Susitna-Watana Hydroelectric Project Document
ARLIS Uniform Cover Page

Title: Fish and aquatics instream flow study, Study plan Section 8.5 : Initial study report -- Part A: Appendices A-C	**SuWa 223**

Author(s) – Personal:	
Author(s) – Corporate: R2 Resource Consultants, Inc. *Appendices A and C prepared also by:* Brailey Hydrologic, Geovera, and GWS.	
AEA-identified category, if specified: Initial study report	
AEA-identified series, if specified:	
Series (ARLIS-assigned report number): Susitna-Watana Hydroelectric Project document number 223	**Existing numbers on document:**
Published by: [Anchorage : Alaska Energy Authority, 2014]	**Date published:** June 2014
Published for: Alaska Energy Authority	**Date or date range of report:**
Volume and/or Part numbers:	**Final or Draft status, as indicated:**
Document type:	**Pagination:** 124 p. in various pagings
Related work(s): The following parts of Section 8.5 appear in separate files: Part A ; Part A Figures ; Part A Appendices A-C ; Part A Appendices D-F ; Part A Appendices G-I ; Part B ; Part C with Appendices J-K ; Appendices L-O.	**Pages added/changed by ARLIS:**
Notes: Contents: Appendix A. Hydrologic data collection methods -- Appendix B. Biological cues study -- Appendix C. 2013 moving boat ADCP measurements. Appendices J-O are in Part C.	

PART A - APPENDIX A: HYDROLOGIC METHODS
PART A - APPENDIX B: BIOLOGICAL CUES STUDY
PART A - APPENDIX C: MOVING BOAT ADCP MEASUREMENTS

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fish and Aquatics Instream Flow Study (8.5)

Part A - Appendix A
Hydrologic Data Collection Methods

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

R2 Resource Consultants, Inc.

Brailey Hydrologic

Geovera

GWS

June 2014

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND SCIENTIFIC LABELS

Abbreviation	Definition
ADCP	Acoustic Doppler Current Profiler
AEA	Alaska Energy Authority
CFR	Code of Federal Regulations
FERC	Federal Energy Regulatory Commission
FHA	Federal Highway Administration
GIS	geographic information system
GPS	global positioning system
IFS	Instream Flow Study
ILP	Integrated Licensing Process
ISR	Initial Study Report
LiDAR	Light Detection and Ranging
NEPA	National Environmental Policy Act
NZNIWAR	New Zealand National Institute of Water and Atmospheric Research
PRM	Project River Mile
Project	Susitna-Watana Hydroelectric Project No. 14241
RTK	real time kinematic
SOP	standard operating procedure
SPD	study plan determination
USGS	United States Geological Survey

1. INTRODUCTION

The Alaska Energy Authority (AEA) is preparing a License Application that will be submitted to the Federal Energy Regulatory Commission (FERC) for the Susitna-Watana Hydroelectric Project (Project) using the Integrated Licensing Process (ILP). The Project is located on the Susitna River, an approximately 300-mile long river in the Southcentral Region of Alaska. The Project's proposed dam site would be located at Project River Mile (PRM) 187.1. The results of this study will provide information that will serve as the basis for the 2013-14 formal study program and in preparing Exhibit E of a license application (18 CFR 4.41) and for use in FERC's National Environmental Policy Act (NEPA) analysis for the Project license.

Recent hydrologic data have been collected in 2012 and 2013 for use in developing the tools for Project effects analysis. This report summarizes the methods used for data collection of hydrologic data collected under the Instream Flow Study (IFS). It also includes information and references for similar data collected for other studies, including Water Quality (Studies 5.5 and 5.6), Geomorphology (Studies 6.5 and 6.6), and Ice Processes (Study 7.6). The main focus of this report is on open-water periods, but some data collection efforts are year-round and are pertinent to ice-covered periods.

2. MAINSTEM SUSITNA RIVER

The mainstem Susitna River hydrologic data collection included stage and discharge measurements, cross-sectional and areal bathymetric surveys, velocity mapping, and roughness determinations. This section is separated by the type of data collected. The surveying and Acoustic Doppler Current Profiler (ADCP) measurements are described first, since those collection techniques are used in multiple study areas. These sections are followed by descriptions of the stage, discharge, and bathymetric surveys, stage-recording measurements, and winter measurements.

2.1. Surveying

A number of different survey methods were used in this study. Global Positioning System (GPS) surveying included both high accuracy methods and the use of hand-held GPS systems for reconnaissance surveying. In some locations, optical level surveying was used to determine water level elevations and to set up temporary benchmarks at hydrology stations.

It is important to ensure that precision-critical data be located from a geodetic control network based on a single datum and epoch. In order to ensure the integrity of precision-critical data, strict standards were implemented for the survey of the geodetic control network from which the data locations were referenced. It was also necessary to implement strict standards for the survey of data locations tied from the control network.

Other aspects of the study require geographic location, but not to a high level of accuracy. It is important to distinguish between geographic data that are based on the geodetic control network (Static and Real-Time Kinematic [RTK] GPS) and data not based on the geodetic control network (hand-held GPS systems). A system of data descriptor quality assurance steps was implemented to distinguish whether a particular data point was based on the geodetic control network or upon a source of less geodetic accuracy.

The Alaska Society of Professional Land Surveyors Standards of Practice Manual adopted the California Geodetic Control Committee "Specifications for Geodetic Control Networks Using High-Production GPS Surveying Techniques 1995" (Anderson et al. 1995) as the standard for GPS surveying in Alaska. Study methods carefully adhered to the California Geodetic Control Committee specifications for GPS surveying.

RTK surveying is the method by which a single reference station is used to provide real-time carrier phase corrections by radio link to one or more roving GPS receivers, providing up to centimeter-level accuracy under ideal conditions. In this study, RTK surveys used two or more GPS units. At least one unit was set up over a known reference station and remained stationary, while the other (roving) GPS units were moved from station to station. All baselines were produced from the GPS unit occupying a reference station to the roving units. The stationary unit provided real-time corrections, which allowed the roving units to resolve integer ambiguities on the fly, providing up to centimeter-level accuracy under ideal conditions.

Data points such as temporary benchmark elevations, which require a level of accuracy greater than RTK methods can provide, were tied using static GPS observations. Typically, those observations were for a minimum period of 15 minutes. The post-processed results using single vector solutions over relatively short distances from the reference station provide the desired accuracy for sub-network level control points.

Static data post-processing was performed according to California Geodetic Control Committee guidelines. Post-processing software used least-squares adjustment algorithms and provided for atmospheric correction. GPS post-processing reports were produced for each day's control network group. Post-processing reports show that GPS observations met the desired specifications Band IV surveys for each vector, as well as for GPS occupation data for each control point and resulting post-processed and adjusted coordinates.

Instantaneous stage measurements were performed using either RTK GPS methods or optical levels, using benchmarks and geodetic control points that are part of the Project control network. The 2012 Susitna River cross-section field program established that the RTK survey method allowed for the greatest number of cross-sections to be surveyed each day and helped maintain safety objectives. In addition, the RTK data quality parameters and time stamp information contained in the field controller database files ensured the accuracy of the water level measurements and eliminated the possibility for transformation of numbers by the field crews. The GPS Project survey-control (control point) network (horizontal and vertical) was evaluated in the spring of 2013. The vertical datum was verified and any missing benchmarks due to bank erosion or other issues were replaced. Additional control point surveys were and will continue to be conducted to support Focus Areas and other studies from the Lower Susitna River Segment to the Upper Susitna River Segment, as needed. RTK survey control points were placed at final Focus Areas to provide study field teams with horizontal and vertical control networks designed to allow efficient ground surveying with RTK, optical levels, and other conventional survey methods.

A standard operating procedure (SOP) guide was established to provide uniform survey methods and data reporting standards. The SOP specifies the use of Focus Area survey control networks (horizontal and vertical) by the various field study teams working in these areas. It also details the appropriate reporting of RTK survey methods and data. All surveying information has been provided in datasets applicable to existing or developing relational or spatial databases.

In order to verify the accuracy of Project Light Detection and Ranging (LiDAR) information (Study 6.6), existing ground shots were taken at 25 locations in the Lower Susitna River Segment and 125 locations in the Middle and Upper Susitna River Segments. Over 19,000 ground shots were collected in 2013 that can be used to spot-check the LiDAR Digital Elevation Model for accuracy. The field plans for collecting the LiDAR validation data were coordinated with the study teams and the Project Geographic Information System (GIS) technical group.

All AEA gaging or water level stations had RTK or control point surveys established as well as temporary benchmarks installed to allow efficient optical-level loop surveys. Project survey control was established at USGS gaging stations on the Susitna River within the Project study area and at key tributaries. The offsets from USGS local datum to Project elevation datum were established to provide USGS to Project vertical datum conversion standards. These conversions are critical to using the USGS gage water levels in all relevant Project hydrology modeling and studies.

2.2. ADCP Measurements

ADCP measurements are described in the technical memorandum titled 2013 Moving Boat ADCP Measurements (ISR Study 8.5, Appendix C). This technical memorandum covers ADCP measurements collected on the mainstem for cross-sections used in the Open-water Flow Routing Model as well as those collected in the Focus Areas. Focus Area measurements are described in additional detail in the Geomorphology section of the ISR (ISR Study 6.6).

2.3. Stage, Discharge, and Bathymetric Surveys

Stage, discharge, and bathymetric surveys are collected at various cross-sections using the surveying and ADCP methods described above. The cross-sections were either surveyed using ADCPs or single-beam depth sounders. In either case, bathymetric data are referenced to the Project geodetic control network using RTK GPS survey methods.

Cross-sectional measurements were collected to meet hydraulic flow routing, sediment transport, riparian, and water quality needs. Cross-sectional profiles were measured using a combination of RTK surveying methods. RTK profiles were taken in the upland portion (from edge of water to edge of vegetation typically) and additional water surface elevations were taken approximately 200 feet upstream and downstream of the baseline. Water level measurements were made primarily by RTK surveying or optical level-loop surveying methods.

