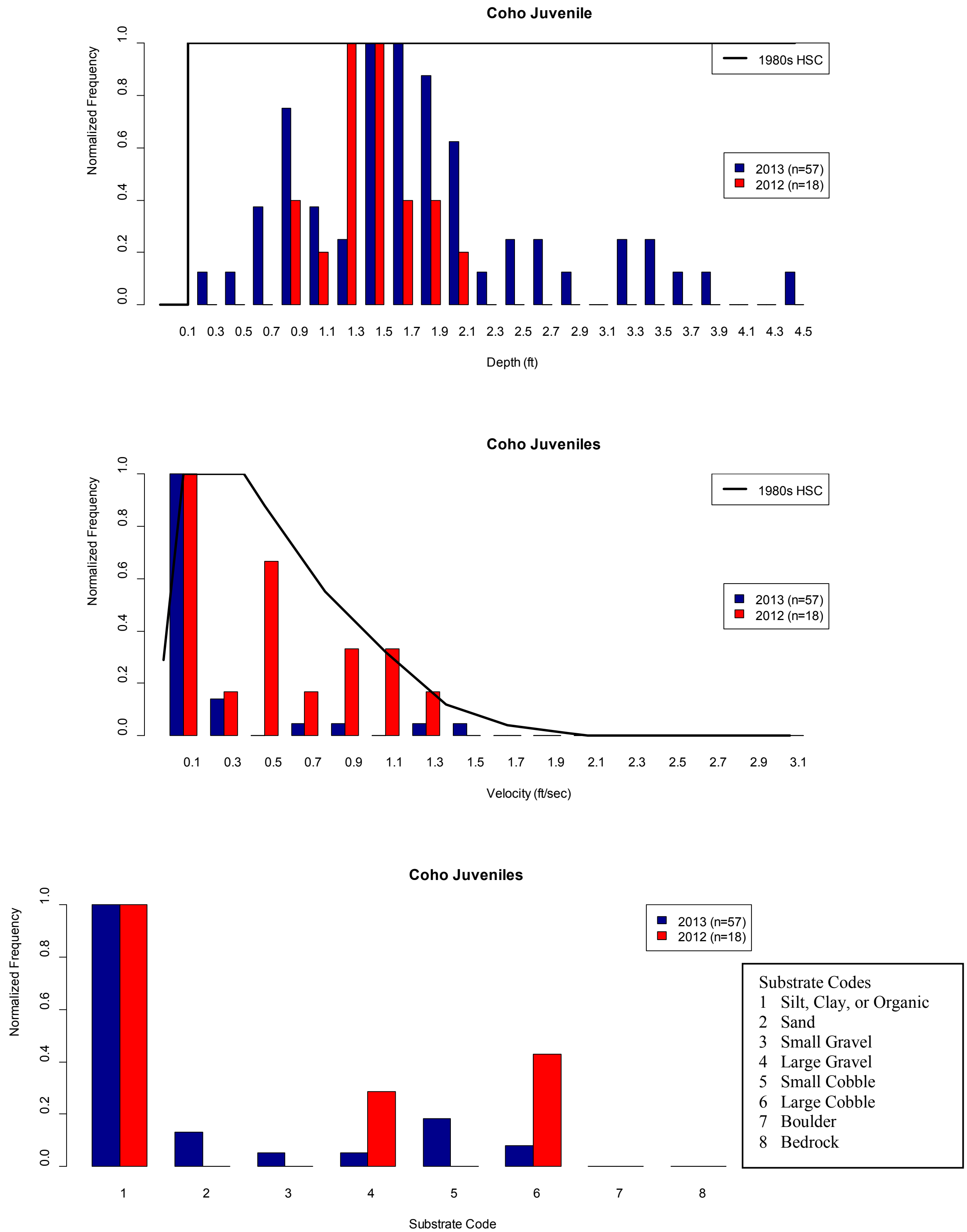


Figure 10. Histogram plots of 2012 and 2013 HSC observations for juvenile life stage of coho salmon normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

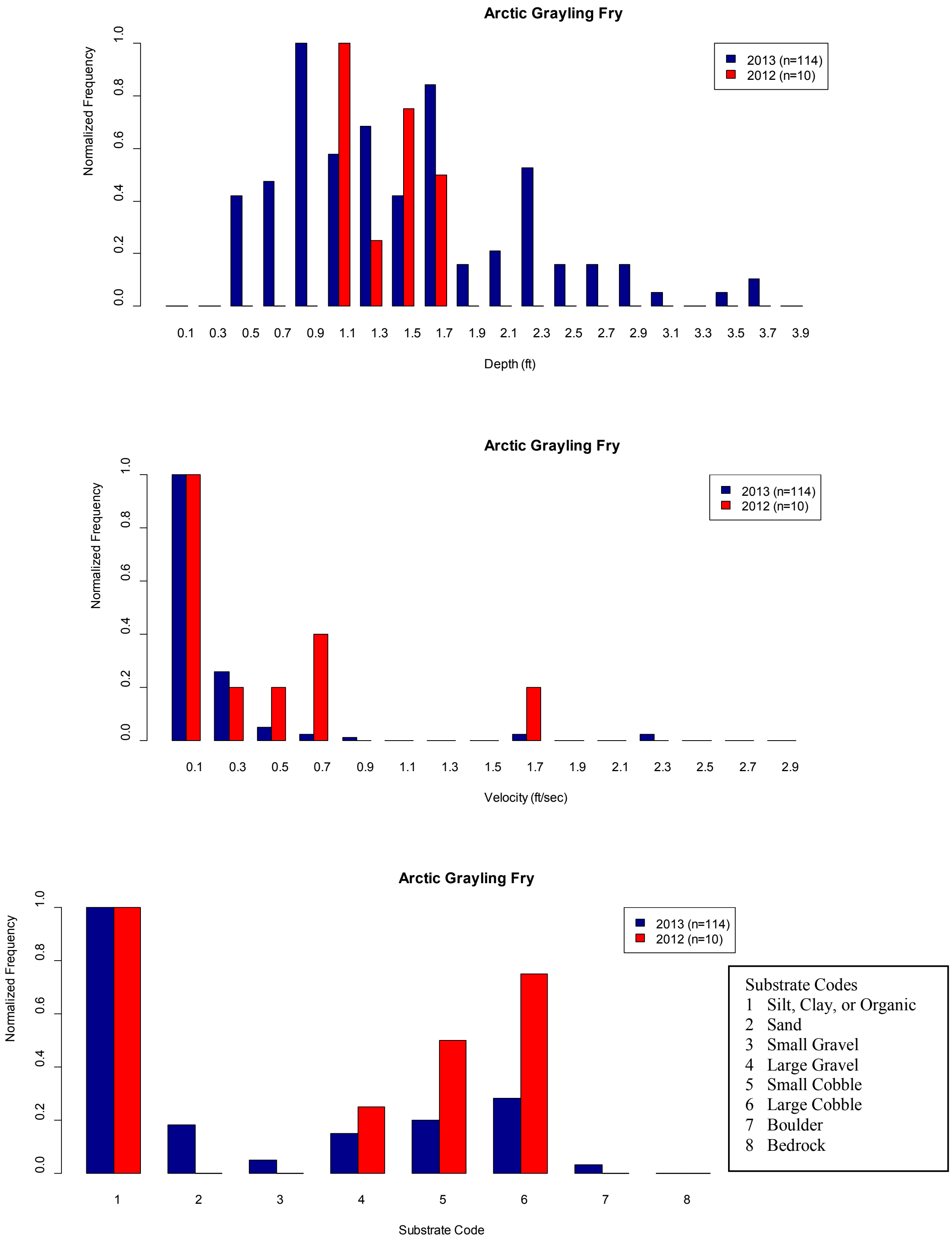


Figure 11. Histogram plots of 2012 and 2013 HSC observations for fry life stage of Arctic grayling normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

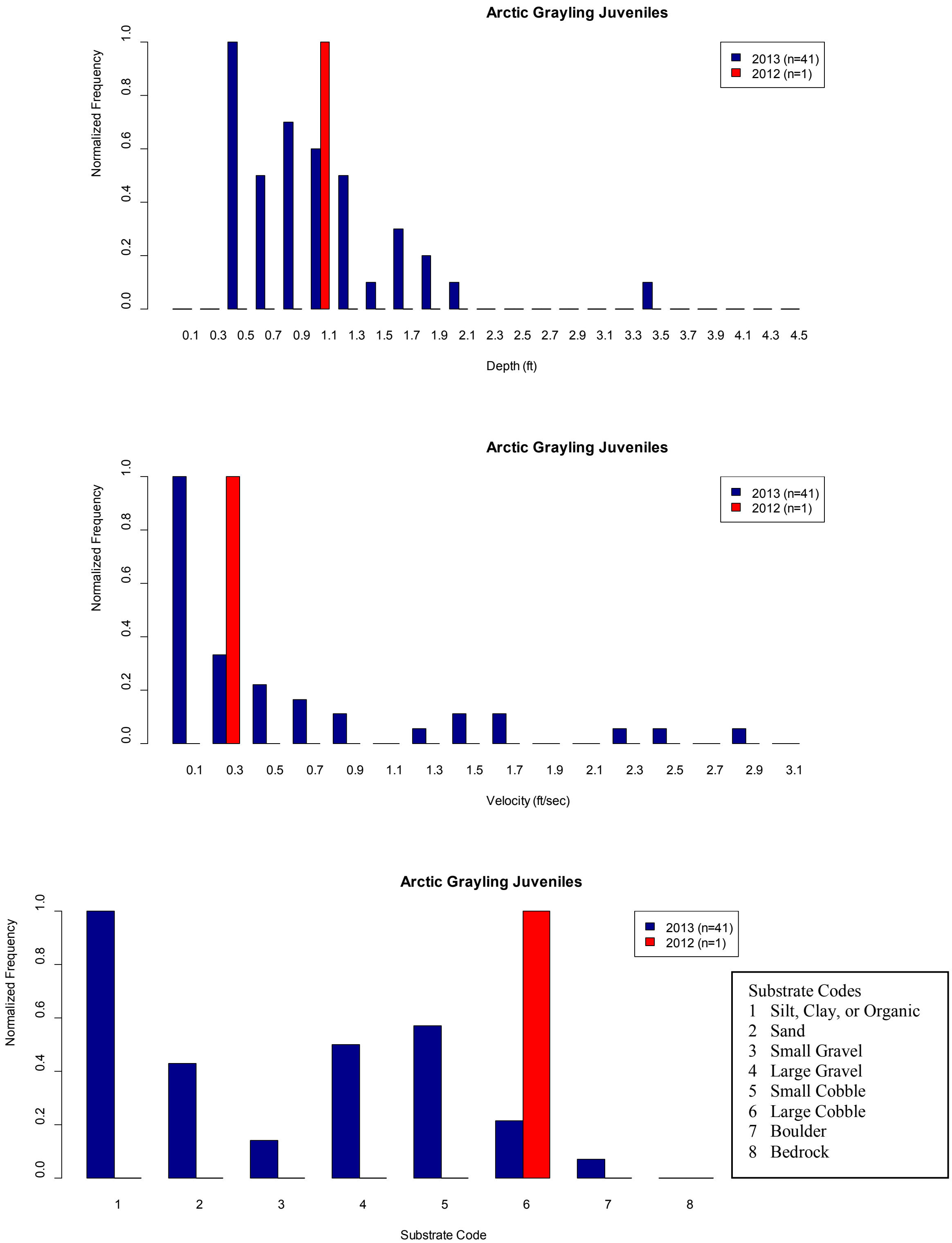


Figure 12. Histogram plots of 2012 and 2013 HSC observations for juvenile life stage of Arctic grayling normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