In all, 88 cross-sections were collected in 2012 between PRM 29.9 and PRM 187.2. Twelve of these cross-sections were located at or near gaging stations operated by USGS or the water level recording stations operated by the AEA. Stage and discharge measurements were also collected at inactive USGS gaging stations in the Lower River (Susitna River at Susitna Station [ESS20], PRM 29.9) and in the upper basin (Susitna River near Cantwell [ESS80], PRM 225) (see Table 1 for station naming convention). Cross-sectional measurements were collected in 2013 at approximately 80 locations between PRM 29.9 and PRM 187.2. An additional 25 cross-sections are scheduled for collection during the second year of study. Stage and discharge measurements from 2012 were used to calibrate Version 1 of the Open-water Flow Routing Model. Stage and discharge measurements from 2012 and 2013 will be used to calibrate Version 2 of the Open-water Flow Routing Model.

Roughness determinations are made by solving Manning's equation using field measurements of discharge and water-surface slope. In order to validate the roughness, vegetation descriptions and photographs (upstream, downstream, into bank, opposite bank) above ordinary high water elevations were collected at each cross-section. The distance away from shoreline for cross-section surveys was determined in the field by the Lead Field Hydrologist. The vegetation descriptions and photographs will be compared to reported values of Manning's n and adjusted as necessary (USGS 1967, NZNIWAR 1998, and FHA 1984).

Stage, discharge, and bathymetric surveys were also collected in Focus Areas. A description of the Focus Area measurements is also provided in Geomorphology (ISR Study 6.6). Measurements were collected in the Focus Areas for calibration of the Focus Area models. Data collected included bathymetry, water-surface elevations, inlet and outlet elevations, and velocity.

2.4. Stage Recording Measurements

Together with water temperature and meteorological data, continuous stage measurements were recorded at AEA hydrology stations at 15-minute intervals and made available to studies via the real-time reporting data network. Continuous stage measurements were made using vented pressure transducers accurate to within about 0.02 feet. The hydrology stations required periodic water elevation surveys, either performed by RTK surveying or by optical-level loop survey methods. The water levels allow the conversion of the pressure transducer data to surface-water elevation in Project vertical datum standards. The elevations surveys were conducted during discharge measurements, changes or repositioning of pressure transducers, and before and after major hydrologic events such as fall freeze-up and spring break-up. The hydrology stations were operated throughout the year to support both summer (open-water) and winter (ice-cover) study needs for the IFS and other studies. Table 2 shows a listing of the stations in the real-time reporting data network.

Maintaining a constant stage record during river freeze-up and spring break-up is a challenge. River ice jams and ice jam break-ups can result in some minor losses of stage data. Pressure transducers and water temperature sensors were added at hydrology stations to provide the Groundwater (Study 7.5) and Ice Processes (Study 7.6) teams with winter pressure (water pressures under ice, water levels in ice-free or partial ice-covered reaches) and water temperature measurements. Sensors lost during spring break-up were replaced as soon as it was safe and practical to install. All data were recorded on Campbell Scientific CR1000 data loggers, with internal memory backup. AEA hydrology stations also have data archived through hourly data retrievals over the radio telemetry network. This approach ensured that no data were lost from icing conditions except for the narrow period when pressure transducers may have been damaged at a gaging station and new sensors had not yet been installed.

2.5. Winter Measurements

Winter streamflow measurements provide valuable information for understanding hydraulic conditions in the Susitna River during seasons when groundwater plays a more prominent role in aquatic habitat functions. Winter streamflow measurements have been coordinated with Ice Processes (Study 7.6) so that measurements also have direct applications to the ice processes analysis and model development efforts. Winter mainstem flows were measured using a combination of current meter and ADCP methods and were coordinated with USGS so that measurements from both programs occurred at the same general time period and are synoptic data sets associated with winter operational logistics. The mainstem discharge measurements will help assess gaining and losing river reaches during winter conditions.

3. TRIBUTARIES TO THE SUSITNA RIVER

Gaging stations were installed at selected tributaries to help provide additional data for hydrologic and fisheries studies. The gaging stations were installed in spring/early summer of 2013 to help measure the spring snowmelt peaks.

There are a total of 12 tributary gaging sites. Ten sites have continuous loggers which measure water pressure data in 15-minute increments. At these sites, streamflow measurements were also collected at up to 4 dates in 2013. Two tributary gaging sites are spot measurement only sites which had streamflow measurements collected at up to three dates in 2013. The locations of these sites are provided in Table 3 and shown in Figure 1. Three of these streams had a companion stage-only site located in the downstream slough of the mainstem of the Susitna River. Most tributary gaging sites were visited three times during the summer of 2013. On the first visit, benchmarks were installed and where possible, a stilling well and staff gage. Benchmarks consisted of either a nail or eyebolt in a tree or stable log. If an adequate site was located, a fencepost was pounded into the stream and a 4-foot PVC tube was mounted to one side of the stilling well. The datalogger was hung on the end of a cable suspended in the stilling well. See Figure 2 for an example photo of the stilling well and staff gage set-up. On the other side, a 3.3-foot staff gage mounted on a 2 inch by 4 inch piece of pressure treated wood was attached. The staff gage is marked with a number at every foot and tenth of a foot and graduated to the hundredths. If no adequate site was located for a stilling well, then a bottom-mounted unit was installed. A bottom-mounted unit consists of a short PVC tube attached horizontally to a brick. The brick was tethered by a cable, which was connected to a tree. The datalogger was attached to a bolt screwed into the tube. See Figure 3 for an example bottom-mounted unit. Each site consisted of one main unit and one back-up unit. All except one tributary gage site had a stilling well set-up for the main unit and all sites had the bottom-mounted units for the back-up. The three companion stage-only sites were all bottom-mounted units.

During each visit, local reference (i.e., benchmark) and water surface elevations were surveyed. All surveying was conducted with a Leica Runner 24 automatic level and elevations surveyed to one-hundredth of a foot. On the first visit, a cross-sectional profile elevation was collected either at the hydraulic control or near the location of the levelogger. The water pressure at each continuous site was measured using a Solinst Model 3001 Levelogger Junior Edge. The leveloggers were set to record pressure in feet of water and temperature in degrees Celsius. The sample mode was set to linear and no offset was included. All loggers were synchronized to the computer time with a note as to if the time was in Alaska daylight or standard time. The loggers were set to record measurements in 15-minute increments starting on the hour. The barometric pressure was measured using a Solinst Model 3001 Barologger Edge. Four barologgers were installed at select sites coinciding with a tributary gage. All barologgers had settings similar to the leveloggers.

Streamflow measurements were collected at all sites. To measure streamflow, depth and velocity information was collected at multiple stations along a transect. Velocity measurements were collected using either the ADCP methods as described above or using a SonTek Flow Tracker attached to a top set wading rod. A top set wading rod is a metal shaft used to measure stream depth and to position the velocity meter at the desired depth in the water. The flow tracker is an acoustic Doppler velocimeter and was set to record the average velocity over a 30-second period. A minimum of 20 stations were collected along the streamflow transect.

Lastly, photographs were collected at each site. Photos were collected looking upstream, downstream, and across the flow transect. At continuous sites, photos were also collected of the staff gage/stilling well.

All data were QA/QC'd for accuracy.

4. REFERENCES

Anderson, M., D. D'Onofrio, G.A. Helmer, W. Wheeler. 1995. Specifications for Geodetic Control Networks Using High-Production GPS Surveying Techniques. California Geodetic Control Committee. Version 2.0, July 1995.

NZNIWAR (New Zealand National Institute of Water and Atmospheric Research). 1998. Roughness characteristics of New Zealand rivers, Water Resources Publications, LLC.

USGS (United States Geological Survey). 1967. Roughness characteristics of natural channels, Geological Survey Water-Supply Paper 1849.

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.

5. TABLES

Table 1. Summary of gaging stations established on Susitna River in 2012.

Gaging Station	Project River Mile	Segment
Susitna River near Cantwell (ESS80)	225.0	Upper Susitna River
Susitna River below Deadman Creek (ESS70)	187.1	Middle Susitna River (above Devils Canyon)
Susitna River below Fog Creek (ESS65)	176.5	
Susitna River above Devil Creek (ESS60)	168.1	
Susitna River above Portage Creek (ESS55)	152.2	Middle Susitna River (below Devils Canyon)
Susitna River at Curry (ESS50)	124.1	
Susitna River below Lane Creek (ESS45)	116.6	
Susitna River above Whiskers Creek (ESS40)	107.2	
Susitna River at Chulitna River (ESS35)	102.1	
Susitna River below Twister Creek (ESS30)	98.4	Lower Susitna River
Susitna River at Susitna Station (ESS20)	29.9	
Susitna River near Dinglishna Hill (ESS15)	24.7	
Susitna River below Flat Horn Lake (ESS10)	17.4	

Notes:
1 ESS = AEA Susitna River Surface-Water Station.

Table 2. Susitna Real-Time Reporting Network Stations.

Site Name	Short Name	Parameters
Upper Segment AEA Gaging Stations		
15291500 Susitna River Near Cantwell	ESS80	discharge, water level, water and air temperature, camera
Middle Segment AEA Gaging Stations		
Susitna River Below Deadman Creek	ESS70	discharge, water level, water and air temperature, camera
Susitna River Below Fog Creek	ESS65	discharge, water level, water and air temperature, camera
Susitna River Above Devil Creek	ESS60	discharge, water level, water and air temperature, camera
Susitna River Below Portage Creek	ESS55	discharge, water level, water and air temperature, camera
Susitna River at Curry	ESS50	discharge, water level, water and air temperature, camera
Susitna River Below Lane Creek	ESS45	discharge, water level, water and air temperature, camera
Susitna River Above Whiskers Creek	ESS40	discharge, water level, water and air temperature, camera
Lower Segment AEA Gaging Stations		
Susitna River at Chulitna River	ESS35	discharge, water level, water and air temperature, camera
Susitna River Below Twister Creek	ESS30	discharge, water level, water and air temperature, camera
15294350 Susitna River at Susitna Station	ESS20	discharge, water level, water and air temperature, camera
Susitna River Near Dinglishna Hill	ESS15	water level, water and air temperature, camera
Susitna River Below Flat Horn Lake	ESS10	water level, water and air temperature, camera
Repeater Stations		
Mount Susitna Near Granite Creek	ESR1	air temperature
Repeater, East of ESM1, First Potential Site	ESR2	air temperature
Repeater, Dam Site to Glacial Repeater	ESR3	air temperature
Curry Ridge near McKenzie Creek Repeater	ESR4	air temperature
Curry Pt. To State Park Repeater	ESR5	air temperature, camera
State Park over Devils Canyon Repeater	ESR6	air temperature, camera
Portage Creek Repeater	ESR7	air temperature
ESR2 to ESS80, ESM2 link	ESR8	air temperature
Base Stations		
Talkeetna Base Station	ESB2	N/A

Notes:

1 ESS = AEA Susitna River Surface-Water Station.

2 ESR = AEA Susitna River Repeater Station

3 ESB = AEA Susitna River Base Station

Table 3. Tributary gaging site information.