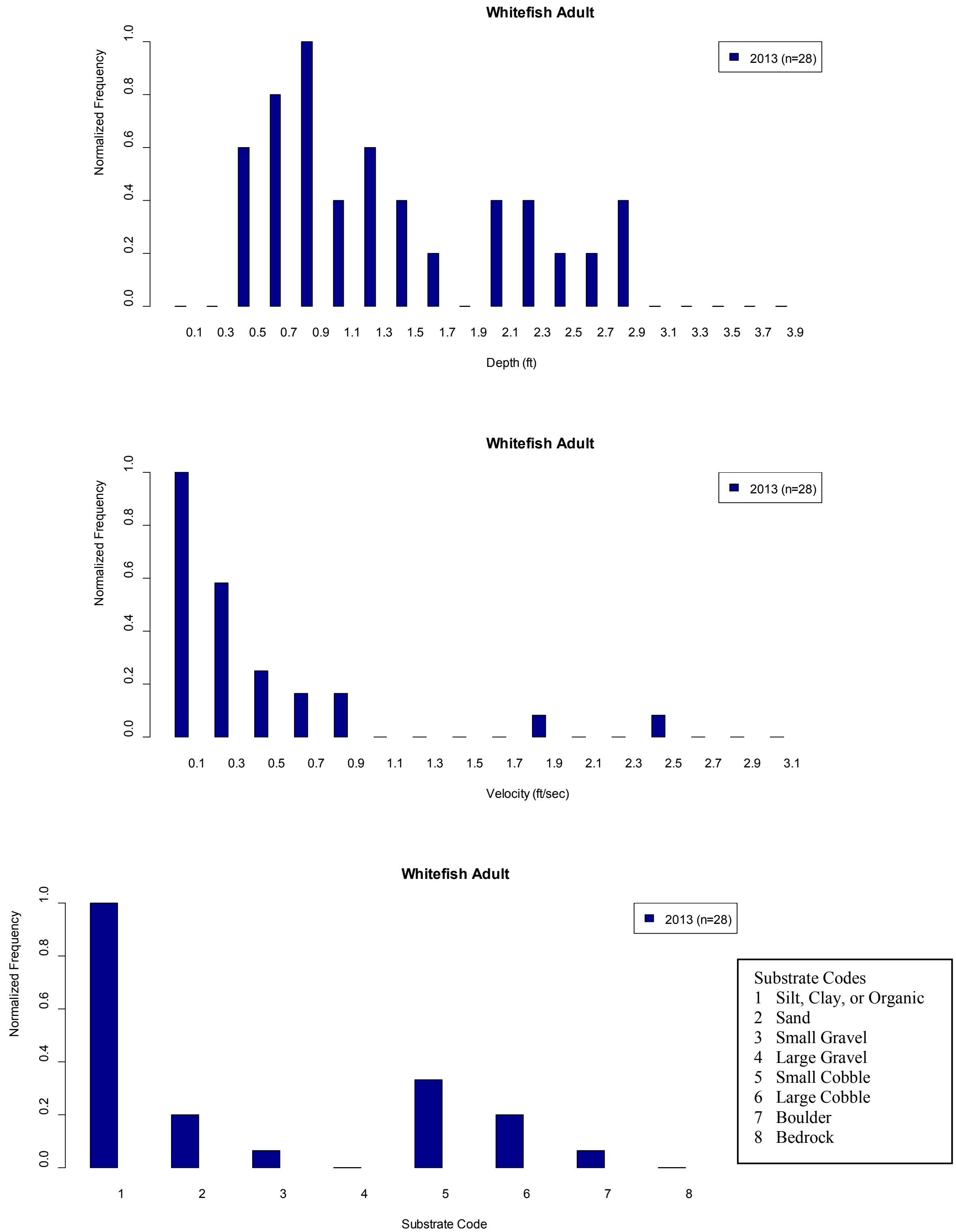
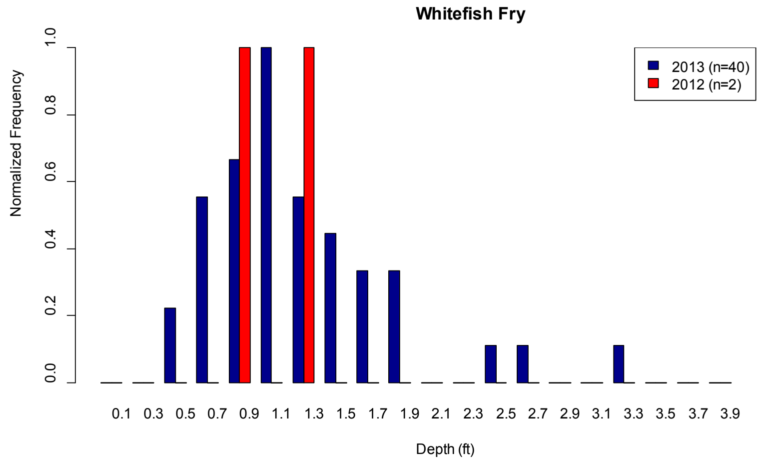
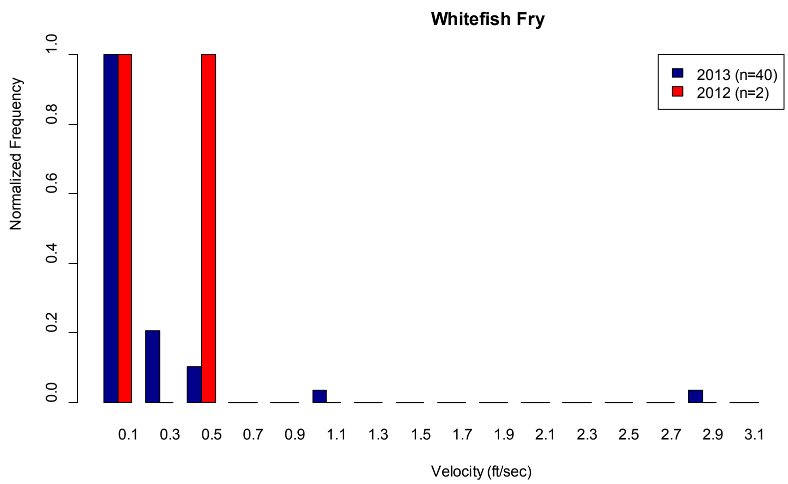


Figure 13. Histogram plots of 2012 and 2013 HSC observations for adult life stage of whitefish normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.





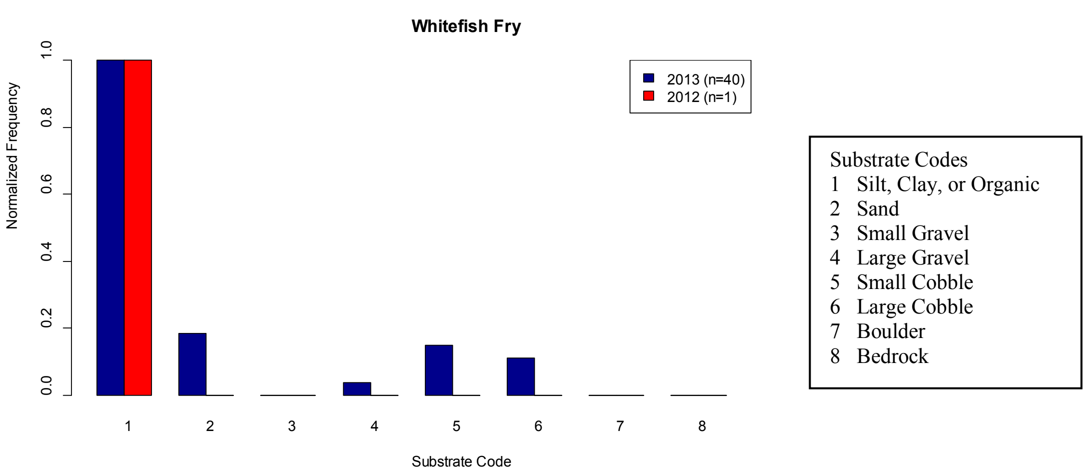


Figure 14. Histogram plots of 2012 and 2013 HSC observations for fry life stage of whitefish normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

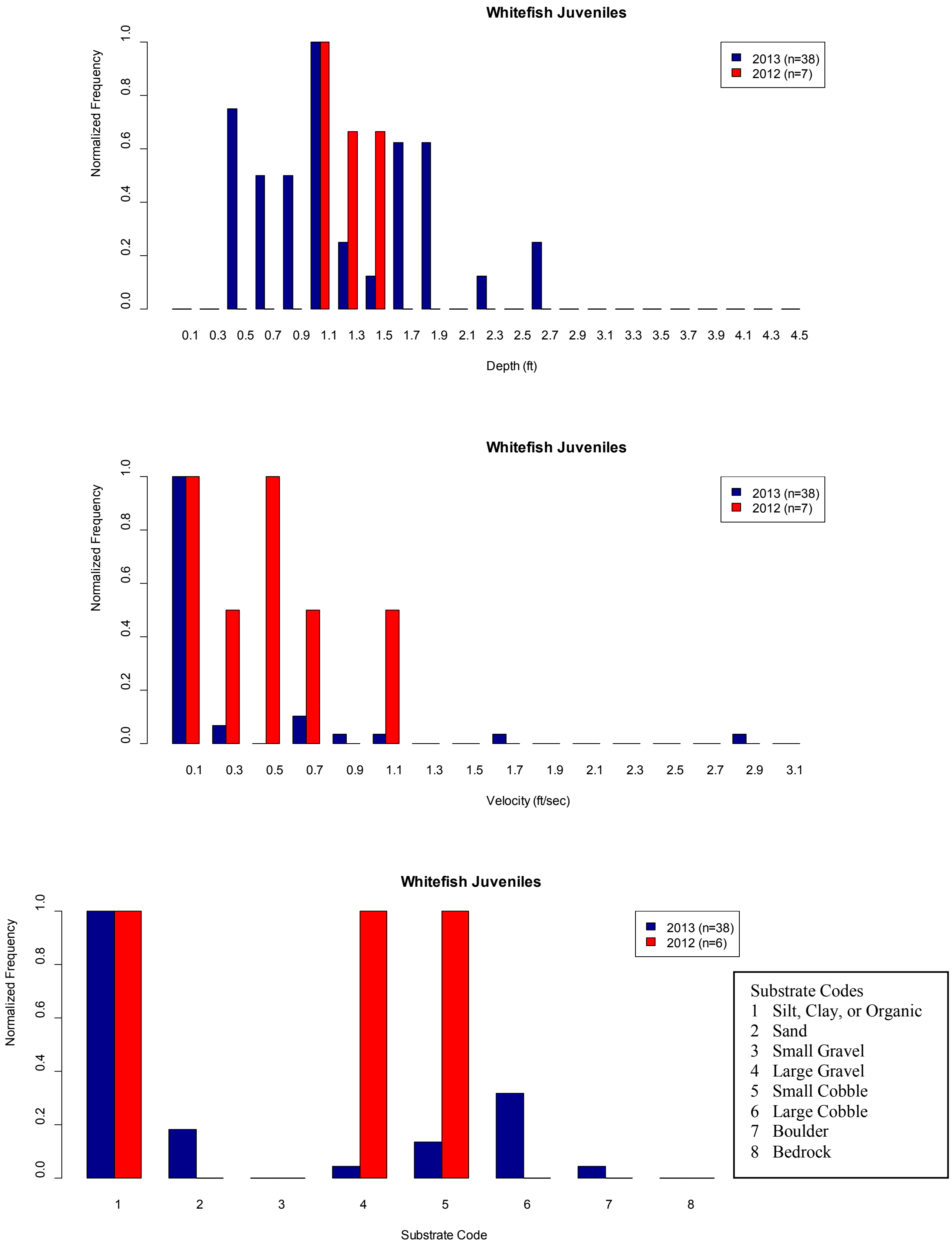


Figure 15. Histogram plots of 2012 and 2013 HSC observations for juvenile life stage of whitefish normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

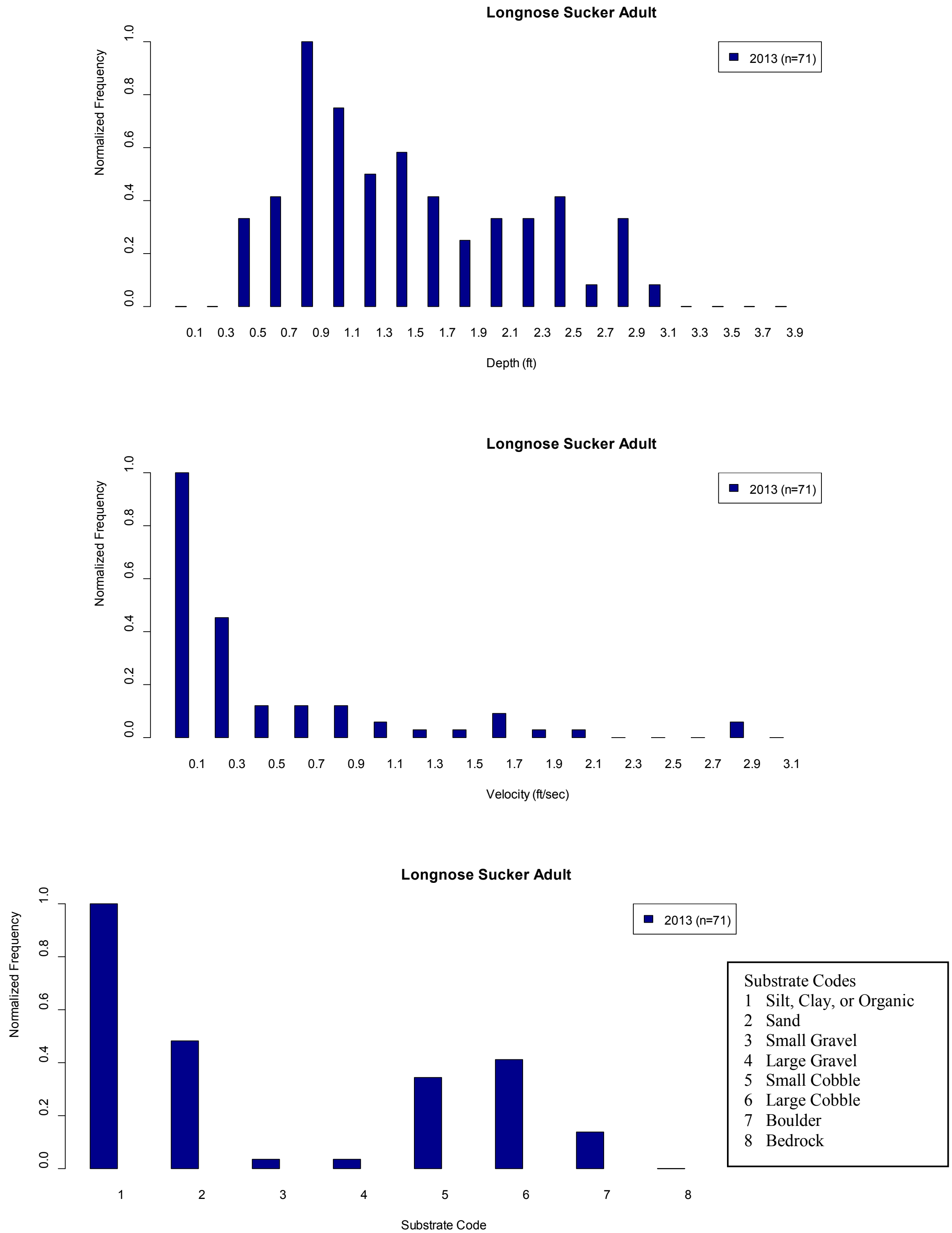


Figure 16. Histogram plots of 2012 and 2013 HSC observations for adult life stage of longnose suckers normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

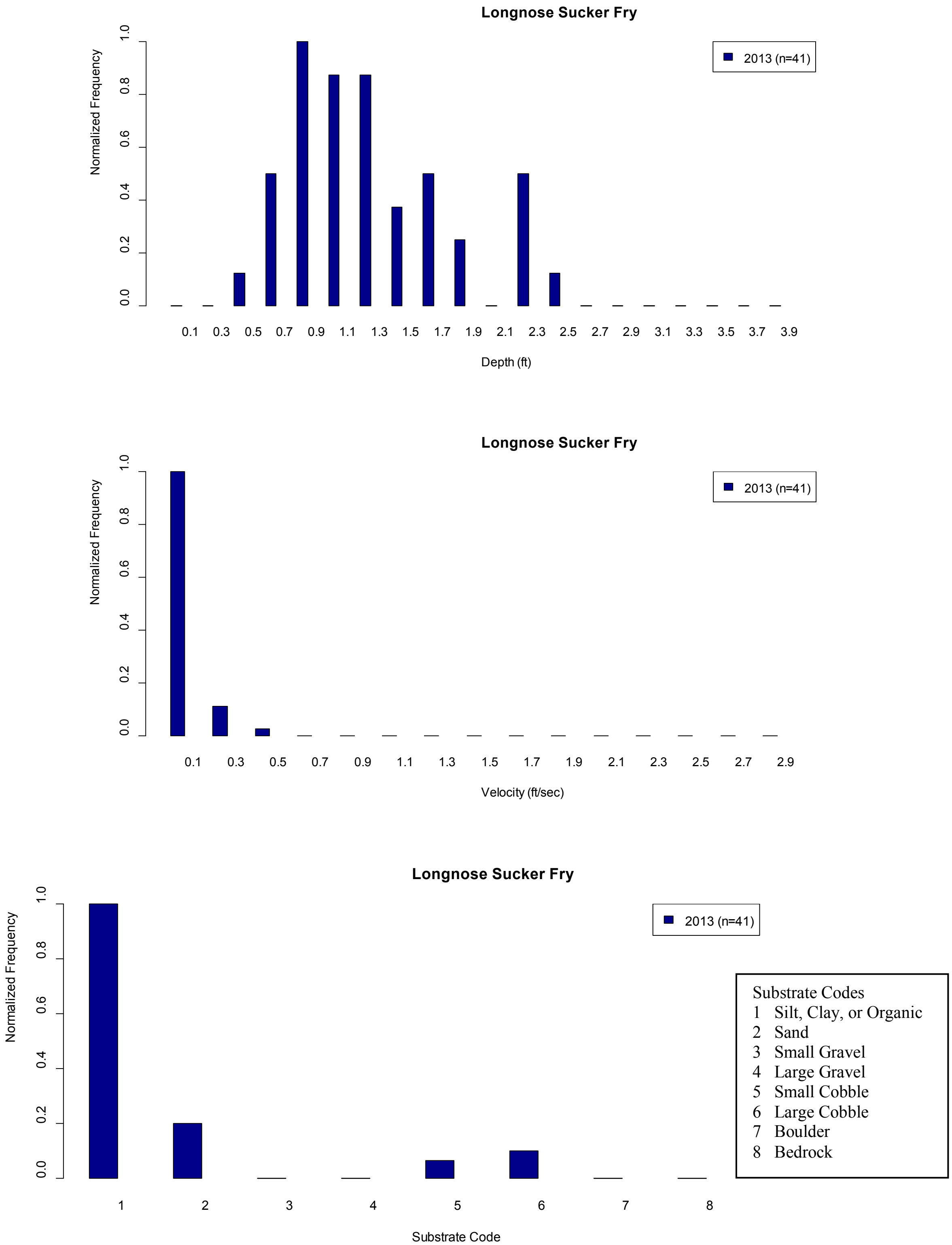
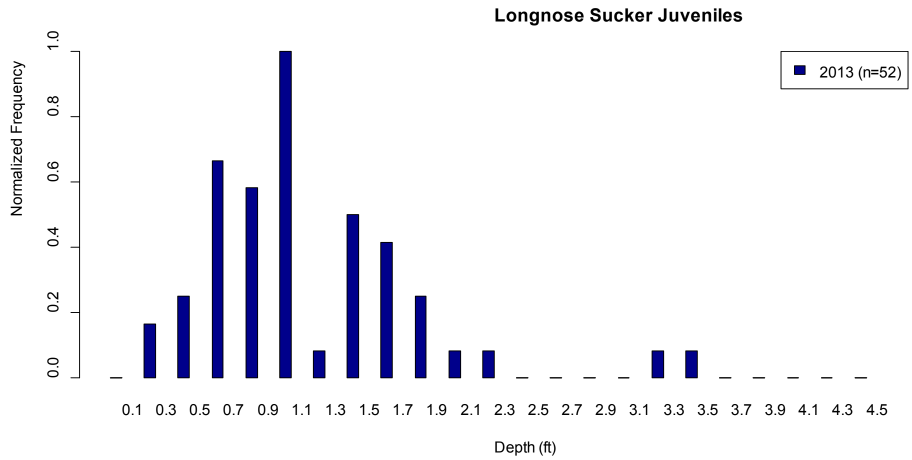
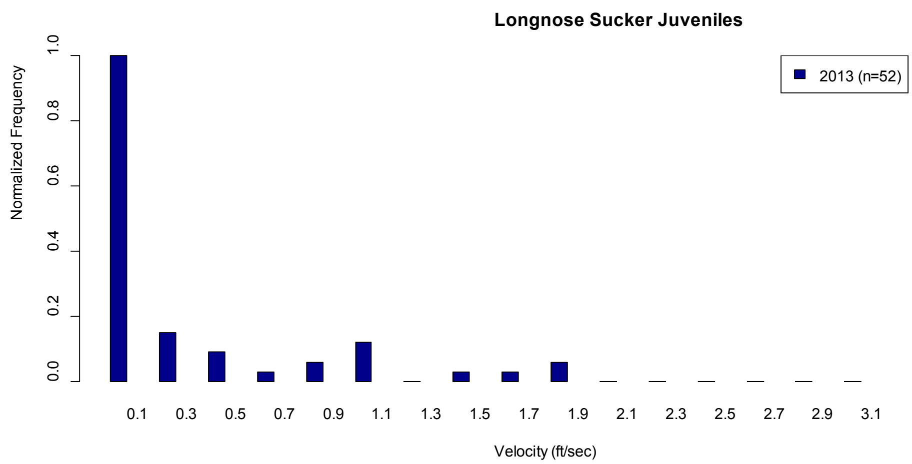


Figure 17. Histogram plots of 2012 and 2013 HSC observations for fry life stage of longnose suckers normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.





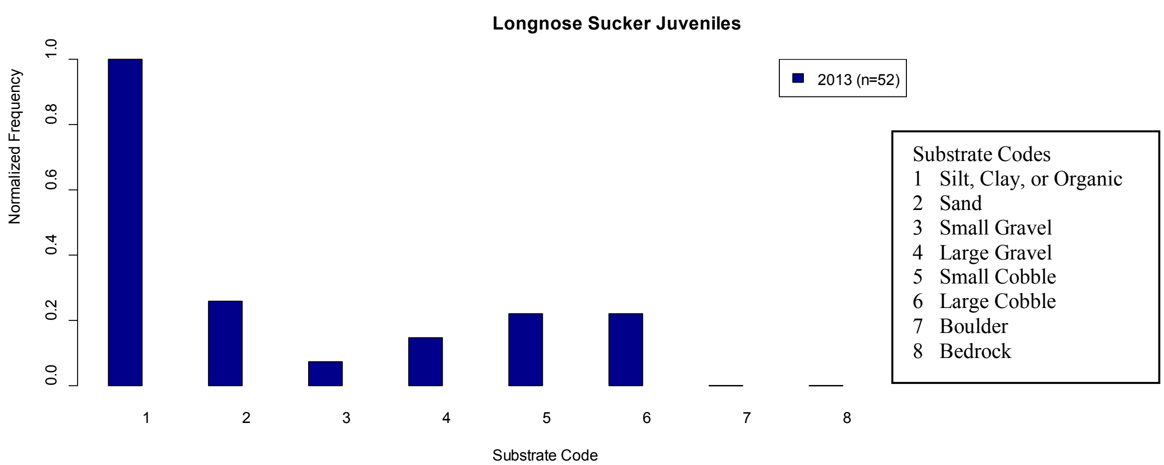


Figure 18. Histogram plots of 2012 and 2013 HSC observations for juvenile life stage of longnose suckers normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (bottom) microhabitat components, Susitna River, Alaska.

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fish and Aquatics Instream Flow Study (8.5)

Appendix H
Periodicity Tables

Initial Study Report

Prepared for

Alaska Energy Authority

Prepared by

R2 Resource Consultants, Inc.

February 2014 Draft

LIST OF TABLES

Table 1. Periodicity of Chinook salmon utilization among macrohabitat types in the Middle (PRM 187.1 – 102.4) and Lower (PRM 102.4 – 0.0) segments of the Susitna River by life history stage. In the Upper Segment (PRM 261.3 – 187.1), adult Chinook are believed to exhibit similar habitat use to that shown for the Middle Segment, while juvenile Chinook rearing and migration timing in this segment is not known. Shaded areas indicate timing of utilization by macrohabitat type and dark gray areas represent areas and timing of peak use.

	Habitat Type																	
Life Stage	Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Middle Susitna River																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Age 0+ Rearing																		
Age 0+ Migration																		
Age 1+ Rearing																		
Age 1+ Migration																		
Lower Susitna River																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Age 0+ Rearing																		
Age 0+ Migration																		
Age 1+ Rearing																		
Age 1+ Migration																		

Table 2. Periodicity of sockeye salmon utilization among macrohabitat types in the Middle (PRM 187.1 – 102.4) and Lower (PRM 102.4 – 0.0) segments of the Susitna River by life history stage. Shaded areas indicate timing of utilization by macrohabitat type and dark gray areas represent areas and timing of peak use.

Life Stage	Habitat Type: Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Middle Susitna River																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Age 0+ Rearing																		
Age 0+ Migration																		
Age 1+ Rearing																		
Age 1+ Migration																		
Lower Susitna River																		
Adult Migration[1]																		
Spawning																		
Incubation																		
Fry Emergence																		
Age 0+ Rearing																		
Age 0+ Migration																		
Age 1+ Rearing																		
Age 1+ Migration																		

Notes:

1. First run sockeye migration timing occurs during May and June and second run sockeye migration is July through September.

Table 3. Periodicity of chum salmon utilization among macrohabitat types in the Middle (PRM 187.1 – 102.4) and Lower (PRM 102.4 – 0.0) segments of the Susitna River by life history stage. Shaded areas indicate timing of utilization by macrohabitat type and dark gray areas represent areas and timing of peak use.

Life Stage	Habitat Type						Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary												
Middle Susitna River																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Age 0+ Rearing																		
Age 0+ Migration																		
Lower Susitna River																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Age 0+ Rearing																		
Age 0+ Migration																		

Table 4. Periodicity of coho salmon utilization among macrohabitat types in the Middle (PRM 187.1 – 102.4) and Lower (PRM 102.4 – 0.0) segments of the Susitna River by life history stage. Shaded areas indicate timing of utilization by macrohabitat type and dark gray areas represent areas and timing of peak use.

Life Stage	Habitat Type: Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Middle Susitna River																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Age 0+ Rearing																		
Age 0+ Migration																		
Age 1+ Rearing																		
Age 1+ Migration																		
Age 2+ Rearing																		
Age 2+ Migration																		
Lower Susitna River																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Age 0+ Rearing																		
Age 0+ Migration																		
Age 1+ Rearing																		
Age 1+ Migration																		
Age 2+ Rearing																		
Age 2+ Migration																		

Table 5. Periodicity of pink salmon utilization among macrohabitat types in the Middle (PRM 187.1 – 102.4) and Lower (PRM 102.4 – 0.0) segments of the Susitna River by life history stage. Shaded areas indicate timing of utilization by macrohabitat type and dark gray areas represent areas and timing of peak use.

Life Stage	Habitat Type: Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Middle Susitna River																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Age 0+ Migration																		
Lower Susitna River																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Age 0+ Migration																		

Table 6. Periodicity of rainbow trout utilization among macrohabitat types in the Susitna River by life history stage. Shaded areas indicate timing of utilization by macrohabitat type and dark gray areas represent areas and timing of peak use.

	Habitat Type																	
Life Stage	Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult Holding																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Juvenile Rearing																		

Table 7. Periodicity of Arctic grayling utilization among macrohabitat types in the Susitna River by life history stage. Shaded areas indicate timing of utilization by macrohabitat type and dark gray areas represent areas and timing of peak use.

	Habitat Type																	
Life Stage	**Main Channel**	**Side Channel**	**Tributary Mouth**	**Side Slough**	**Upland Slough**	**Tributary**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Adult Holding																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Juvenile Rearing																		

Table 8. Periodicity of burbot utilization among macrohabitat types in the Susitna River by life history stage. Shaded areas indicate timing of utilization by macrohabitat type and dark gray areas represent areas and timing of peak use.

Life Stage	Habitat Type						Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary												
Adult Holding																		
Adult Migration																		
Spawning																		
Incubation																		
Juvenile Migration																		
Juvenile Rearing																		

Table 9. Periodicity of round whitefish utilization among macrohabitat types in the Susitna River by life history stage. Shaded areas indicate timing of utilization by macrohabitat type and dark gray areas represent areas and timing of peak use.

Life Stage	Habitat Type						Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary												
Adult Holding																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Juvenile Migration																		
Juvenile Rearing																		

Table 10. Periodicity of humpback whitefish utilization among macrohabitat types in the Susitna River by life history stage. Shaded areas indicate timing of utilization by macrohabitat type and dark gray areas represent areas and timing of peak use.

Life Stage	Habitat Type						Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary												
Adult Holding																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Juvenile Migration																		
Juvenile Rearing[1]																		

Notes:

1. A portion of juvenile humpback whitefish may utilize estuarine habitats to rear during the first two years of life.

Table 11. Periodicity of longnose sucker in the Susitna River by life history stage and habitat type. Shaded areas represent utilization of habitat types and temporal periods and dark gray areas indicate peak use.

Life Stage	Habitat Type						Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary												
Adult Holding																		
Adult Migration																		
Spawning[1]																		
Incubation																		
Fry Emergence																		
Juvenile Migration																		
Juvenile Rearing																		

Notes:

1. Longnose sucker typically spawn in spring, however, a second unconfirmed spawn period may occur during the late summer in October or November.

Table 12. Periodicity of Dolly Varden in the Susitna River by life history stage and habitat type. Shaded areas represent utilization of habitat types and temporal periods and dark gray areas indicate peak use.

	Habitat Type																	
Life Stage	Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult Holding																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Juvenile Rearing																		

Table 13. Periodicity of Bering cisco utilization among macrohabitat types in the Susitna River by life history stage. Shaded areas indicate timing of utilization by macrohabitat type and dark gray areas represent areas and timing of peak use.

	Habitat Type																	
Life Stage	Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult Holding[1]																		
Adult Migration																		
Spawning																		
Incubation																		
Fry Emergence																		
Juvenile Migration[2]																		

Notes:

1. Adult Bering Cisco holding and feeding habitat use in the Susitna River is not known; it is possible these fish reside in marine areas until spawning.
2. Juvenile rearing is not represented here because Bering cisco fry migrate to marine nursery habitats soon after hatching.

Table 14. Periodicity of eulachon utilization among macrohabitat types in the Susitna River by life history stage. Shaded areas indicate timing of utilization by macrohabitat type and dark gray areas represent areas and timing of peak use.

Life Stage	Habitat Type: Main Channel	Side Channel	Tributary Mouth	Side Slough	Upland Slough	Tributary	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult Migration																		
Spawning																		
Incubation																		
Juvenile Migration[1]																		

Notes:

1. Juvenile rearing is not represented here because eulachon larvae migrate soon after hatching to estuarine nursery habitats to rear.