Tributary Name	Susitna PRM	Gage Site Type	Elevation (ft)	Latitude	Longitude
Oshetna River	235.1	Continuous	2173	62.628520	-147.369830
Kosina Creek	209.1	Continuous with barologger	1911	62.755970	-147.955150
Unnamed Tributary 144.6	144.6	Spot	750	62.803980	-149.591350
Indian River	142.1	Continuous	775	62.800826	-149.664417
Skull Creek	128.1	Continuous with barologger	599	62.657530	-149.932540
Gash Creek	115	Continuous	460	62.504288	-150.104018
Slash Creek	114.9	Spot	452	62.503202	-150.103737
Unnamed Tributary 113.7	113.7	Continuous	455	62.486316	-150.093785
Whiskers Creek	105.1	Continuous with barologger	370	62.378096	-150.170806
Trapper Creek	95.4	Continuous	310	62.257540	-150.172762
Susitna River at Trapper Creek	95.4	Continuous stage only	306	62.253622	-150.168375
Birch Creek	93.3	Continuous	307	62.250468	-150.089622
Susitna River at Birch Creek Slough	92.6	Continuous stage only	291	62.223373	-150.116821
Deshka River	44.9	Continuous with barologger	83	61.754230	-150.328540
Susitna River at Deshka River	44.9	Continuous stage only	78	61.696491	-150.313659

6. FIGURES

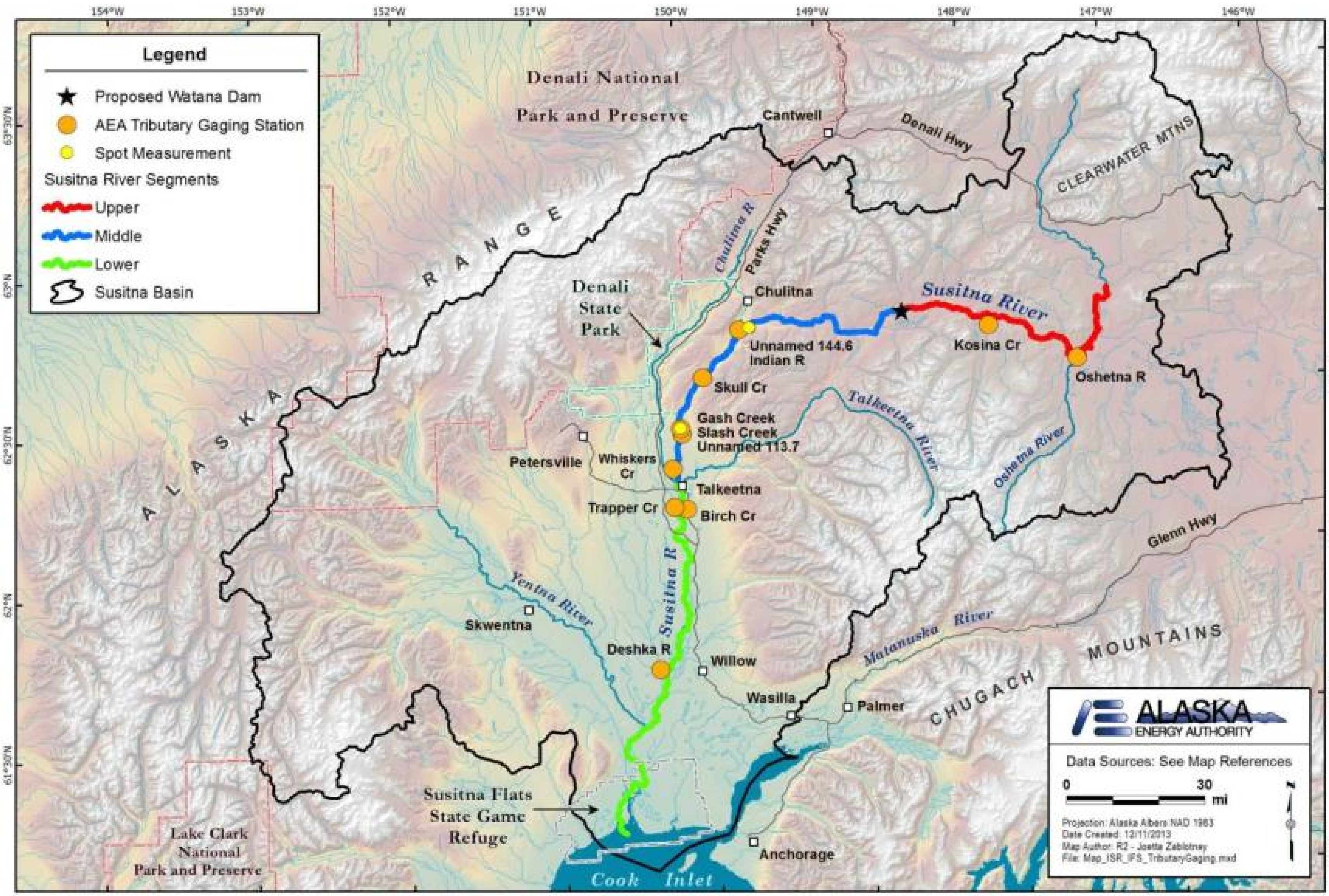


Figure 1. 2013 Tributary Gaging Locations.

Figure 2. Example stilling well and staff gage setup.

Figure 3. Example bottom-mounted unit.

Susitna-Watana Hydroelectric Project

(FERC No. 14241)

Fish and Aquatics Instream Flow Study (8.5)

Part A - Appendix B

Biological Cues Study

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

R2 Resource Consultants, Inc.

June 2014

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND SCIENTIFIC LABELS

Abbreviation	Definition
ADF&G	Alaska Department of Fish and Game
AEA	Alaska Energy Authority
AIC	Akaike's Information Criteria
cfs	cubic feet per second
EFC	Environmental Flow Component
FERC	Federal Energy Regulatory Commission
IHA	Indicators of Hydrologic Alteration
ILP	Integrated Licensing Process
ISR	Initial Study Report
PDO	Pacific Decadal Oscillation
Project	Susitna-Watana Hydroelectric Project No. 14241
SPD	study plan determination

1. INTRODUCTION

Climatic and hydrologic patterns are important considerations in determining salmon distribution and abundance. Large-scale climatic changes (e.g., Pacific Decadal Oscillation [PDO]) affect regional weather conditions that subsequently influence hydrologic conditions (Hartmann and Wendler 2005). Changes in river hydrology can influence the stability and persistence of aquatic habitats and can determine fish distribution and abundance (Connor and Pflug 2004). In the Alaska Energy Authority (AEA) Study Plan (RSP Section 8.5.4.5.1.3), AEA stated it would examine long-term adult salmon escapement data to identify relationships between temporal patterns in environmental conditions and salmon distribution, abundance, and migration. Analyses of these flow-dependent biological cues, such as possible relationships between climatic, hydrologic, and fish habitat indices and salmon abundance and migration timing, was to be based on available long-term datasets for Deshka River Chinook salmon and Yentna River sockeye salmon. Other Susitna River Basin long-term datasets pertaining to salmon migration timing and abundance would also be included if available.

Estimated escapement for Yentna River sockeye salmon was below the sustainable escapement goal for most years between 1999 and 2005. This prompted an Alaska Department of Fish and Game (ADF&G) action plan and research into the escapement estimates for sockeye. This research is ongoing, but it has uncovered major uncertainties in historical run-size estimation methods for the Yentna River. The uncertainties are related to the Bendix-based sonar estimation limitations, as well as to species selectivity in fishwheels (Westerman and Willette 2013; Yanusz et al. 2011). These concerns led ADF&G to stop using these escapement estimates in 2010 (Westerman and Willette 2013). A study conducted in 2012 estimated a range of escapement from 30,000 (estimated using sonar and fishwheel apportionment) to 99,000 (estimated using gill nets; Westerman and Willette 2013).

Historical escapement estimates for Deshka River Chinook salmon are more defensible. However, there is a very short period of record for measured flows on the Deshka River. Further, Deshka River flows could not be estimated by correlation with other nearby reference gages in the basin because the Deshka is not influenced by glacial runoff. Thus, hydrological data were not sufficient for creating the metrics that were required for this type of analysis.

Through examination of data reports and available hydrological data, and discussions with ADF&G personnel (R. Clark, J. Ericson, and J. Klein, ADF&G, personal communication, August 9, 2013), the Deshka River and the Yentna River were ruled out as plausible datasets to examine relationships between hydrology and biological response relevant to Susitna River salmon stocks. Furthermore, the ADF&G personnel suggested that the Taku River and Stikine River would likely be better representatives to make these assessments, since both are glacial river systems and therefore should have similar runoff response patterns to the Susitna River, and both support populations of Chinook salmon. Moreover, ADF&G has been monitoring both systems for a number of years and both are included as “indicator stocks” in the Chinook Salmon Stock Assessment and Research Plan for 2013 (ADF&G Chinook Research Team 2013). The Copper River was also considered by the ADF&G but because of data quality issues and the different life history strategy exhibited by Chinook in that system, it was not recommended for evaluation (J. Klein, ADF&G, personal communication, September 29, 2013). Thus, this analysis centered on the assessment of Chinook stocks in the Taku and Stikine rivers.

2. METHODS

The objective of this exploratory analysis was to look for general relationships between hydrological variables and biological responses of salmon species that may be relevant to the Susitna River. If such relationships exist, they are likely to be highly complex and interactive. This study was based on available data only, and is not meant to be exhaustive. Rather, we looked for moderate correlations and evaluated relationships visually and using regression analysis. It is possible and perhaps likely that some observed correlations in these data are not causally linked. In turn, it is likely that some relationships exist that are not discoverable without more detailed population models.