Susitna-Watana Hydroelectric Project

(FERC No. 14241)

Fish and Aquatics Instream Flow Study (8.5)

Appendix I

Lower River Hydraulic Model Calibration

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Golder Associates

February 2014 Draft

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXHIBITS

LIST OF ACRONYMS AND SCIENTIFIC LABELS

Abbreviation	Definition
1-D	One dimensional
ADCP	Acoustic Doppler Current Profiler
cfs	cubic feet per second
FA-IFS	Fish and Aquatics Instream Flow Study
FHWA	Federal Highway Association
ft	feet
ISR	Initial Study Report
LiDAR	Light Detection And Ranging
LR	Lower River
PRM	Project River Mile
RTK	Real-Time Kinematic

1. INTRODUCTION

The Fish and Aquatic Instream Flow Study (FA-IFS) for the Lower River Segment (LR) of the Susitna River is one component of the overall Study Plan for the FA-IFS program (Study 8.5). Five sites consisting of 3 to 17 cross-section transects per site were established within Geomorphic Reach LR-1 between Project River Mile (PRM) 92.9 and PRM 97 in June 2013 (Figure 1). The basis, methodology and results of the hydraulic modeling are documented in this report for the Birch Creek site (PRM 93.3) and the PRM 97 site, which is a main channel site located at approximately PRM 97 (Figure 1).

2. FIELD DATA

2.1. Field Surveys

For the LR fish habitat sites, single transect surveys were completed using the protocols described in ISR 8.5, Section 4.3 for surveying, acoustic Doppler current profiler (ADCP) measurements and stage, discharge and bathymetric surveys. Field surveys were conducted during three site visits (June, August, and September) to coincide with high, moderate and low flow conditions. Details of the field surveys are described in ISR Study 8.5, Section 5.3. The primary calibration survey and channel geometry survey was completed during the high flow survey from June 10 to June 15, 2013 at flows ranging between approximately 70,000 cfs and 90,000 cfs at the Susitna River at Sunshine gage (provisional). The August and September field surveys collected water surface elevation data and substrate distribution data to support model calibrations at moderate and low flow conditions.

A tributary gage was installed on Birch Creek as part of the Study Plan (ISR Study 8.5, Section 5.3) and was relied on to provide tributary inflow data for the corresponding August and September field surveys.

2.2. Survey Data Processing

The Real-Time Kinematic (RTK) ground survey data and bathymetric survey data were processed as described in ISR Study 8.5, Section 4.3. The processed field survey data were combined with 2011 Matanuska-Susitna Borough LiDAR topographic data to extend transects beyond the top of bank that was directly surveyed during the RTK survey. These integrated survey data were used to generate the cross-section profile at each river/creek station in the HEC-RAS hydraulic model. The channel geometric data created from the June 2013 survey were used for all model runs.

3. HYDRAULIC MODELING

3.1. Introduction

The 1-D HEC-RAS hydraulic model (Version 4.1) developed by the Hydrologic Engineering Center, U.S. Army Corps of Engineers (Brunner 2010) was used to simulate water levels at the Birch Creek site and the PRM 97 site. The hydraulic modeling analysis involved the following:

- Preparation of the model input data for the study reach;
- Calibration of hydraulic models using available survey data collected in June, August, and September 2013; and
- Sensitivity analysis.

3.2. Birch Creek Modeling

3.2.1. Model Input Data and Assumptions

3.2.1.1. Channel Geometry

The HEC-RAS hydraulic model was set up based on the surveyed bathymetric and topographic data collected in June 2013. In total, 15 surveyed cross-sections were used in the model as shown in Figure 2. The Birch Creek site was further divided into three reaches in the HEC-RAS hydraulic model, namely Birch Creek Slough Upstream Reach, Birch Creek Slough Downstream Reach, and Birch Creek (Tributary Flow). Additional transects on Birch Creek Slough (T1 and T11) were measured at the downstream connection with the main channel, but were not included as part of the HEC-RAS model domain.

3.2.1.2. Hydraulic Roughness

The values of Manning's roughness coefficient n were initially assumed and assigned to each cross-section based on the observed bed materials in the channel. Bed materials in Birch Creek Slough were observed to be predominantly cobbles with small mixtures of sand, silt and clay (Figure 2). The bed materials were predominantly fines within Birch Creek (Figure 2) although the hydraulic roughness of the Birch Creek channel was also affected by bedforms and fallen trees creating partial barriers across the channel, which are visible from pictures taken during the low flow survey.

Reasonable Manning's n values range from 0.025 to 0.05 based on published data for similar channel bed conditions (FHWA 1984 and Chow 1959). The estimated Manning's n values were subsequently adjusted during the model calibration based on the surveyed flow and water level data.

3.2.1.3. Boundary Conditions

Measured discharge in June 2013 was used as the model upstream boundary condition for the high flow model calibration. The upstream boundary condition for the low flow model calibration was calculated as the difference between the measured discharge at Birch Creek

Slough Downstream Reach and the gaged discharge at Birch Creek during the September survey. The corresponding surveyed water levels from each field survey at the most downstream cross-section were used as the downstream boundary conditions. A reasonable estimate of August discharge within the Birch Creek Slough channel was not possible with the data available at the time of this report. A summary of the boundary conditions for the low flow and high flow calibration is provided in Table 1.

3.2.2. Model Calibration

The model was calibrated using surveyed water levels along the study reach for two flow scenarios in June and September which represent high and low flow conditions in the Birch Creek site, respectively. The model calibration for August has not been completed since model outputs from other studies were not available at the time of this report. These flow values are needed to support the estimates of boundary conditions for the August survey, since discharge within Birch Creek Slough was not directly measured during the August survey.

3.2.2.1. High Flow Calibration – June 2013 Survey

Calibration results for the June 2013 flow conditions are plotted in Figure 3 and Figure 4 for the Birch Creek Slough and the Birch Creek reaches, respectively.

Table 2 compares the surveyed water levels to the HEC-RAS simulated water levels from the high flow model calibration run. The difference between the simulated and surveyed water levels ranges from -0.08 m (-0.28 ft) to 0.04 m (0.11 ft). This deviation is considered to be well within the expected error between observed and simulated values. The calibrated Manning's n values are 0.03 for the Birch Creek Slough reaches, and 0.025 for the Birch Creek reach. This range of n values is considered to be reasonable for high flow conditions in these channels.

3.2.2.2. Low Flow Calibration – September 2013 Survey

Low flow calibration was conducted using September 2013 surveyed data and the surveyed discharge was about 12 percent of the June high flow in the Birch Creek Slough channel. The low flow calibration results are plotted on Figure 5 and Figure 6 for the Birch Creek Slough and Birch Creek channels, respectively.

The water level differences between the surveyed and simulated water levels are presented in Table 3. The difference between the simulated and surveyed water levels ranges from -0.19 m (-0.62 ft) to 0.21 m (0.69 ft). The deviations are larger under the low flow condition than under high flow conditions because local variation of channel features such as riffle, run and pools have a larger impact on water levels under low flow conditions relative to high flow conditions when the channel geometry was surveyed. In addition, significant obstructions of flows also occurred in the Birch Creek channel and to a lesser extent in the Birch Creek Slough channel mainly due to fallen trees across the channels (see pictures in Exhibit 1 from September survey) which may create additional hydraulic controls under low flow conditions and affect local water levels not captured when the channel topography was surveyed under high flow conditions. The calibrated low flow Manning's n values are 0.050 for the Birch Creek Slough channel and 0.045 for the Birch Creek channel. This range of n values is considered to be reasonable for the low flow conditions observed in each channel.

3.3. Sensitivity Analysis

Sensitivity analyses were conducted on the Manning's roughness coefficient n. This was completed by increasing and decreasing Manning's n values by 15 percent from the calibrated n values. The results of the sensitivity analyses for the two flow scenarios are presented in Table 4. Figure 7 and Figure 8 present the model sensitivity results for the Birch Creek Slough and Birch Creek channels under high flow conditions.

The high flow sensitivity analysis indicates an average water level increase of 0.11 m (0.39 ft) for higher Manning's n values and an average reduction of water levels of 0.12 m (0.43 ft) for a smaller Manning's n values. The low flow sensitivity analysis indicates average water level variations of ±0.05 m (0.19 ft/-0.20 ft) when the Manning's n values changes by ±15 percent from the calibrated n values for low flow conditions.

3.4. PRM 97 Site Modelling

3.4.1. Model Input Data and Assumptions

3.4.1.1. Channel Geometry

The HEC-RAS hydraulic model was set up based on the surveyed bathymetric and topographic data collected in June 2013. Three surveyed cross-sections were used in the model as shown in Figure 9. The surveyed ADCP/RTK data was merged with the LiDAR topographic data to create a single integrated survey dataset. This dataset was then used to generate the cross-section profiles at each main channel station in the HEC-RAS hydraulic model. Three additional transects (transects at PRM 98.4, PRM 97.0 and PRM 91.6) from the 1-D Open-water Flow Routing Model (Version 1) were incorporated in the model for a better representation of the main river channel flow and to establish single channel boundary conditions. Two of the flow routing model transects (PRM 98.4 and PRM 97.0) were located immediately upstream of the fish habitat transects at the PRM 97 site and one transect (PRM 91.6) was located downstream.

3.4.1.2. Hydraulic Roughness

The values of Manning's roughness coefficient n were initially assumed and assigned to each cross-section based on the observed bed materials in the channel. Bed materials in the PRM 97 site were observed to be predominantly cobbles with small mixtures of sand, silt and gravel (Figure 9). Due to limited information available for the additional cross-sections, the channel bed materials were assumed to be predominantly cobbles.

Reasonable Manning's n values range from 0.025 to 0.05 based on published data for similar channel bed conditions (FHWA 1984 and Chow 1959). The estimated Manning's n values were subsequently adjusted during the model calibration based on the surveyed flow and water level data. The sensitivity analysis of Manning's n values was conducted in this study.

3.4.1.3. Boundary Conditions

The average of the calculated discharges from the three fish habitat transects surveyed at the PRM 97 site was used as the upstream boundary condition due to the variability observed in calculated discharge values among the transects. The calculated discharge values from field measurements at the PRM 97 site on July 16, 2013 ranged from 57,000 cfs to 63,390 cfs; which compared to the provisional discharge reported at the Sunshine gage station of 75,000 cfs and the predicted discharge of 55,515 cfs based on the Open-water Flow Routing Model rating curve at PRM 97.0 using the water level surveyed at T3. Since discharge was not measured at the PRM 97 site transects in August and September, rationales and relationships between field measured discharges, gaged discharges and flow routing model results need to be studied prior to model calibration to establish an appropriate upstream boundary condition. Therefore, model calibration has only been performed for the June data (Table 5). Model calibration for the August and September flow conditions will be completed when Version 2 of the Open-water Flow Routing Model is available, which will include additional transects near the PRM 97 site, and relationships between the site measured discharge and gaged discharge are established.

3.4.2. Model Calibration

The model was calibrated by comparing surveyed and simulated water levels along the study reach for the average discharge measured in June 2013 for PRM 97.

3.4.2.1. High Flow Calibration – June 2013 Flow

Calibration results for June 2013 average discharge are plotted in Figure 10 and Figure 11 for the full modeled length including the Open-water Flow Routing Model transects and the PRM 97 site transects, respectively.

Table 6 compares the surveyed water levels to the HEC-RAS simulated values from the high flow model calibration run. The difference between the simulated and surveyed water levels ranged from -0.15 m (-0.49 ft) to 0.27 m (0.87 ft). This deviation is considered to be well within the expected error between observed and simulated values. The calibrated Manning’s n values are 0.030 for the Main Channel. This range of n values is considered to be reasonable for high flow conditions in PRM 97.

3.5. Sensitivity Analysis

A sensitivity analysis was conducted on the Manning’s roughness coefficient n. The Manning’s n values were increased and decreased by 15 percent from the calibrated n values. The results of the sensitivity analysis for June 2013 are presented in Table 7. Figure 12 and Figure 13 present the model sensitivity results for the full model length and PRM 97, respectively, during high flow event.

The high flow measured discharge sensitivity analysis indicates an average water level increase of 0.19 m (0.61 ft) for higher Manning’s n values and an average reduction of water levels of -0.21 m (-0.69 ft) for a smaller Manning’s n values.

4. CONCLUSIONS

One-dimensional HEC-RAS hydraulic models were setup using the June 2013 channel survey data at the Birch Creek site and the PRM 97 site at the lower Susitna River LR-1 reach.

Bathymetric survey data along with LiDAR and RTK survey data were used in combination to generate the cross-section profiles in the HEC-RAS model. Three additional transects obtained from the 1-D Susitna River Open-water Flow Routing Model (Version 1) were added upstream and downstream of the PRM 97 site for better representation of the river channel and to provide single channel flow conditions at the model boundaries.

For the Birch Creek site, the HEC-RAS model was calibrated for high flow (June 2013) and low flow (September 2013) conditions. The calibrated Manning's n values varied between the different flow conditions and were in the range of 0.025 to 0.05. A sensitivity analysis was conducted for ±15 percent variation on the Manning's n values. Model calibration for the August 2013 (moderate flow) survey will be studied after a better understanding of the relationship between the Susitna River main channel and Birch Creek Slough channel flows has been developed and after results from the Open-water Flow Routing Model (Version 2) become available.

For the PRM 97 site, the HEC-RAS model was calibrated for high flow condition in June 2013 using the average measured discharge from the fish habitat transects. A sensitivity analysis was conducted for ± 15 percent variation on the Manning's n value. Moderate flow and low flow models for the PRM 97 site will be developed once the results from the Open-water Flow Routing Model (Version 2) become available and the relationship between the measured discharge at the PRM 97 site and the gaged discharge from the Susitna River at Sunshine station are established.

5. REFERENCES

Brunner, G.W. 2010. HEC-RAS River Analysis System: Hydraulic Reference Manual, Version 4.1, U.S. Army Corps of Engineers, Davis, California.

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

FHA (Federal Highway Administration). 1984. Guide for Selecting Manning's Roughness Coefficient for Natural Channels and Floodplains. Report No. FHWA-TS-84-204, McLean, Virginia.

6. TABLES

Table 1. Boundary Conditions for Birch Creek Site HEC-RAS Model Calibrations

Flow Scenario	Reach	Discharge (cms (cfs))	Water Level at downstream end (m (ft))
June 2013 (High Flow Scenario)	Birch Creek Slough Upstream Reach	79.3 (2800)	89.6 (294.0)
	Birch Creek Tributary	1.7 (60)	
	Birch Creek Slough Downstream Reach	81.0 (2860)	
September 2013 (Low Flow Scenario)	Birch Creek Slough Upstream Reach	8.65 (306)	88.5 (290.4)
	Birch Creek Tributary	0.8 (28)	
	Birch Creek Slough Downstream Reach	9.45 (334)	

Notes: cms = cubic meters per second, cfs = cubic feet per second

Table 2. Comparison of Surveyed and HEC-RAS Simulated Water Levels for June 2013 High Flow Calibration at Birch Creek Site

Reach	Cross-Section ID	Channel Bed Thalweg Elevation	Average Survey Water Edge Elevation	Simulated Water Level	Water Level Difference (Simulated - Surveyed)
		m (ft)	m (ft)	m (ft)	m (ft)
Birch Creek Slough (Upstream Reach)	BCS T10	88.56 (290.55)	90.85 (298.05)	90.76 (297.77)	-0.08 (-0.28)
	BCS T9	87.86 (288.25)	90.68 (297.51)	90.63 (297.34)	-0.06 (-0.16)
	BCS T8	87.69 (287.70)	90.55 (297.08)*	90.59 (297.21)	-0.04 (0.11)
	BCS T7	88.27 (289.60)	90.48 (296.83)	90.43 (296.69)	-0.04 (-0.15)
	BCS T6	87.88 (288.32)	90.35 (296.41)	90.31 (296.29)	-0.03 (-0.11)
Birch Creek Slough (Downstream Reach)	BCS T5	87.73 (287.83)	90.17 (295.83)	90.13 (295.70)	-0.04 (-0.13)
	BCS T4	87.88 (288.32)	89.99 (295.23)	89.95 (295.11)	-0.03 (-0.11)
	BCS T3	87.78 (287.99)	89.89 (294.90)	89.86 (294.82)	-0.03 (-0.08)
	BCS T2	88.07 (288.94)	89.62 (294.01)	89.62 (294.03)	0.00 (0.00)
Birch Creek	BC T6	88.98 (291.93)	90.21 (295.95)	90.23 (296.03)	0.02 (0.08)
	BC T5	88.63 (290.78)	90.20 (295.92)	90.23 (296.03)	0.03 (0.11)
	BC T4	88.63 (290.78)	90.24 (296.05)	90.22 (296.00)	-0.02 (-0.05)
	BC T3	88.71 (291.04)	90.22 (295.98)	90.22 (296.00)	0.00 (0.02)
	BC T2	88.48 (290.29)	90.24 (296.05)	90.22 (296.00)	-0.02 (-0.05)
	BC T1	88.52 (290.42)	90.19 (295.88)	90.22 (296.00)	0.03 (0.11)
			Maximum		0.04 (0.11)
			Minimum		-0.08 (-0.28)
			Average		-0.02 (-0.06)

Notes: BCS = Birch Creek Slough; BC = Birch Creek
* right edge of water level only

Table 3. Comparison of Surveyed and HEC-RAS Simulated Water Levels for September 2013 Low Flow Scenario at Birch Creek Site

Reach	Cross-Section ID	Channel Bed Thalweg Elevation	Average Survey Water Edge Elevation	Simulated Water Level	Water Level Difference (Simulated - Surveyed)
		m (ft)	m (ft)	m (ft)	m (ft)
Birch Creek Slough Upstream Reach	BCS T10	88.56 (290.55)	89.62 (294.06)	89.59 (293.93)	-0.03 (-0.13)
	BCS T9	87.86 (288.25)	89.45 (293.48)	89.45 (293.47)	0.00 (-0.01)
	BCS T8	87.69 (287.70)	89.43 (293.41)	89.43 (293.41)	0.00 (0.00)
	BCS T7	88.27 (289.60)	89.43 (293.41)	89.36 (293.18)	-0.07 (-0.24)
	BCS T6	87.88 (288.32)	89.39 (293.29)	89.21 (292.68)	-0.17 (-0.61)
Birch Creek Slough Downstream Reach	BCS T5	87.73 (287.83)	88.99 (292.00)	89.03 (292.09)	0.04 (0.09)
	BCS T4	87.88 (288.32)	88.94 (291.83)	88.94 (291.80)	0.00 (-0.03)
	BCS T3	87.78 (287.99)	88.65 (290.85)	88.86 (291.54)	0.21 (0.69)
	BCS T2	88.07 (288.94)	88.52 (290.40)	88.52 (290.42)	0.00 (0.02)
Birch Creek Tributary	BC T6	88.98 (291.93)	89.54 (293.77)	89.35 (293.14)	-0.19 (-0.62)
	BC T5	88.63 (290.78)	89.36 (293.18)	89.22 (292.72)	-0.14 (-0.46)
	BC T4	88.63 (290.78)	89.21 (292.68)	89.16 (292.52)	-0.05 (-0.16)
	BC T3	88.71 (291.04)	89.1 (292.32)	89.10 (292.32)	0.00 (0.00)
	BC T2	88.48 (290.29)	89.03 (292.08)	89.07 (292.22)	0.04 (0.15)
	BC T1	88.52 (290.42)	89.01 (292.03)	89.05 (292.16)	0.04 (0.13)
			Maximum Difference		0.21 (0.69)
			Minimum Difference		-0.19 (-0.62)
			Average Difference		-0.02 (-0.08)

Notes: BCS = Birch Creek Slough; BC = Birch Creek

Table 4. Birch Creek Site Sensitivity Analysis on Manning's Roughness Coefficient n

Flow Scenario	Predicted Water Level Differences (Sensitivity Run - Calibration Run)			
	15% Higher Manning's n Values		15% Lower Manning's n Values	
	Average Difference m (ft)	Difference Range m (ft)	Average Difference	Difference Range m (ft)
June 2013 (High Flow Scenario)	0.11 (0.39)	0.10 to 0.13 (0.33 to 0.43)	-0.12 (-0.43)	-0.11 to -0.16 (-0.36 to -0.52)
September 2013 (Low Flow Scenario)	0.05 (0.19)	0.02 to 0.07 (0.07 to 0.23)	-0.05 (-0.20)	-0.01 to -0.09 (-0.07 to -0.30)

Table 5. Boundary Conditions for PRM 97 Site HEC-RAS Model Calibration

Flow Scenario	Reach	Discharge cms (cfs)	Water Level at downstream end m (ft)
June 2013 (Measured Discharge)	Main Channel	1,712 (60,459)	87.4 (286.69)

Table 6. Comparison of Surveyed and HEC-RAS Simulated Water Levels for June 2013 High Flow Calibration for PRM 97 Site

Cross-Section ID	Channel Bed Thalweg Elevation	Average Survey Water Edge Elevation	Simulated Water Level	Water Level Difference (Simulated - Surveyed)
	(m) / (ft)	(m) / (ft)	(m) / (ft)	(m) / (ft)
PRM 97 T3	92.40 (303.15)	97.13 (318.65)	97.39 (319.52)	0.27 (0.87)
PRM 97 T2	92.16 (302.36)	97.04 (318.36)	96.94 (318.04)	-0.09 (-0.31)
PRM 97 T1	92.56 (303.67)	96.99 (318.21)	96.84 (317.72)	-0.15 (-0.49)
		Maximum		0.27 (0.87)
		Minimum		-0.15 (-0.49)
		Average		0.01 (0.12)

Table 7. Sensitivity Analysis for Manning's Roughness Coefficient n for PRM 97 Site

Data Source	Predicted Water Level Differences (Sensitivity Run - Calibration Run)			
	15% Higher Manning's n Values		15% Lower Manning's n Values	
	Average Difference m (ft)	Difference Range m (ft)	Average Difference m (ft)	Difference Range m (ft)
Measured Discharge	0.19 (0.61)	0.15 to 0.22 (0.49 to 0.72)	-0.21 (-0.69)	-0.16 to -0.26 (-0.52 to -0.85)

7. FIGURES

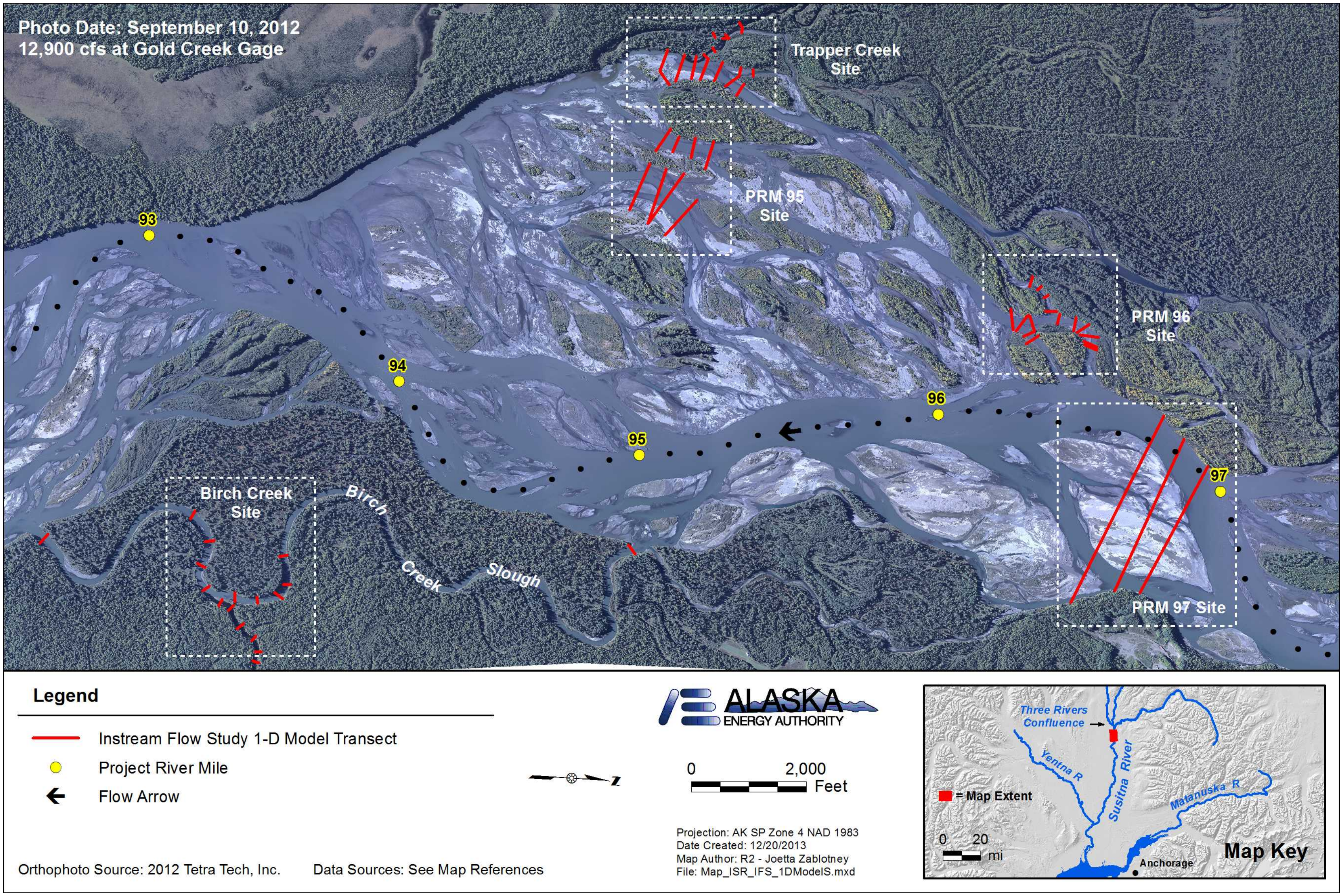


Figure 1. Locations of Selected Sites for the Lower Susitna Instream Flow Study.

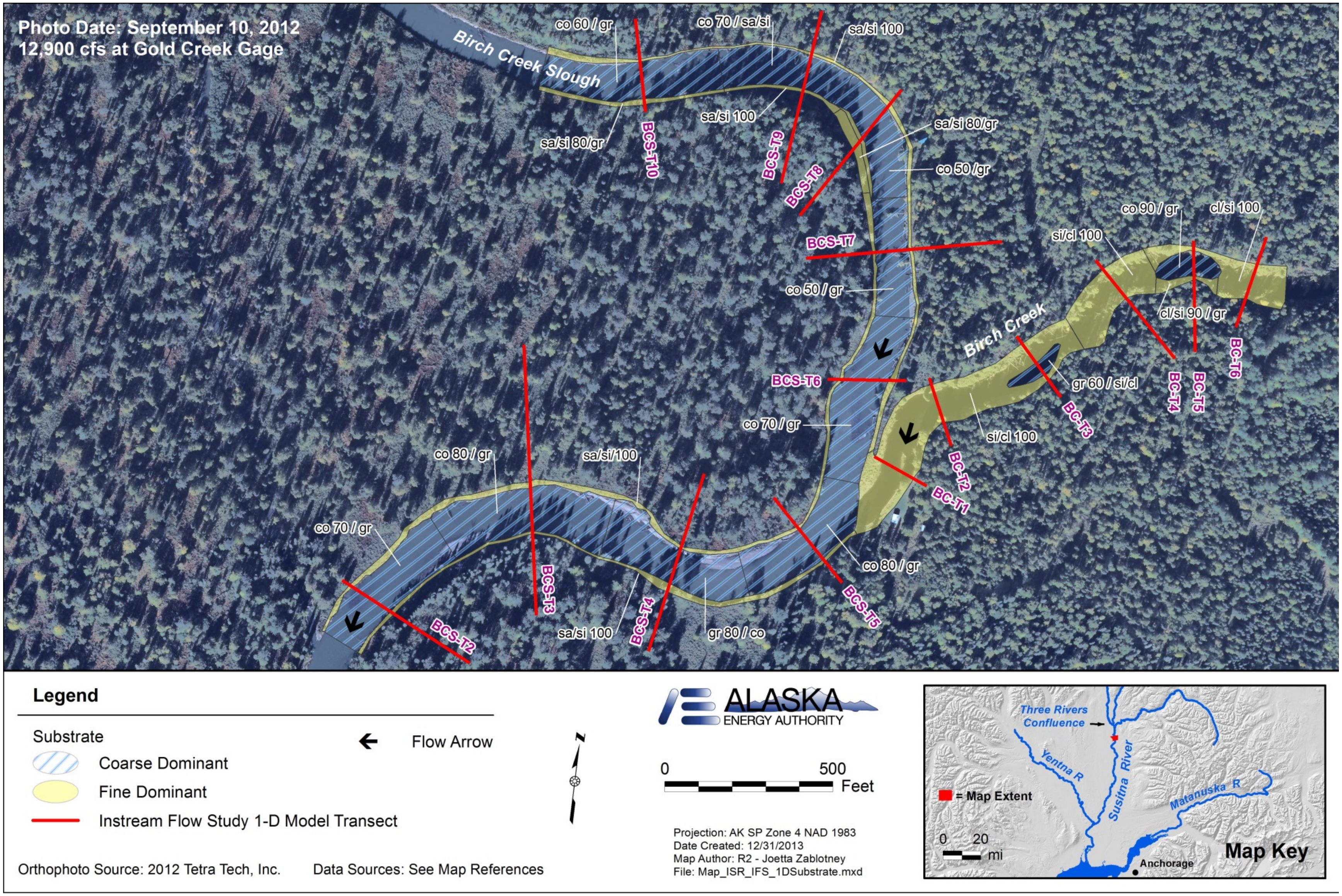


Figure 2: Birch Creek HEC-RAS Model Boundaries.