2.1 Biological Indicators

Chinook salmon harvest levels and smolt and adult abundance levels for the Taku and Stikine rivers were acquired from ADF&G (R. Phillips, ADF&G biologist, personal communication, September 6-12, 2013). Data collection methods are described in McPherson et al. (2010) for the Taku River and in Richards et al. (2012) for the Stikine River. For each river, annual data consisted of the following:

- Harvest levels downstream of the fish-counting station
- Harvest levels upstream of the counting station
- In-river run size at the counting station
- In-river age structure (percent of run in ages 3-7)
- Smolt abundance by brood year

These data were refined into two types of biological indicators for this analysis, as shown in Table 1. Estimated values for these indicators in both river systems are provided in Table 2 and Table 3 and plotted in Figure 1 through Figure 6. In river age structure was used to calculate the number of fish by age class. Returns by brood year were calculated by summing the appropriate age classes across years. Escapement was estimated by subtracting the upstream harvest levels from the in-river run size.

2.2 Hydrologic and Environmental Metrics

Daily flow data were acquired from USGS gages located in the lower Stikine and lower Taku rivers (Gage 15024800 and Gage 14041200). The gage record for the Taku River extended from 1988 to 2012 (25 years) and from 1977 to 2012 (36 years) for the Stikine River. PDO data were acquired from the University of Washington Joint Institute for the Study of the Atmosphere and Ocean (UWJISAO 2013). The hydrologic data were initially analyzed using The Nature Conservancy's (TNC) Indicators of Hydrologic Alteration (IHA) and Environmental Flow Component (EFC) software (TNC 2009). This resulted in the calculation of 33 IHA metrics and 34 EFC metrics for each system. The raw outputs of IHA metrics are presented in Table 4 through Table 8 (note that raw EFC results are not reported as they were not robust and were not used in the analysis). The outputs were subsequently post-processed in Excel to compute flow metrics specific to the life history characteristics of Chinook salmon.

For this, daily flow values were summarized over periods considered potentially critical for survival during egg incubation, winter rearing, summer rearing, out-migration, and early ocean rearing (Table 9). These included specific flow values associated with these life history functions, as well as rates of flow change during the spawning period that may disrupt spawning activity, and during the juvenile rearing period that may result in trapping or stranding of fish. In addition, Mantua et al. (1997) demonstrated a relationship between the PDO in sea surface temperatures with the productivity of salmon stocks in Alaska and the west coast of North America. Consequently, a PDO index was also included in the pool of potential covariates. For median run timing two potential flow metrics were considered as potential covariates while three indices were considered for run duration (Table 10).

Estimates for hydrologic and environmental variables used in this analysis are displayed in Table 11 and Table 12. Note that these displayed values are matched to the brood year – some are for subsets of time within the year two years after the displayed brood year (Table 9).

2.3 Statistical Analysis

Scatterplots with linear and local regression fits were plotted to visually discern potential linear or non-linear relationships between selected biological and hydrological variables. Dependent variables that were not approximately normal (tested using Shapiro-Wilk's goodness-of-fit test with alpha = 0.05) were transformed using a natural log (LN) transformation if necessary. Pearson's correlation estimates were obtained for each paired relationship with a potentially meaningful causal mechanism based upon an understanding of mechanisms observed in other systems. If an approximate normal distribution could not be attained using transformations, a non-parametric correlation test was used instead.

Rather than compute p-values for each correlation coefficient, we generally note that the critical value for a correlation coefficient with n = 18 and a one-tailed alpha-level of 0.10 is 0.33. Smaller sample sizes and smaller alpha levels would increase the magnitude of the critical value. Thus, we use 0.30 as a screening value for correlation coefficients, and only consider relationships with greater correlation as potentially correlative. For relationships that passed this screening criteria, we fit single or multiple linear regressions, including two-way interactions, and selected the best-fitting model using Akaike's Information Criteria (AIC) corrected for sample size (Burnham and Anderson 2002). Comparisons with significant regression relationships are summarized and discussed in Section 4, Discussion.

3. RESULTS

3.1 Taku Production Indicators

Scatterplots of relationships between hydrological variables and run-size variables are displayed in Figure 7 to Figure 10. Correlation coefficients are displayed in Table 13. Overall, there were only four total correlations greater than or equal to the 0.30 screening level. These relationships are further described below. Some relationships in the plots appear non-linear based on the local regression smoother; however, since these relationships were not very strong and no theoretical reason for these non-linear responses was readily apparent, they were not explored further.

3.1.1 Total Returns

There were no observed correlations between hydrologic variables and total returns for the Taku River data.

3.1.2 Returns per Spawner

There was weak positive correlation between returns per spawner and peak winter rearing flow if the influential outlier (peak flow = 4,750 cfs) was removed. In addition there was weak positive correlation with the range of flows experienced during the observed return period, and weak negative correlation between returns per spawner and the trapping maximum daily decrease.

The best-fit linear regression model including these predictors and two-way interactions was the model containing the three main effects and interaction between WR_Peak and TRP_Max_Dec ($p = 0.02$, adjusted $R^2 = 0.52$). One low outlier (1993, returns per spawner = 0.2) impacts the strength of this relationship. With this value removed, the same best-fit result is obtained, but the regression was stronger ($p = 0.0002$; adjusted $R^2 = 0.85$).

Figure 11 displays the significant interactive relationship by breaking the maximum trapping decrease in flow at the median value of -7,000 cfs. There was an overall increasing relationship between winter-rearing peak flow and returns per spawner (when 1990 high flow of 7,339 cfs was removed), but this relationship does not hold when there was a large trapping flow decrease in the time preceding the winter-rearing period (BY+1).

3.1.3 Smolts per Spawner

There was positive correlation and a significant linear relationship between summer-rearing 7-day minimum flow and LN-transformed smolts per spawner ($p = 0.045$, adjusted $R^2 = 0.20$). There is evidence that higher minimum flows during summer rearing in the Taku River result in more smolts per spawner.

3.1.4 Returns per Smolt

There are no observed correlations between hydrological variables and smolts to adult returns for the Taku River data.

3.2 3.2 Taku Run Timing

Scatterplots of relationships between hydrological variables and run-timing variables are displayed in Figure 12. There are four years for which the start of the run may have been missed (no data prior to June). These four years are highlighted in Figure 12 and are excluded from the analyses discussed below. In 2012, the end of the run may have been missed, as sampling ceased on July 9. Data for this year are included below; however, it is noted if this year is influential in the results. Correlation coefficients for Taku River run-timing variables are displayed in Table 14.

3.2.1 Median Run Timing

There are no observed correlations between hydrological variables and median run timing for the Taku River data. If two additional "outlying" years with very early run timing (<Julian day 140;

2009 and 2012) are excluded, there was weak negative correlation between the day of maximum flow increase and the median run date. In 2012, the median run timing may have been underestimated as discussed above. However, the resulting linear relationship without these points is not significant ($p = 0.12$, $R^2 = 0.077$).

3.2.2 Duration of Run

There was positive correlation between flow range and run duration, and between flow standard deviation and run duration. These predictors are different indices for essentially the same environmental phenomenon, so each was fit as a single regression and compared. The regressions are both significant (best-fit $p = 0.006$, $R^2 = 0.28$). The result for 2012 was not an outlier from these relationships, and was retained. There is evidence that more variability in flow during the upstream migration period increases the duration of the run for Chinook salmon in the Taku River.

3.3 Stikine Production Indicators

Scatterplots of relationships between hydrologic variables and run-size variables are displayed in Figure 13 to Figure 15. There are only 10 years of data for smolts per spawner and the data are bimodal. That is, there are three values greater than 100 smolts per spawner and seven values less than 65 smolts per spawner, and no values in between. These data could not be transformed to normality, so nonparametric correlation and grouping was used for this analysis. Correlation coefficients are displayed in Table 15. Five correlations greater than the screening level are further described below.

3.3.1 Total Returns

There was weak positive correlation between winter-rearing 7-day minimum flow and total returns, and weak negative correlation with early ocean-rearing PDO. The model including these two factors and interaction is not significant ($p = 0.29$, adjusted $R^2 = 0.05$). The best model based on AIC corrected for sample size includes early ocean PDO only, but this model is also weak (p-value = 0.13, $R^2 = 0.12$).

3.3.2 Returns per Spawner

There was some positive correlation with trapping maximum decrease, but this correlation was strongly affected by one large decrease in 1994, which was matched with a low return/spawner for the 1993 brood year. Therefore, this relationship was not explored further.

3.3.3 Smolts per Spawner

There was negative rank correlation between smolts per spawner and spawning maximum decrease (i.e., large decreases associated with more smolts per spawner). We explored this relationship further using a nonparametric regression (linear regression on rankit scores). The nonparametric regression model was not significant ($p = 0.38$). Because this relationship is not biologically explainable, we consider this spurious.

3.4 Stikine Run Timing

Scatterplots of relationships between hydrological variables and run-timing variables are displayed in Figure 16. Correlation coefficients are displayed in Table 16; there are three correlations greater than the screening level, as discussed below.

3.4.1 Median Run Timing

The median date of the run was weakly negatively correlated with the day of maximum flow (i.e., late maximum flows associated with early runs). However, the linear model is not statistically significant ($p = 0.11$, $R^2 = 0.11$).

3.4.2 Duration of Run

Similar to the Taku, there was a positive correlation between the Stikine River flow range and run duration, and between flow standard deviation and run duration. These regressions are both statistically significant (best-fit $p = 0.005$, $R^2 = 0.36$).

4. DISCUSSION

As noted above, the objective of this exploratory analysis was to look for general relationships between hydrological variables and biological responses of salmon species, in this case Chinook salmon, which may be relevant to the Susitna River. The analysis centered on two glacially fed river systems, the Taku and Stikine rivers. These systems were deemed the most suited for drawing inferences related to hydrologic variables and attributes of salmon escapement that might pertain to the Susitna River system, due to their glacial origin and the length of both their hydrologic and escapement records.

Overall, there were a number of weak to moderate correlations found between productivity or run-timing metrics and hydrologic indices for the Taku and Stikine rivers. For the Taku River, observed relationships are as follows:

- There were more returns per spawner when a wider range of flows occurred during adult migration.
- There were more returns per spawner when there were high winter flows combined with no large summer-flow decreases that could result in trapping events.
- There were more smolts per spawner when the summer low flow was moderate or relatively high.
- The duration of the Chinook salmon run was longer when flows were more variable.

For the Stikine River, observed relationships are as follows:

- Total returns tended to be higher when the winter minimum flow was higher.
- Total returns tended to be lower when PDO was higher during early ocean rearing.
- There tended to be fewer smolts per spawner when there were large flow decreases during the spawning period.

- The duration of the Chinook salmon run was longer when flows were more variable.
- The median date of the run was earlier when there were late high flows.