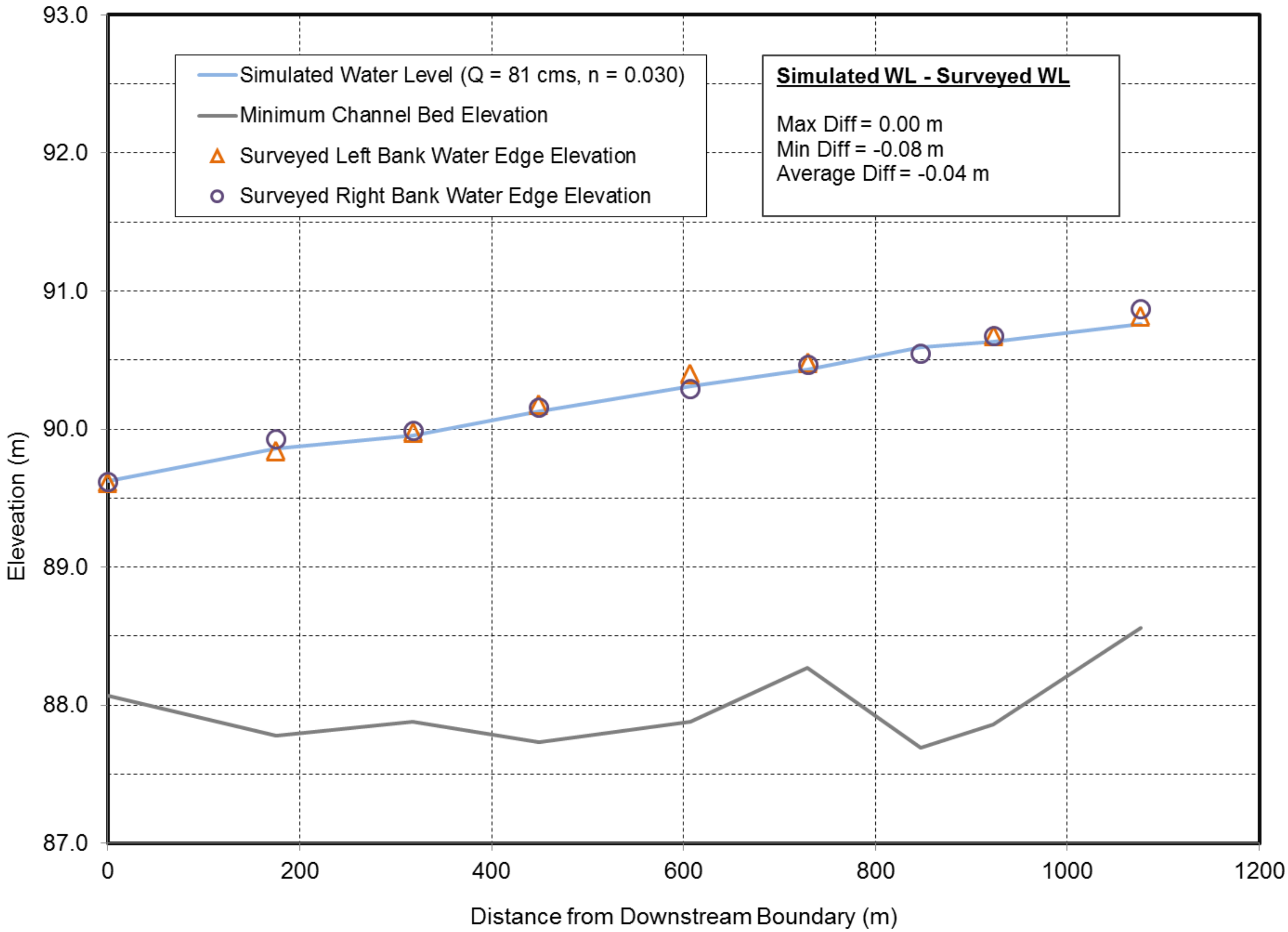


Figure 3. High Flow Calibration for the Birch Creek Slough Upstream and Downstream Reaches.

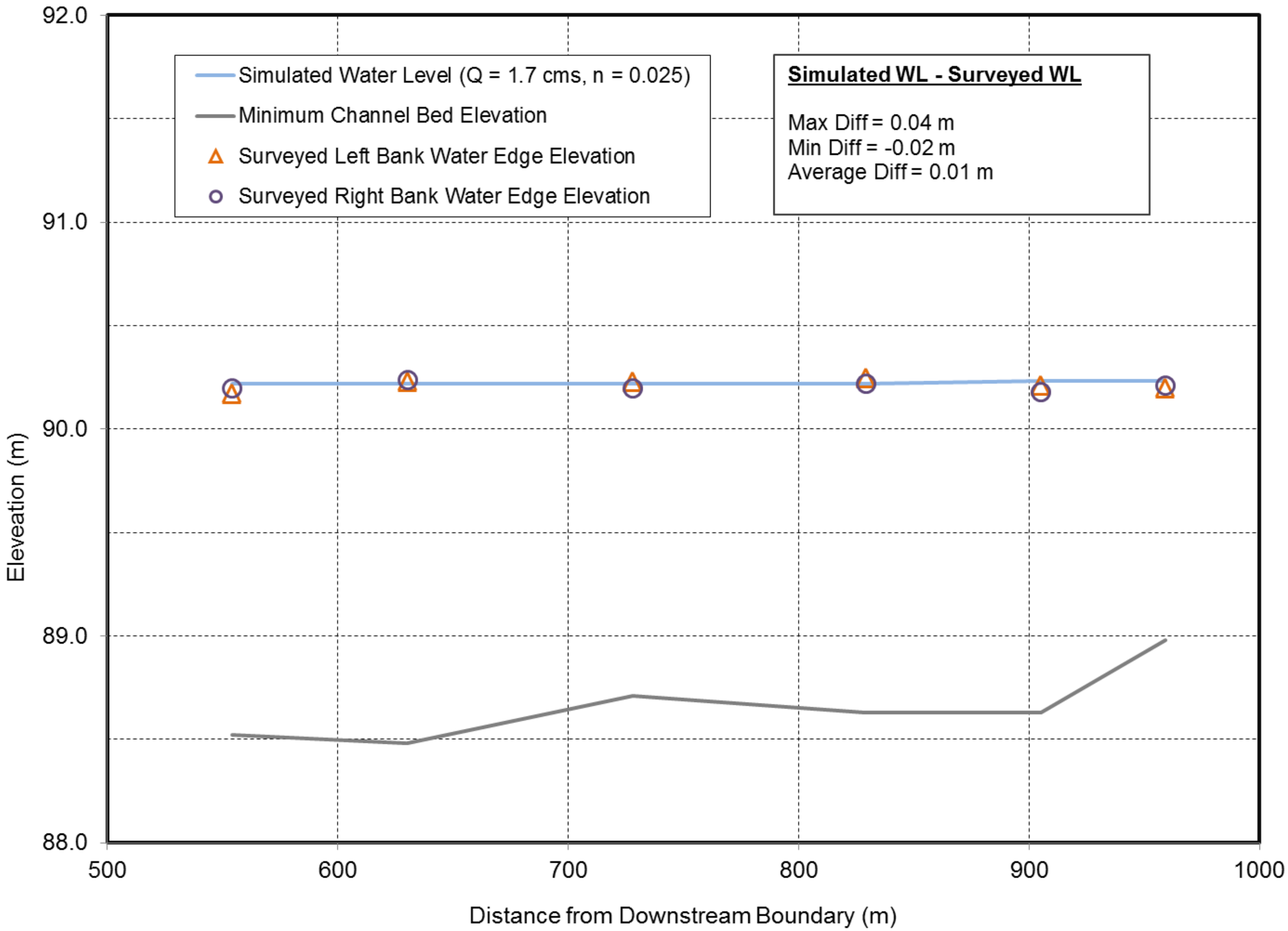


Figure 4. High Flow Calibration for Birch Creek.

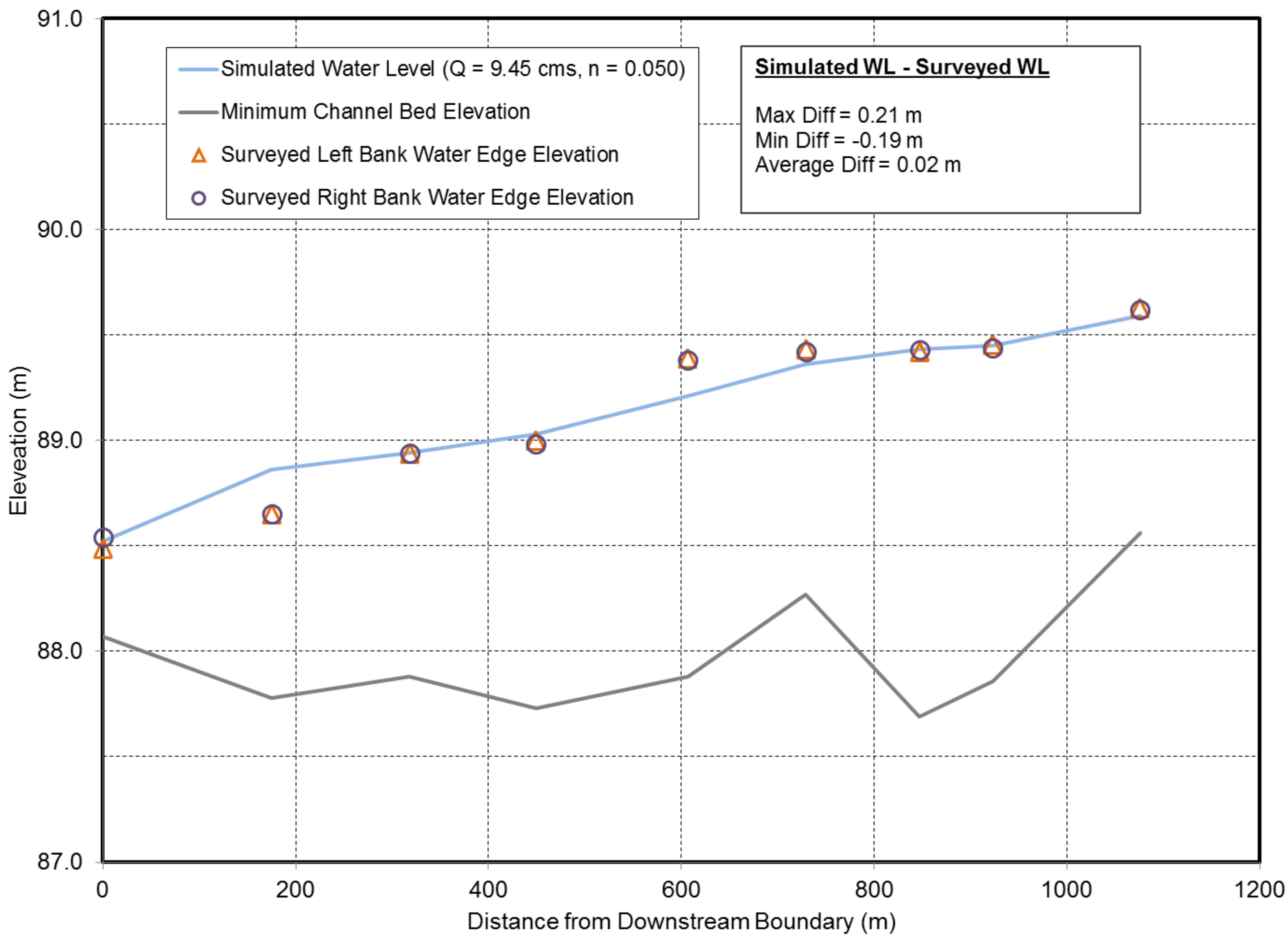


Figure 5. Low Flow Calibration for the Birch Creek Slough Upstream and Downstream Reaches.

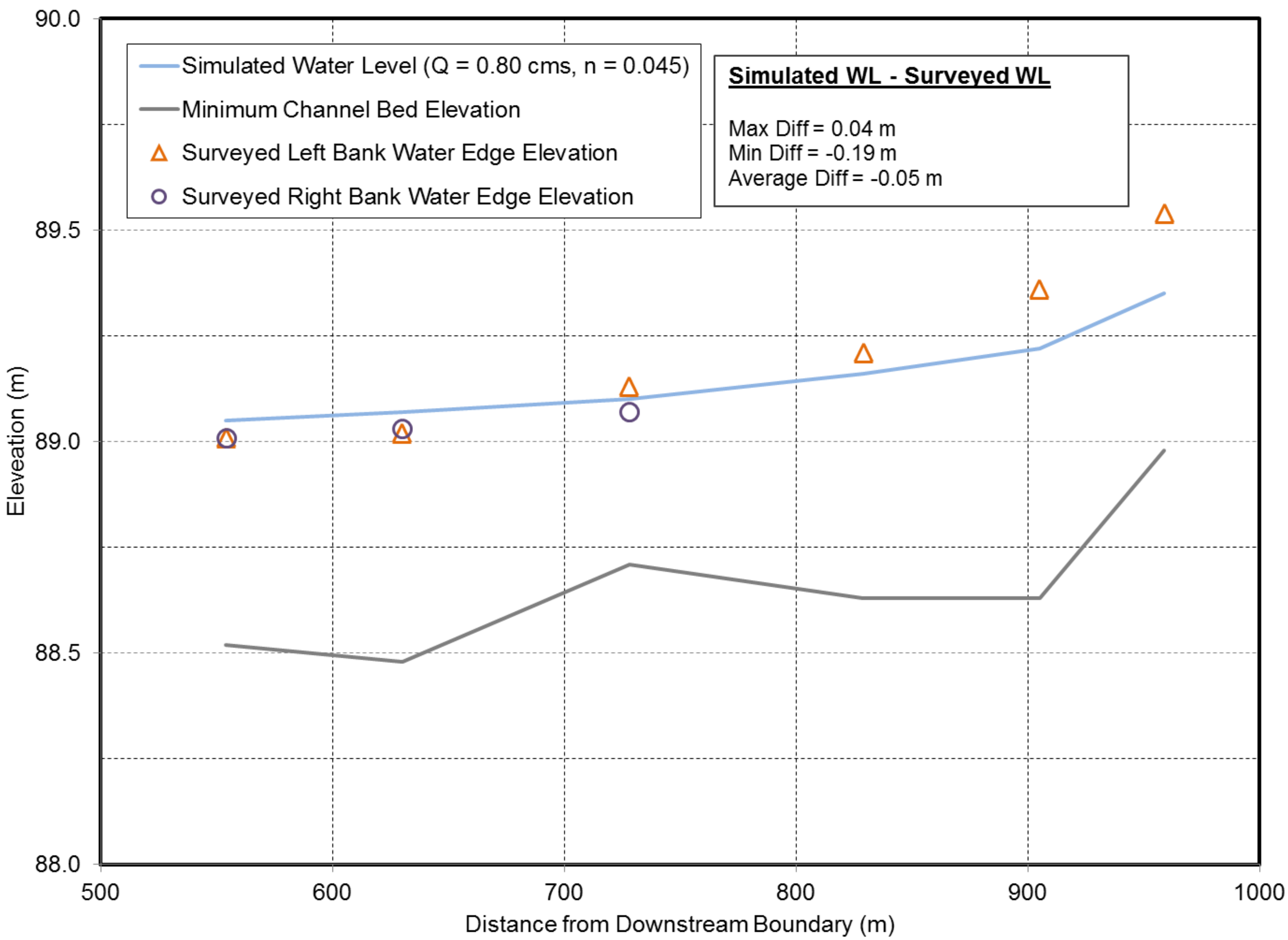


Figure 6. Low Flow Calibration for the Birch Creek Tributary.