In general, significant correlations were inconsistent for similar indices analyzed from the Taku River and Stikine River datasets. Thus, applying the results from the Taku or Stikine rivers to other Chinook salmon populations, such as the Susitna River could be erroneous and should be done with caution. However, there was one consistent result for the two rivers: variable flows during the spring and summer were correlated with broader upstream migration periods. Upon further investigation, we found that run duration was negatively correlated with total counts at the fishwheels or test fishery locations for both rivers: i.e., a more prolonged migration period was associated with smaller total counts. From these relationships: a) more variable flows in spring/summer are associated with broader/longer upstream migration periods; and b) broader/longer migration periods are associated with smaller runs, we could conclude that more consistent flows during the migration period may lead to larger runs. However, comparing flow range to total returns or returns per spawner does not result in significant correlations for either river. Therefore, the applicability of this relationship between flow variability and length of migration period to the Susitna River is unclear.

5. REFERENCES

ADF&G (Alaska Department of Fish & Game) Chinook Research Team. 2013. Chinook salmon stock assessment research plan. Alaska Department of Fish and Game. Division of Sport Fish and Commercial Fisheries. Special Publication 13-01.

Burnham, K.P., and D.R. Anderson. 2002. *Model selection and multimodel inference: A practical information-theoretic approach.* 2nd Edition. Springer-Verlag, New York.

Connor, E., and D. Pflug. 2004. Changes in the distribution and density of pink, chum, and Chinook salmon spawning in the upper Skagit River in response to flow management measures. North American Journal of Fisheries Management, 24(3), 835-852.

Hartmann, B., and G. Wendler. 2005. The significance of the 1976 Pacific Climate Shift in the climatology of Alaska. Journal of Climate, 18, 4824:4839.

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society. 78(6):1069-1079.

McPherson, S.A., E.L Jones III, S.J. Fleischman, and I.M. Boyce. 2010. Optimal production of Chinook salmon from the Taku River through the 2001 year class. Fishery Manuscript No. 10-03. Alaska Department of Fish and Game, Anchorage, Alaska. 108 pp.

Richards, P., K. Pahlke, and P. Etherton. 2012. Abundance of the Chinook salmon escapement in the Stikine River, 2006-2008. Fishery Data Series No. 12-15. Alaska Department of Fish and Game, Anchorage, Alaska. 70 pp.

TNC (The Nature Conservancy). 2009. Indicators of hydrologic alteration, Version 7.1, User's Manual, April.

UWJISAO (University of Washington Joint Institute for the Study of the Atmosphere and Ocean) 2013. PDO Index. http://jisao.washington.edu/pdo/PDO.latest. Accessed September 13, 2013.

Westerman, D.L., and T.M. Willette. 2013. Upper Cook Inlet salmon escapement studies, 2012. Fishery Data Series No. 13-30. Alaska Department of Fish and Game, Anchorage, Alaska. 135 pp.

Yanusz, R.J., R.A. Merizon, T.M. Willette, D.G. Evans, and T.R. Spencer. 2011. Inriver abundance and distribution of spawning Susitna River sockeye salmon *Oncorhynchus nerka*, 2007. Fishery Data Series No. 11-19. Alaska Department of Fish and Game, Anchorage, Alaska. 44 pp.

6. TABLES

Table 1. Chinook salmon productivity and run-timing indicators for the Taku and Stikine rivers.

Indicator	Description	Years of Data	
		Taku River	Stikine River
Production Indicators			
RET	Total returns resulting from spawning during brood year	20	29
R/S	Returns per spawner	16	21
SM/SP	Smolts per spawner from brood year	16	10
SAR	Returns per smolt (smolt to adult returns)	13	4
Run Timing Indicators			
Med_Jday	Median Julian day of run	26	18
Run_Length	Number of days from 10^{th} to 90^{th} percentile of run	26	18

Table 2. Biological indicators estimated for the Taku River and used in this analysis.

BY	RET	R/S	SM/SP	SAR	Med_Jday	Run_Length
1988	83252	1.3	n/a	n/a	158	38
1989	70876	1.4	n/a	n/a	157	37
1990	36191	0.61	n/a	n/a	161	46
1991	201326	2.7	29	0.096	168	21
1992	79925	1.1	26	0.041	178	19
1993	17975	0.23	14	0.016	175	22
1994	35762	0.67	27	0.025	174	18
1995	58137	0.88	19	0.047	153	40
1996	79957	0.89	21	0.042	155	31
1997	60230	0.51	16	0.031	153	35
1998	52213	1.3	31	0.044	158	39
1999	111966	4.4	68	0.064	159	37
2000	123397	2.8	46	0.062	150	45
2001	58977	1.1	41	0.028	145	41
2002	24726	0.41	25	0.016	153	47
2003	49840	0.96	28	0.034	148	45
2004	51191	n/a	36	n/a	149	35
2005	n/a	n/a	47	n/a	150	54
2006	n/a	n/a	50	n/a	152	48
2007	n/a	n/a	n/a	n/a	153	51
2008	n/a	n/a	n/a	n/a	153	45
2009	n/a	n/a	n/a	n/a	139	49
2010	n/a	n/a	n/a	n/a	158	43
2011	n/a	n/a	n/a	n/a	156	47
2012	n/a	n/a	n/a	n/a	138	46
2013	n/a	n/a	n/a	n/a	163	38

Notes:

n/a = not available

BY = Brood Year

Table 3. Biological indicators estimated for the Stikine River and used in this analysis.

BY	RET	R/S	SM/SP	Med_Jday	Run_Length
1981	32180	0.79	n/a	n/a	n/a
1982	55328	1.1	n/a	n/a	n/a
1983	22470	1.6	n/a	n/a	n/a
1984	41998	2.3	n/a	n/a	n/a
1985	21458	1.0	n/a	n/a	n/a
1986	49813	2.4	n/a	n/a	n/a
1987	74548	2.5	n/a	n/a	n/a
1988	42310	0.97	n/a	n/a	n/a
1989	19788	0.64	n/a	n/a	n/a
1990	18089	0.56	n/a	n/a	n/a
1991	69627	2.2	n/a	n/a	n/a
1992	36682	0.91	n/a	n/a	n/a
1993	24306	0.37	n/a	n/a	n/a
1994	27180	0.69	n/a	n/a	n/a
1995	41902	1.7	n/a	n/a	n/a
1996	110286	2.7	n/a	163	42
1997	33816	0.80	n/a	162	38
1998	67198	2.3	126	167	43
1999	96943	3.4	119	156	48
2000	162038	4.7	101	155	41
2001	31759	0.44	63	156	44
2002	n/a	n/a	39	153	43
2003	n/a	n/a	35	166	36
2004	n/a	n/a	48	155	39
2005	n/a	n/a	37	159	36
2006	n/a	n/a	44	157	52
2007	n/a	n/a	39	171	52
2008	n/a	n/a	n/a	158	47
2009	n/a	n/a	n/a	171	50
2010	n/a	n/a	n/a	168	46
2011	n/a	n/a	n/a	169	50
2012	n/a	n/a	n/a	158	53
2013	n/a	n/a	n/a	146	51

Notes:
n/a = not available
BY = Brood Year

Table 4. IHA Results for Stikine River, 1977 – 1994.

Year		1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Magnitude of Monthly Water Conditions																			
October	*Mean monthly flow, cfs*	57810	39930	84750	71570	102600	49110	57190	36860	47260	30590	113300	77970	65010	53360	44690	80900	45140	63470
November		37330	15240	58280	19730	40110	42110	16550	15310	11940	10010	33610	32630	22630	28090	15600	30720	22940	37360
December		15770	8094	15010	11550	10210	12010	10070	7881	7135	11090	17420	18040	23740	25780	12370	18510	13360	17950
January		13830	5958	7426	8787	39450	6094	8348	9410	18870	9539	15070	6797	14180	10700	9248	17100	8574	10840
February		19080	5539	7775	8090	17980	5700	6864	10530	8754	8936	8789	10180	10260	6618	10220	11600	12990	7661
March		9451	4719	6619	7477	13170	6035	6335	12980	7635	17600	6735	11960	5774	12480	8165	42340	11970	11550
April		20790	10380	16120	17410	13710	9070	13670	17260	11200	10910	14170	19170	16940	21350	21430	31960	24430	18590
May		58860	36720	60950	70880	94280	32260	65650	43030	52960	39180	55260	79350	117100	86290	95870	78770	119100	66420
June		125100	103400	130600	156200	144800	159900	134100	106100	118300	121900	120500	142400	148800	173400	147800	199900	139900	109900
July		140400	109900	158800	152200	140700	130000	109100	120100	163800	148100	154200	147300	143700	140100	123000	150200	120000	122500
August		134200	109200	109100	119200	124700	89720	101200	117700	99370	97580	84890	122700	114800	123100	104400	87650	93830	110700
September		56020	53090	74750	80750	128600	81410	70970	58690	63330	50760	88880	88010	81050	86260	109800	63540	71780	116600
Magnitude and Duration of Annual Extreme Water Conditions																			
1-Day Min	*Mean flow, cfs*	7490	4500	5600	6600	7500	5600	6000	5500	6000	5200	5000	4000	5100	5600	6200	5400	7500	6900
3-Day Min		7840	4533	5633	6800	7567	5600	6067	5600	6100	5233	5033	4050	5100	5600	6367	5467	7500	6967
7-Day Min		8117	4571	5700	7143	7657	5600	6114	5900	6114	5414	5157	4129	5171	5657	6600	5657	7543	7029
30-Day Min		9265	4710	6577	7420	9737	5663	6327	7743	7000	7190	6310	5433	5743	6340	8083	8795	8393	7580
90-Day Min		13750	5333	7110	8043	14900	5879	7088	9087	9217	9530	9549	9582	9253	9669	9177	14950	11100	10090
1-Day Max		190000	152000	213000	203000	298000	191000	199000	154000	197000	183000	226000	225000	205000	238000	208000	270000	199000	324000
3-Day Max		188300	147000	208300	201300	282000	189000	192700	147000	194000	180300	222300	211700	203300	230700	205700	263000	195300	286300
7-Day Max		178100	139700	186900	199300	234600	182100	169300	143100	192700	176900	205700	185400	195700	212600	196100	247900	192900	216100
30-Day Max		148400	120200	161800	159000	154300	166000	134800	128200	164400	151600	157900	150600	153900	175900	154600	209800	170200	128000
90-Day Max		134500	108700	134300	145500	143700	127100	115000	116700	132500	124400	123100	141800	140300	149700	129100	152500	135400	117300
Base Flow Index	*7-day min/mean annual flow*	0.141	0.109	0.093	0.118	0.105	0.108	0.122	0.127	0.119	0.116	0.086	0.065	0.081	0.088	0.112	0.083	0.132	0.121
Timing of Annual Extreme Water Conditions																			
Date Min	*Julian day*	73	80	62	70	362	20	72	365	89	53	74	43	77	45	11	50	23	58
Date Max		173	217	203	162	255	173	155	223	195	200	185	277	152	156	177	169	151	267
Frequency and Duration of High and Low Pulses																			
Low Pulse	*# of*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
High Pulse	*# of*	3	7	10	3	7	7	8	6	5	4	10	4	7	8	11	5	4	11
	Mean duration, days	25.7	5.4	7.6	30.3	16.6	9.9	7.8	9.3	13.0	16.3	8.1	22.8	13.7	12.1	8.1	15.6	21.0	6.9
Rate and Frequency of Water Condition Changes																			
Rise Rate	*Mean of +/- consecutive daily differences*	5341	4394	8351	5785	8979	6240	6043	3825	5155	4778	7825	6275	6187	6734	5554	6893	4328	7259
Fall Rate		-4364	-3671	-6079	-4635	-7397	-5308	-4061	-2755	-3308	-2785	-4791	-4529	-3963	-5166	-4474	-4874	-2920	-6262
Reversals	*in flow, # of*	89	71	73	95	82	67	66	73	81	75	78	82	64	80	80	81	88	85