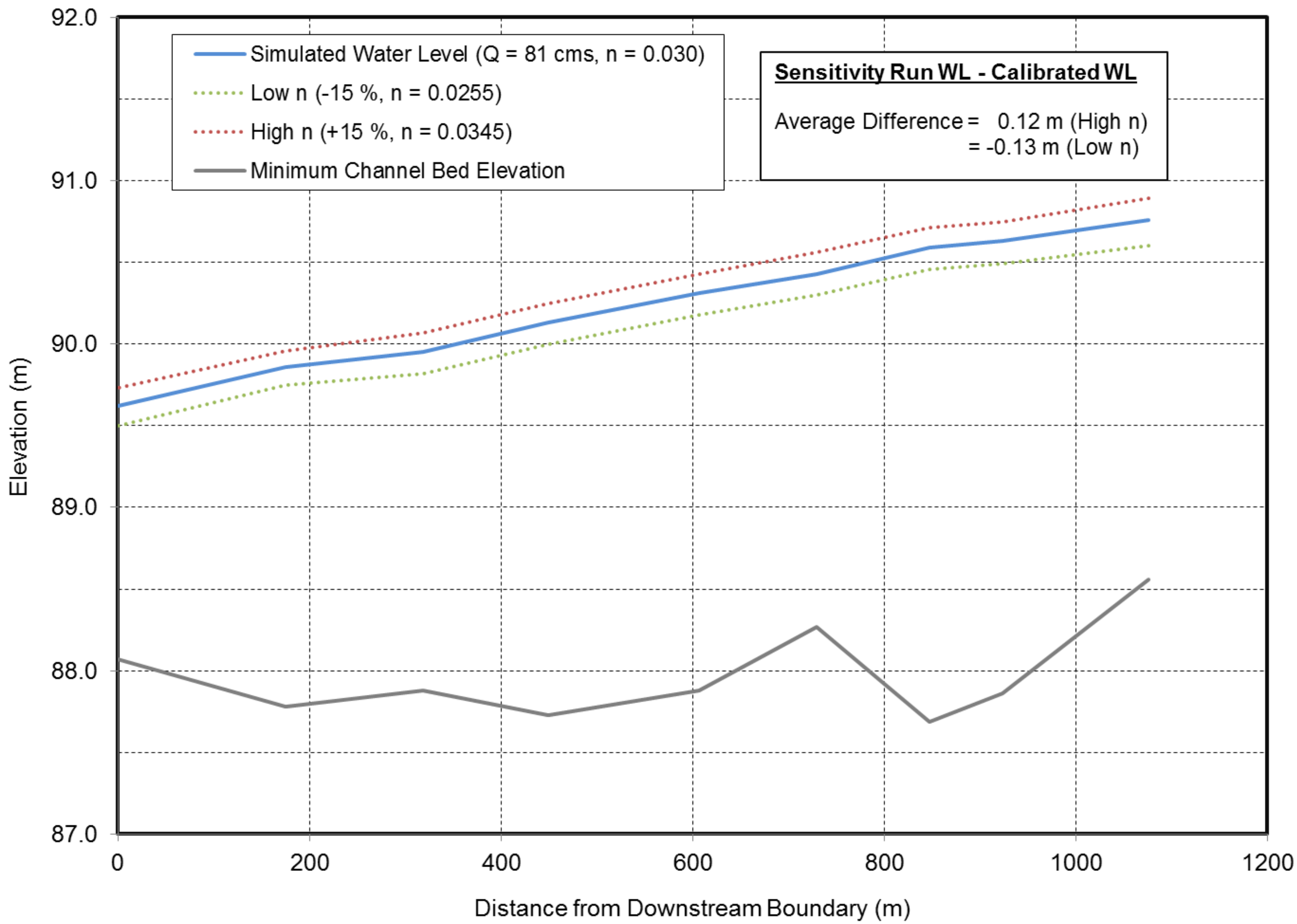


Figure 7. Sensitivity Analysis on Manning's n along the Birch Creek Slough for High Flow Scenario.

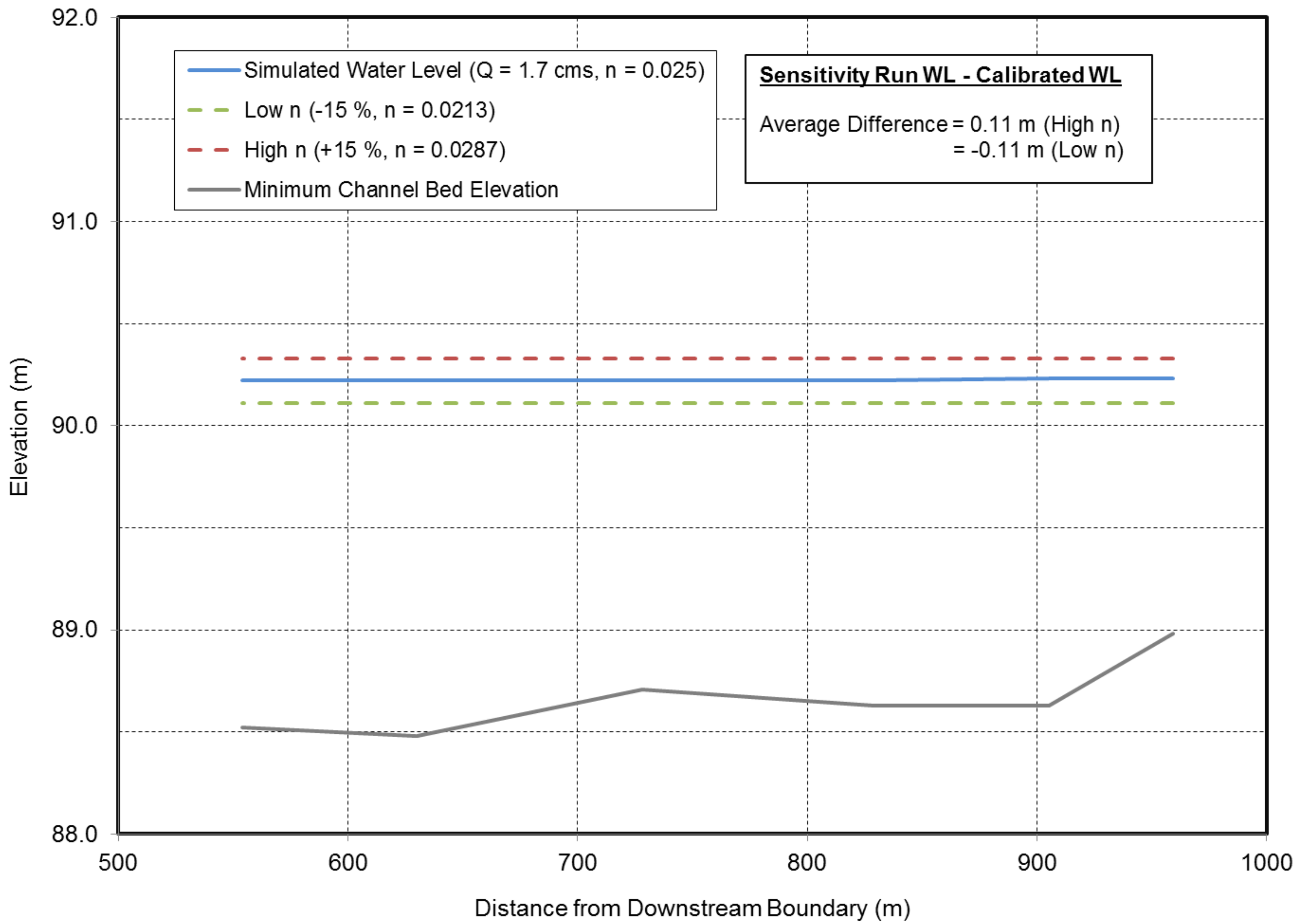


Figure 8. Sensitivity Analysis on Manning's n along the Birch Creek Tributary for High Flow Scenario.

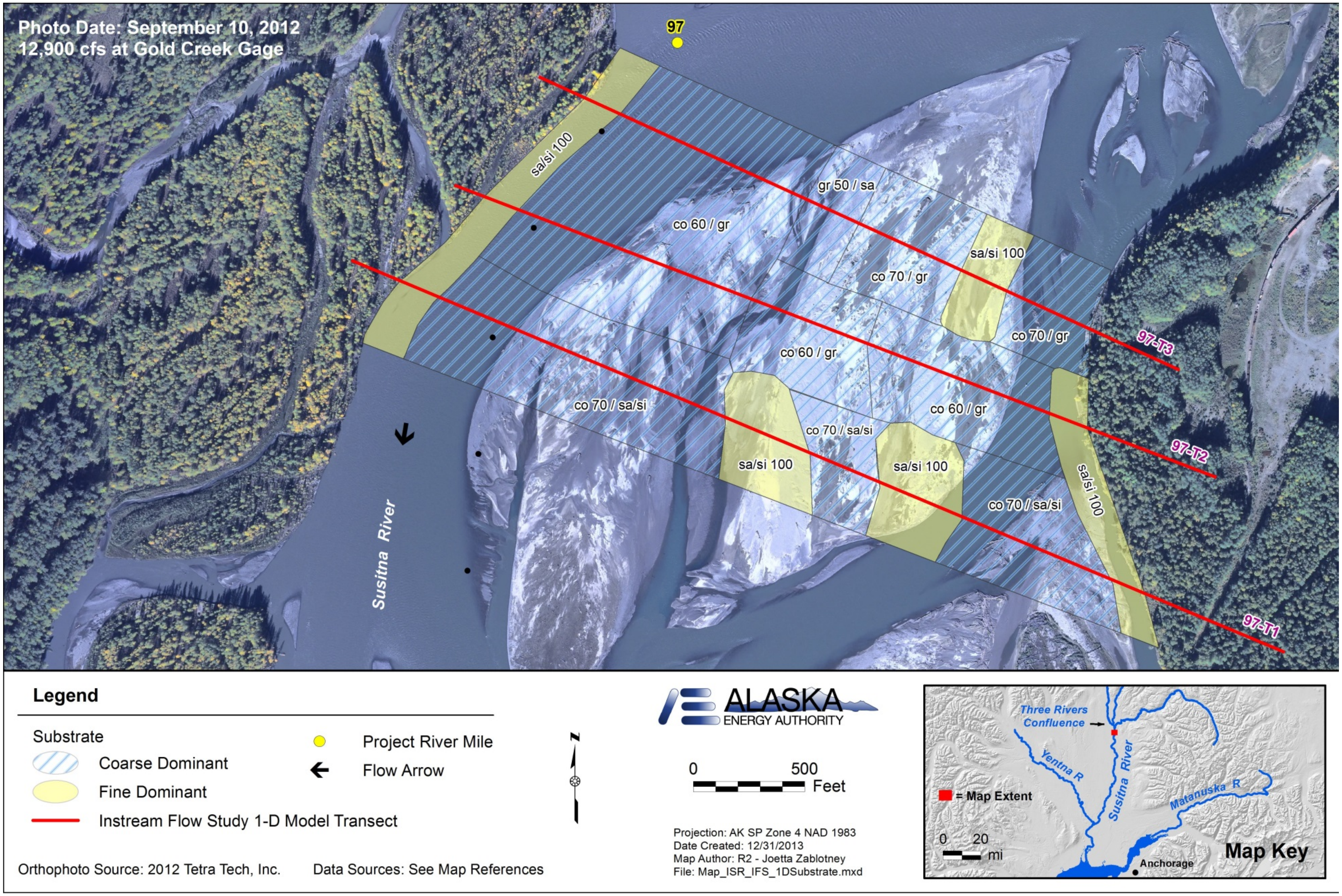


Figure 9. PRM 97 Site HEC-RAS Model Boundaries and Substrate Conditions.