Table 5. IHA Results for Stikine River, 1995 – 2012.

Year		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Magnitude of Monthly Water Conditions																			
October	*Mean monthly flow, cfs*	57940	35380	38140	45000	49730	52190	55850	36470	48600	64500	54700	38840	62770	42410	52410	42770	60030	48140
November		19350	13240	12330	28130	14760	22560	26500	15200	22950	20190	25770	40930	18100	18020	20130	19800	27510	21520
December		11750	10010	5593	22960	8110	21840	15510	9806	20420	9045	27110	28630	13750	7761	12190	10410	10260	12450
January		7187	7787	6006	11790	8774	14060	15360	7513	17850	6939	8957	11430	12070	6581	7784	9816	9894	10260
February		6407	8234	6281	11790	5111	9730	9111	7568	7971	7017	8500	8246	11550	6100	7318	9296	7711	8893
March		7610	7548	6166	10670	5477	7629	9313	6142	6506	9045	11580	8471	11180	6929	6781	11460	5744	6526
April		21120	17830	17410	15180	13500	14650	13070	7292	16530	23160	25060	13820	19520	11850	10100	19650	10880	18640
May		91050	43530	73270	86110	51600	42570	34860	52320	58250	87990	105400	56770	65410	75790	70680	65910	70440	53340
June		105900	118300	131500	141500	147000	117000	133800	134500	122600	149200	136700	156400	184300	111700	166500	106400	130800	144000
July		110300	119400	127800	117100	129800	149200	142300	122200	135500	139900	120600	133000	168900	117400	142000	101600	106200	136000
August		76770	95120	118000	97880	109200	115700	109600	119800	88060	98760	106400	91110	98620	110300	107400	94660	109700	105800
September		86020	64520	96400	67190	74780	105200	83280	82440	89200	66190	72320	99580	74470	63850	102500	65650	139700	92730
Magnitude and Duration of Annual Extreme Water Conditions																			
1-Day Min	*Mean flow, cfs*	5800	6200	5000	8000	4000	6400	7500	5300	4500	5700	7500	7400	9900	5300	6500	9000	5190	6000
3-Day Min		5833	6200	5000	8233	4000	6433	7533	5300	4600	5700	7567	7400	9967	5367	6567	9067	5230	6000
7-Day Min		5929	6286	5033	8714	4086	6529	7671	5314	4743	5800	7843	7471	10100	5471	6629	9086	5281	6029
30-Day Min		6187	7080	5294	10450	4427	7567	8607	5553	5643	6503	8539	7758	10960	5970	6767	9307	5579	6480
90-Day Min		7068	7816	5902	10890	6326	9832	9655	6622	8711	7250	9706	9309	11380	6538	7186	9711	7642	8187
1-Day Max		202000	165000	179000	223000	220000	204000	201000	226000	157000	199000	160000	224000	273000	170000	241000	136000	340000	222000
3-Day Max		177700	161300	167000	220300	218700	186000	196300	212700	154300	196300	150700	221700	267700	165000	241000	132300	307000	215000
7-Day Max		137600	153000	159900	206000	210600	163900	176600	188000	150300	192600	148300	211400	247400	154300	234000	126400	254300	193300
30-Day Max		115500	124800	141800	156400	158500	151900	146400	136600	136100	162400	140400	158500	184900	124100	167100	110100	158000	150900
90-Day Max		105000	111100	125700	125600	130700	128900	129600	126800	119100	134600	125500	130800	155100	116400	140500	106300	122600	129900
Base Flow Index	*7-day min/mean annual flow*	0.118	0.139	0.094	0.159	0.079	0.116	0.141	0.106	0.089	0.102	0.133	0.130	0.163	0.113	0.112	0.195	0.092	0.110
Timing of Annual Extreme Water Conditions																			
Date Min	*Julian day*	47	30	1	68	72	74	54	83	72	35	10	75	93	41	71	37	71	83
Date Max		255	178	189	153	169	262	204	241	194	177	233	167	160	188	162	206	254	177
Frequency and Duration of High and Low Pulses																			
Low Pulse	*# of*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
High Pulse	*# of*	7	6	12	8	7	6	6	7	7	8	8	6	3	7	8	9	10	5
	Mean duration, days	6.4	8.0	7.3	7.5	10.4	13.7	12.2	10.3	8.3	10.4	10.6	13.5	25.7	7.7	11.0	4.3	7.5	14.8
Rate and Frequency of Water Condition Changes																			
Rise Rate	*Mean of +/- consecutive daily differences*	4968	4021	5733	6017	6167	6170	4652	6026	6026	6128	5583	7128	4832	4530	5403	4407	6743	5290
Fall Rate		-4279	-3973	-4081	-4283	-4511	-4358	-3647	-4255	-3702	-4897	-5235	-4178	-3741	-3436	-4496	-3427	-5975	-4261
Reversals	*in flow, # of*	74	68	66	97	78	78	85	86	94	72	76	66	74	82	68	72	69	90

Table 6. IHA Results for Taku River, 1988 – 2000.

Year		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Magnitude of Monthly Water Conditions														
October	*Mean monthly flow, cfs*	16540	11960	11980	8207	17250	6790	14730	16140	9105	6265	8577	11080	9950
November		6966	4098	5689	2644	5115	3591	8633	4669	2929	2488	4394	4569	4459
December		2967	4647	4832	2204	3660	2565	4573	3046	2528	1256	3461	2611	6613
January		1125	2662	2427	1676	3824	1451	2674	1905	1650	1329	1914	1819	4223
February		1891	1983	1408	1963	3682	2501	1909	1706	1329	1490	1913	1041	2569
March		2101	1405	2555	1359	10500	3051	2841	2044	1525	1387	1749	2805	2006
April		3791	5116	5576	4878	6815	5837	5593	4769	3404	3707	3642	3258	2846
May		20230	30600	24650	22680	19970	33800	20920	22770	13890	20370	19680	10810	12130
June		30640	38350	41290	36150	49280	39760	35690	23170	29280	28850	28710	33150	33650
July		26390	36010	35900	29690	41080	33630	35980	30960	25040	33860	26000	26750	36910
August		24400	32450	32150	27420	28740	22580	30120	18610	19750	26580	21640	25900	26440
September		15250	20020	24550	25880	11180	21020	26550	22640	18970	22730	12020	15920	20610
Magnitude and Duration of Annual Extreme Water Conditions														
1-Day Min	*Mean flow, cfs*	710	1250	1200	1170	1170	1200	1700	1550	1150	1180	1480	800	1680
3-Day Min		713.3	1253	1210	1183	1183	1200	1717	1550	1163	1180	1490	810	1687
7-Day Min		721.4	1261	1229	1243	1226	1207	1737	1579	1184	1187	1506	822.9	1711
30-Day Min		965	1363	1399	1333	1981	1390	1889	1657	1302	1224	1709	911.5	1991
90-Day Min		1684	1995	2123	1647	3214	2127	2492	1882	1489	1329	1845	1415	2425
1-Day Max		61700	77000	69400	55300	75200	70300	85500	81800	52000	65000	62200	56400	93100
3-Day Max		43570	67770	62030	54400	67900	60470	64530	59200	40930	52930	48900	49330	72870
7-Day Max		41540	50140	57110	50590	62910	54900	49670	44210	35370	42390	45490	47900	53370
30-Day Max		31160	39430	43420	39800	53170	49190	37730	31790	29310	35540	33290	35690	37600
90-Day Max		27690	36830	37830	31580	41240	38060	34660	26290	24920	30330	27620	28890	32660
Base Flow Index	*7-day min/mean annual flow*	0.0567	0.0795	0.076	0.0902	0.0729	0.0817	0.109	0.1235	0.1096	0.0943	0.1344	0.0703	0.1261
Timing of Annual Extreme Water Conditions														
Date Min	*Julian day*	43	77	48	13	52	24	57	55	28	366	71	74	73
Date Max		214	230	233	176	233	210	212	208	262	209	215	233	208
Frequency and Duration of High and Low Pulses														
Low Pulse	*# of*	4	2	2	7	1	2	1	1	4	3	3	4	5
	Mean duration, days	23	32	28.5	18.71	20	28.5	37	85	27	50	33.67	26.75	13
High Pulse	*# of*	10	6	11	11	5	6	6	8	7	8	4	11	8
	Mean duration, days	3.5	16.33	8.636	6.091	15.8	13	16.5	5.25	3.714	6.75	7.25	4.636	8.625
Rate and Frequency of Water Condition Changes														
Rise Rate	*Mean of +/- consecutive daily differences*	1584	1871	2557	2000	2085	1809	2133	2065	1413	1711	1166	1748	1850
Fall Rate		-1202	-1174	-1701	-1393	-1727	-1035	-1887	-1650	-1201	-1316	-980.5	-1029	-1350
Reversals	*in flow, # of*	84	70	85	82	87	92	83	74	70	72	93	72	84

Table 7. IHA Results for Taku River, 2001 – 2012.

Year		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Magnitude of Monthly Water Conditions													
October	*Mean monthly flow, cfs*	14590	9176	13820	11220	12640	7599	16420	11290	13880	10280	9200	7546
November		5557	3384	6478	4917	5642	13060	5763	4805	4985	5334	4740	3715
December		2840	2411	4995	3173	5848	3969	3145	2129	2997	2265	1958	2523
January		2332	1856	3748	2174	2058	2902	2587	1574	2158	1665	1661	2134
February		1793	1810	1824	2013	1979	2864	1604	1386	1968	1568	1329	1741
March		1795	1481	1414	2147	2462	2351	1383	1671	1835	1723	1274	1394
April		3009	1870	4550	5005	7835	2970	3621	2560	2976	4689	2467	4653
May		9652	16920	13640	28050	35520	15850	21190	20570	21680	18050	17120	14780
June		36680	29600	24550	44430	35570	44920	55350	24640	41240	23810	28140	42230
July		32010	25660	30070	37770	29650	30620	45720	25030	36270	22580	23990	33030
August		27450	33330	23340	25880	25970	23550	29250	26990	28540	22660	20720	23930
September		16740	15220	16810	16570	16280	27970	19800	16530	21400	11700	21370	20610
Magnitude and Duration of Annual Extreme Water Conditions													
1-Day Min	*Mean flow, cfs*	1450	1300	1200	1500	1800	2180	1300	1300	1700	1400	1100	1200
3-Day Min		1483	1300	1200	1500	1833	2190	1310	1300	1733	1467	1100	1200
7-Day Min		1509	1301	1229	1543	1871	2201	1337	1343	1771	1486	1129	1243
30-Day Min		1684	1360	1349	1872	1967	2319	1369	1387	1830	1527	1197	1352
90-Day Min		1877	1600	1995	2105	2172	2633	1658	1542	1967	1616	1424	1744
1-Day Max		67600	69200	57700	113000	72000	77400	91000	75400	79800	53900	52100	67300
3-Day Max		51300	55100	46630	84630	55600	63430	81670	53630	66570	43600	49770	64630
7-Day Max		41710	46660	34760	64010	45130	60260	71140	45400	63370	34910	46460	55890
30-Day Max		37250	34720	30250	47780	40430	46900	56240	30010	43270	27240	31080	42610
90-Day Max		32250	29610	26730	38370	34050	34180	45190	27640	36040	24870	25670	34050
Base Flow Index	*7-day min/mean annual flow*	0.1167	0.1087	0.1009	0.1007	0.123	0.1477	0.0776	0.1153	0.1175	0.1403	0.1007	0.0941
Timing of Annual Extreme Water Conditions													
Date Min	*Julian day*	85	83	70	34	14	79	97	38	82	54	69	85
Date Max		223	230	223	177	182	246	203	232	205	211	154	177
Frequency and Duration of High and Low Pulses													
Low Pulse	*# of*	3	3	2	2	2	1	1	1	1	2	1	3
	Mean duration, days	37	46	36.5	39	36	25	87	132	108	57.5	142	40.67
High Pulse	*# of*	5	9	8	9	5	12	4	7	7	6	7	9
	Mean duration, days	13.4	5.778	5	9.889	15.8	6.667	22.25	5.571	11.14	4.5	4.714	7.778
Rate and Frequency of Water Condition Changes													
Rise Rate	*Mean of +/- consecutive daily differences*	1450	1735	1775	2275	1863	2323	2365	1844	2292	1323	1918	1785
Fall Rate		-1168	-1122	-1282	-1689	-1631	-1617	-1679	-1599	-1822	-1132	-1515	-1174
Reversals	*in flow, # of*	87	81	93	78	83	76	60	60	66	62	70	74

Table 8. Summary of IHA Results for Full Period of Record for Stikine (1977-2012) and Taku Rivers (1988-2012).

		Stikine		Taku	
		Means	*Coeff. Of Variation*	*Means*	*Coeff. Of Variation*
Magnitude of Monthly Water Conditions					
October	*Mean monthly flow, cfs*	55760	0.327	11450	0.286
November		24370	0.4317	5145	0.4158
December		14270	0.4241	3329	0.3871
January		11120	0.5367	2221	0.3529
February		9011	0.3326	1890	0.2917
March		9661	0.6516	2250	0.7978
April		16610	0.3107	4218	0.34
May		67730	0.329	20220	0.3266
June		136700	0.1648	35170	0.237
July		133200	0.1275	31620	0.1825
August		105500	0.1217	25940	0.15
September		81950	0.2509	19130	0.2374
Magnitude and Duration of Annual Extreme Water Conditions					
1-Day Min	*Mean flow, cfs*	6136	0.2155	1347	0.2325
3-Day Min		6196	0.2176	1358	0.2341
7-Day Min		6314	0.219	1383	0.2315
30-Day Min		7138	0.2228	1533	0.2243
90-Day Min		8973	0.2563	1920	0.2273
1-Day Max		211600	0.2149	71250	0.2036
3-Day Max		203900	0.2007	58460	0.1935
7-Day Max		187900	0.174	49810	0.1928
30-Day Max		150400	0.1334	38600	0.2005
90-Day Max		128800	0.09667	32290	0.1679
Base Flow Index	*7-day min/mean annual flow*	0.1143	0.2276	0.1027	0.2286
Timing of Annual Extreme Water Conditions					
Date Min	*Julian day*	53.11	0.07454	56.2	0.07177
Date Max		196.1	0.102	212.2	0.06708
Frequency and Duration of High and Low Pulses					
Low Pulse	*# of*	0	0	2.44	0.6157
	Mean duration, days	0	0	48.39	0.7216
High Pulse	*# of*	6.944	0.3319	7.56	0.3009
	Mean duration, days	12.21	0.5056	9.143	0.5515
Rate and Frequency of Water Condition Changes					
Rise Rate	*Mean of +/- consecutive daily differences*	5827	0.2022	1878	0.1812
Fall Rate		-4391	-0.2241	-1403	-0.1975
Reversals	*in flow, # of*	77.92	0.1138	77.52	0.1275

Table 9. Hydrologic and environmental metrics analyzed for correlations with Chinook salmon productivity indices.

Variable	Description	Period	Lag[1]	Rationale/Hypothesis
Inc_Peak	Peak flow during incubation period	Sept - March	BY	High peak flows may result in scour that dislodges eggs.
Inc_Min	7-day minimum flow during incubation period	Sept – March	BY	Low flows may result in de-watering or freezing of eggs. A 7-day running average reduces the influence of single day extreme values.
WR_Peak	Winter-rearing peak flow	Oct – March	BY+1	High peak flows during winter rearing may displace fish from winter rearing habitat.
WR_Mean	Winter-rearing mean flow	Oct – March	BY+1	Mean flow is an indicator of winter rearing habitat quantity.
WR_Min	Winter-rearing 7-day minimum flow	Jan – March	BY+2	Low flows may result in a low quantity and poor quality winter rearing habitat. A 7-day running average reduces the influence of single day extreme values.
SR_Min	Summer-rearing 7-day minimum flow	Aug – Sept	BY+1	Low flows may result in a low quantity and poor quality summer rearing habitat. A 7-day running average reduces the influence of single day extreme values.
Out_Mean	Outmigration mean flow	May – July	BY+2	High mean flows may increase movement rates and decrease susceptibility to in-river fish predation.
EO_Mean	Early ocean-rearing mean flow	May - Sept	BY+2	High mean flows may increase upwelling and early ocean survival of outmigrants.
EO_PDO	Early ocean-rearing Pacific Decadal Oscillation index	May – Sept	BY+2	Salmon productivity has been shown to be correlated to PDO for several west coast and Alaska stocks (Mantua et al. 1997).
FlowRange	Range of flows during returns	Upstream migration duration (varies)	BY	A wide range in flows may result in fish spawning in habitat that subsequently becomes unsuitable.
SP_Max_Inc	Spawning maximum daily Increase	July – Sept	BY	Rapid increases in flow during spawning may result in disruption of spawning behavior.
SP_Max_Dec	Spawning maximum daily decrease	July – Sept	BY	Rapid decreases in flow during spawning may result in exposure of redds to desiccation and freezing.
TRP_Max_Dec	Trapping maximum daily decrease	June - Oct	BY+1	Rapid decreases in flow may result in trapping or stranding of fry and juveniles.

Notes:

BY = Brood Year

Table 10. Hydrologic metrics analyzed for correlations with Chinook salmon run-timing and duration indices.

Variable	Description	Rationale/Hypothesis
Median Run Timing		
MaxFlowDay	Julian day of maximum flow	Peak flows may cue upstream migratory behavior.
MaxIncDay	Julian day with highest increase over previous day	Rapid increase in flows may cue upstream migratory behavior.
Run Duration		
MeanFlow	Mean flow during migration period	Higher average flows may increase run duration.
FlowRange	Range of flows during migration period	A wide range of flows may increase run duration.
FlowSD	Standard deviation of flows during migration period	High variability of flows may increase run duration.

Note: All variables are for the Brood Year

Table 11. Estimates for hydrologic and environmental metrics for the Taku River as used in this analysis.