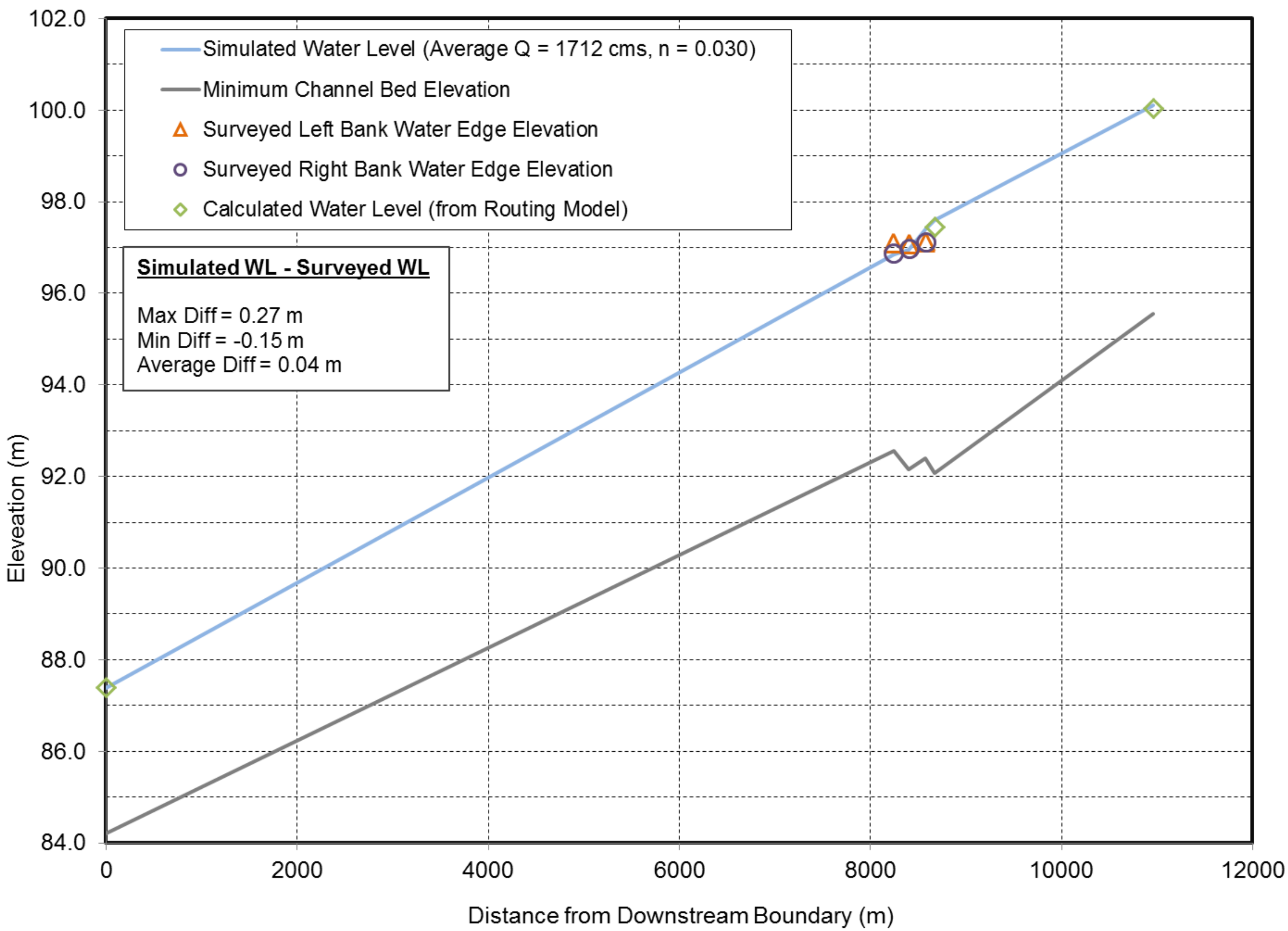


Figure 10. Calibration for June 2013 Average Discharge for the Full Modeled Length of PRM 97.

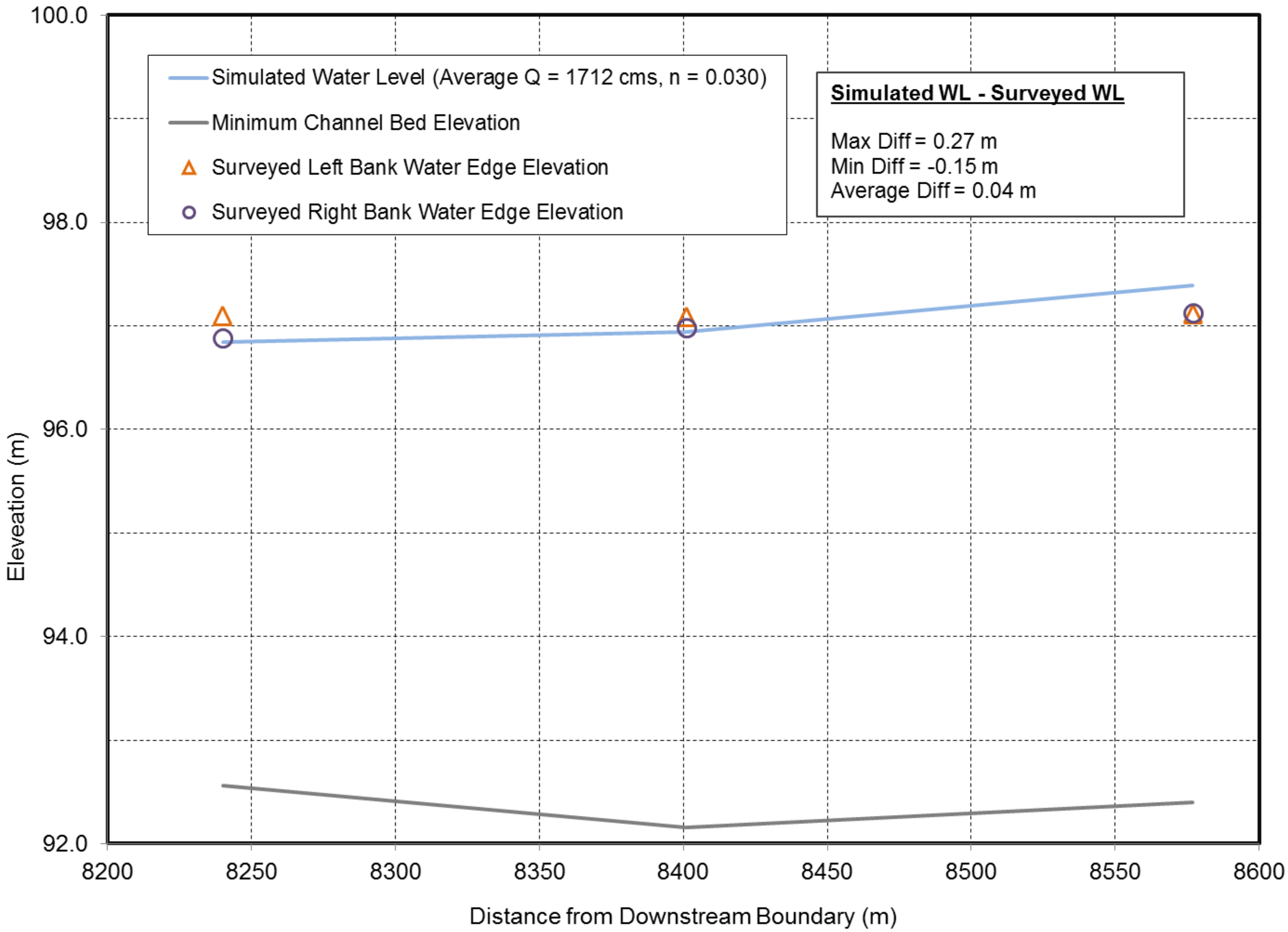


Figure 11. Calibration for June 2013 Average Discharge for the PRM 97 Site.

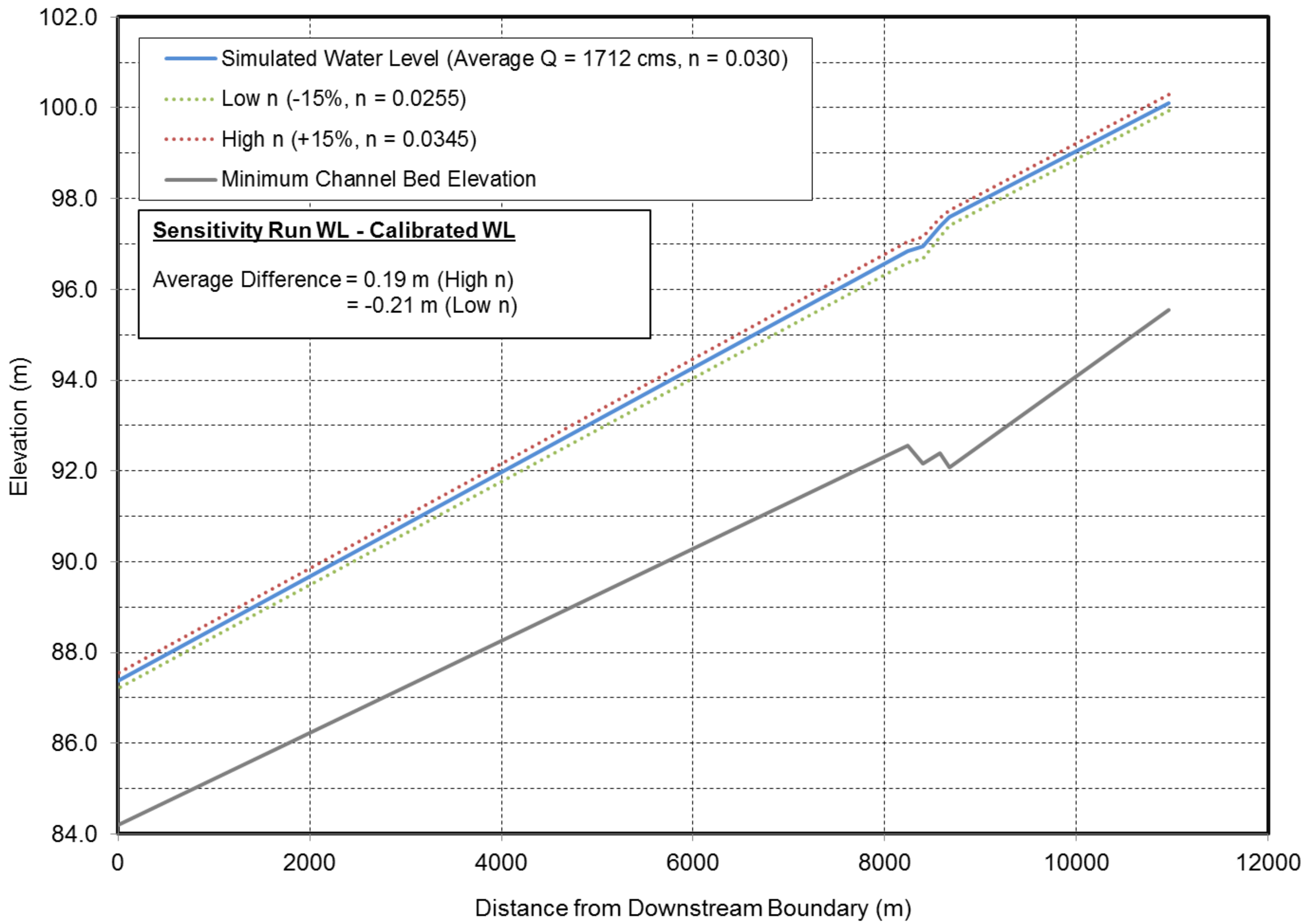


Figure 12. Measured Discharge Sensitivity Analysis for Manning's n for the Full Model Length under High Flow Scenario.

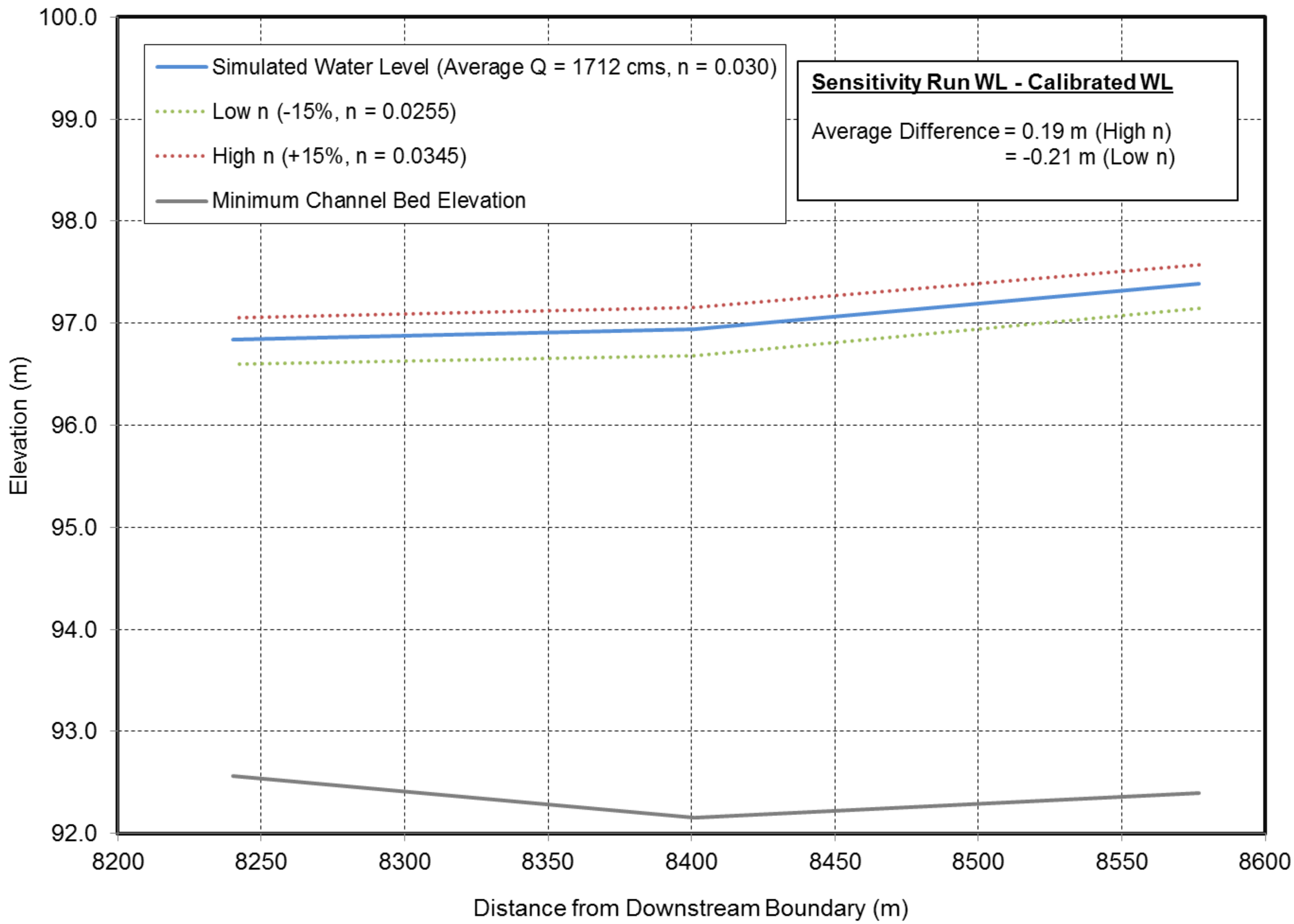


Figure 13. Measured Discharge Sensitivity Analysis for Manning's n for PRM 97 under for High Flow Scenario.

EXHIBIT 1. PHOTOGRAPHS OF THE BIRCH CREEK SITE

Photo 1. Aerial View of the Birch Creek Site (10 June 2013).

Photo 2. Birch Creek Slough Downstream Reach (10 June 2013).

Photo 3. Birch Creek Confluence of the Birch Creek Slough (10 June 2013).

Photo 4. Birch Creek (10 June 2013).

Photo 5. Birch Creek Slough T6 looking Downstream under High Flow Conditions (15 June 2013).

Photo 6. Birch Creek Slough T6 looking Downstream under Low Flow Conditions (25 September 2013).

Photo 7. Birch Creek at Transect 3 Looking Upstream under High Flow Conditions (June 15, 2013).

Photo 8. Birch Creek at Transect 3 Looking Upstream under Low Flow Conditions (September 25, 2013).

Photo 9. Birch Creek at Transect 2 Looking Downstream – Exposed Bed (September 25, 2013).