BY	Inc_ Peak	Inc_ Min	WR_ Peak	WR_ Mean	WR_ Min	SR_ Min	Out_ Mean	EO_ Mean	EO_ PDO	SP_Max _Inc	SP_Max _Dec	TRP_Max _Dec	MaxFlow Day	MaxInc Day	Mean Flow	Flow Range	Flow SD
1988	35000	1261	2100	4815	1229	12476	29434	31692	0.33	4929	-5443	-7286	162	156	28567	25600	8435
1989	35600	1229	1700	3009	1243	15247	36641	28328	-0.21	7429	-7286	-7029	152	146	36621	36700	9079
1990	64800	1243	4750	7339	1226	16843	35685	30048	1.4	6986	-7029	-4443	153	147	38572	39900	10346
1991	54200	1226	2800	3325	1207	8813	30810	30154	2.2	4757	-4443	-7671	175	169	41177	29500	8763
1992	18000	1207	2300	5894	1737	11317	25662	29835	-0.08	7014	-7671	-6014	190	179	49515	39400	11983
1993	41700	1737	1920	4918	1579	12371	22664	23642	1.2	5514	-6014	-7043	169	188	32135	29800	8134
1994	65700	1579	1500	3178	1184	10654	27681	21349	0.83	8071	-7043	-9286	171	170	37937	26800	7080
1995	64900	1184	1370	2369	1194	8496	24756	26488	2.4	7471	-9286	-5186	163	157	22500	21800	5841
1996	52000	1187	2080	3668	1506	11940	23465	21627	-0.074	5143	-5186	-7457	156	150	25972	22000	6048
1997	64700	1506	1190	3987	823	7910	27496	22479	-1.0	7671	-7457	-6000	157	172	25733	18400	4720
1998	40000	823	2460	4970	1711	7944	25998	25933	-0.72	4943	-6000	-6214	149	143	29440	36200	10470
1999	34700	1711	2300	4818	1509	14729	24002	24476	-0.84	4271	-6214	-9014	168	157	29197	38200	12469
2000	42600	1509	1890	3353	1333	10986	22736	24170	-0.052	8771	-9014	-6186	167	161	22455	45870	11915
2001	26000	1333	2200	5379	1229	10254	36665	21696	0.68	5443	-6186	-4729	164	147	21761	39940	13698
2002	31200	1229	2500	4274	1543	10573	33554	30539	0.59	5557	-4729	-3529	167	135	26268	41420	10097
2003	30000	1543	2100	5104	1871	9051	30305	28631	0.70	5029	-3529	-9329	152	146	19505	24940	7766
2004	33100	1871	2550	5457	2201	10217	40594	28480	0.06	3469	-2714	-6029	161	171	36450	32400	7777
2005	51900	2201	1410	5150	1337	13271	23402	34219	0.18	5243	-6029	-7529	136	175	36406	30900	6811
2006	77400	1337	1400	3810	1343	12557	32975	22782	-1.5	6786	-7529	-8171	155	177	34182	59640	18957
2007	30200	1343	1900	4637	1771	11783	21458	29808	-0.22	4986	-8171	-6986	158	151	43471	73700	19111
2008	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	150	143	23835	45650	12325
2009	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	160	153	34238	51600	15340
2010	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	150	139	22555	26400	8374
2011	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	153	146	23260	47970	13466
2012	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	161	155	25111	52880	14290
2013	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	151	144	41569	52100	13490

Table 12. Estimates for hydrologic and environmental metrics for the Stikine River as used in this analysis.

BY	Inc_ Peak	Inc_ Min	WR_ Peak	WR_ Mean	WR_ Min	SR_ Min	Out_ Mean	EO_ Mean	EO_ PDO	SP_Max _Inc	SP_Max _Dec	TRP_Max _Dec	MaxFlow Day	MaxInc Day	Mean Flow	Flow Range	Flow SD
1981	298000	5600	160000	538150	6114	51371	102597	96109	2.1	33429	-21571	-17514	n/a	n/a	n/a	n/a	n/a
1982	160000	6114	54500	474317	6414	43929	89577	89226	0.39	9771	-13871	-13000	n/a	n/a	n/a	n/a	n/a
1983	145000	5900	89800	518600	6286	38143	111611	99665	0.50	7386	-12714	-9800	n/a	n/a	n/a	n/a	n/a
1984	89800	6114	60800	447300	5414	52200	102850	91569	0.77	7057	-9800	-9143	n/a	n/a	n/a	n/a	n/a
1985	91400	5414	205000	997167	5157	30700	109897	100709	2.0	9714	-9000	-15600	n/a	n/a	n/a	n/a	n/a
1986	205000	5157	225000	805367	4129	61171	122779	115937	0.48	20314	-11457	-23571	n/a	n/a	n/a	n/a	n/a
1987	225000	4129	99300	722700	5171	44686	136413	121178	0.36	23614	-11000	-17114	n/a	n/a	n/a	n/a	n/a
1988	195000	5171	114000	699998	5657	52357	132826	121718	0.33	14286	-17114	-9429	n/a	n/a	n/a	n/a	n/a
1989	121000	5657	91900	510450	6600	69229	121948	115999	-0.21	10171	-8429	-14043	n/a	n/a	n/a	n/a	n/a
1990	157000	6600	151000	1030357	5657	76929	142337	115807	1.4	12886	-14043	-16543	n/a	n/a	n/a	n/a	n/a
1991	191000	5657	87700	583717	7543	37171	126183	108961	2.2	13329	-16543	-13714	n/a	n/a	n/a	n/a	n/a
1992	115000	7543	245000	758883	7029	40943	99503	105128	-0.080	9443	-13714	-26729	n/a	n/a	n/a	n/a	n/a
1993	245000	7029	98100	563167	5929	57157	102374	93981	1.2	9943	-4629	-35100	n/a	n/a	n/a	n/a	n/a
1994	324000	5929	54000	419717	6286	49143	93464	88123	0.83	25571	-35100	-18857	n/a	n/a	n/a	n/a	n/a
1995	202000	6286	87000	379778	5136	40729	110646	109333	2.4	19486	-18857	-9171	n/a	n/a	n/a	n/a	n/a
1996	112000	5033	89800	662790	8714	45500	114616	101928	-0.074	7343	-9171	-15400	178	172	88639	143400	42220
1997	155000	8714	91100	470130	4086	42186	109074	102379	-1.0	14557	-15400	-13229	188	130	115572	145800	34852
1998	116000	4086	128000	654397	6529	34557	102778	105867	-0.72	12700	-13229	-16429	152	145	122372	180500	49117
1999	154000	6529	82200	671200	7671	66386	103335	100670	-0.84	13843	-16429	-17314	168	161	110998	199500	56477
2000	204000	7671	80000	421000	5400	59129	102672	102175	-0.052	17700	-17314	-11857	181	175	92230	150000	44707
2001	151000	5400	79900	634400	4743	56186	105283	98641	0.68	12529	-11857	-17571	173	147	99677	158800	51954
2002	145000	4743	176000	597433	5800	61743	125467	108433	0.59	22643	-17571	-20714	168	161	104578	171200	43784
2003	176000	5800	126000	697312	7843	41329	120708	108315	0.70	10586	-8986	-14586	185	140	103244	116800	35967
2004	151000	7843	125000	694582	7471	48100	114954	107109	0.056	16043	-14586	-8871	177	155	129778	140200	39720
2005	125000	7471	113000	659900	10100	47400	139063	118203	0.18	6143	-8871	-15571	152	129	129029	89300	20254
2006	190000	10100	70300	448600	5471	48371	101539	95915	-1.5	20771	-14243	-13429	166	160	116105	199300	56618
2007	96900	5471	103000	543817	6629	45171	125970	117611	-0.22	14571	-10857	-11729	159	153	138126	235800	62043
2008	103000	6629	67500	527083	9086	53957	91136	86853	-0.71	9471	-11729	-15629	150	143	102190	134500	34938
2009	172000	9086	109000	617510	5281	37614	102200	111072	-1.3	12443	-15629	-9429	161	154	126242	188200	55123
2010	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	151	185	89664	98900	29853
2011	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	153	136	105254	161700	43783
2012	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	177	171	103831	186300	51093
2013	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	176	146	127476.6	129700	37378.1

Table 13. Pearson correlation coefficients for hydrological versus biological variables describing run size for the Taku River.

	LN[1] Total Returns	LN[1] Returns/ Spawner	LN[1] Smolts/ Spawner	Returns/ Smolt (SAR)
Inc_Peak	-0.05	-0.21	-0.14	n/a
Inc_Min	-0.17	-0.09	0.27	n/a
WR_Peak	-0.06	0.03	0.16	n/a
WR_Peak (< 3500)	0.23	***0.36***	n/a	n/a
WR_Mean	-0.29	-0.18	0.23	n/a
WR_Min	-0.18	0.02	0.15	n/a
SR_Min	-0.08	0.07	***0.51***	n/a
Out_Mean	-0.14	-0.09	n/a	-0.25
EO_Mean	0.10	0.10	n/a	0.18
EO_PDO	-0.11	-0.20	n/a	0.02
FlowRange	0.03	***0.30***	n/a	n/a
SP_Max_Inc	-0.04	-0.16	-0.22	n/a
SP_Max_Dec	-0.10	-0.06	0.03	n/a
TRP_Max_Dec	-0.29	***-0.34***	-0.27	n/a

Notes:

1 "LN" indicated values were natural-log transformed prior to correlation estimation

n/a Not applicable

Values greater than the screening limit are highlighted in red.

Table 14. Pearson correlation coefficients for hydrologic versus biological variables describing run timing for the Taku River.

	Median Run Time (w/o 1991-1994)	Median Run Time (w/o 1991-1994, 2009, 2012)	Run Duration (w/o 1991-1994)
mean.flow			0.15
flow.range			0.56
flow.sd			0.50
jday.max	-0.22	-0.15	
jday.MI	-0.26	-0.35	

Notes:

Values greater than the screening limit are highlighted in red.

Table 15. Pearson correlation coefficients for hydrological versus biological variables describing run size for the Stikine River. Values greater than the screening limit are highlighted in red.

	LN[2] Total Returns	LN[2] Returns/ Spawner	Smolts/ Spawner[1]
Inc_Peak	-0.02	-0.19	0.12
Inc_Min	-0.10	-0.19	-0.13
WR_Peak	-0.23	-0.10	-0.20
WR_Mean	-0.21	-0.12	-0.18
WR_Min	0.31	0.23	-0.45
SR_Min	-0.10	-0.19	0.31
Out_Mean	-0.09	0.035	n/a
EO_Mean	0.05	0.14	n/a
EO_PDO	-0.34	-0.23	n/a
flow.range	0.10	0.25	n/a
SP_Max_Inc	0.08	0.008	0.20
SP_Max_Dec	-0.04	0.003	-0.54
TRP_Max_Dec	0.18	0.39	-0.19
TRP_Max_Dec > -30000	n/a	0.17	n/a

Notes:

1 Values for Smolts/Spawner are Spearman Rank Correlation coefficients, the screening value is the critical value for n=10 and one tailed alpha = 0.10 (critical value = 0.46).

2 "LN" indicated values were natural-log transformed prior to correlation estimation.

Values greater than the screening limit are highlighted in red.

Table 16. Pearson correlation coefficients for hydrologic versus biological variables describing run timing for the Stikine River.

	Median Run Time	Run Duration
mean.flow		0.13
flow.range		0.63
flow.sd		0.63
jday.max	-0.39	
jday.MI	-0.061	

Notes:

1. Values greater than the screening limit are highlighted in red.

7. FIGURES

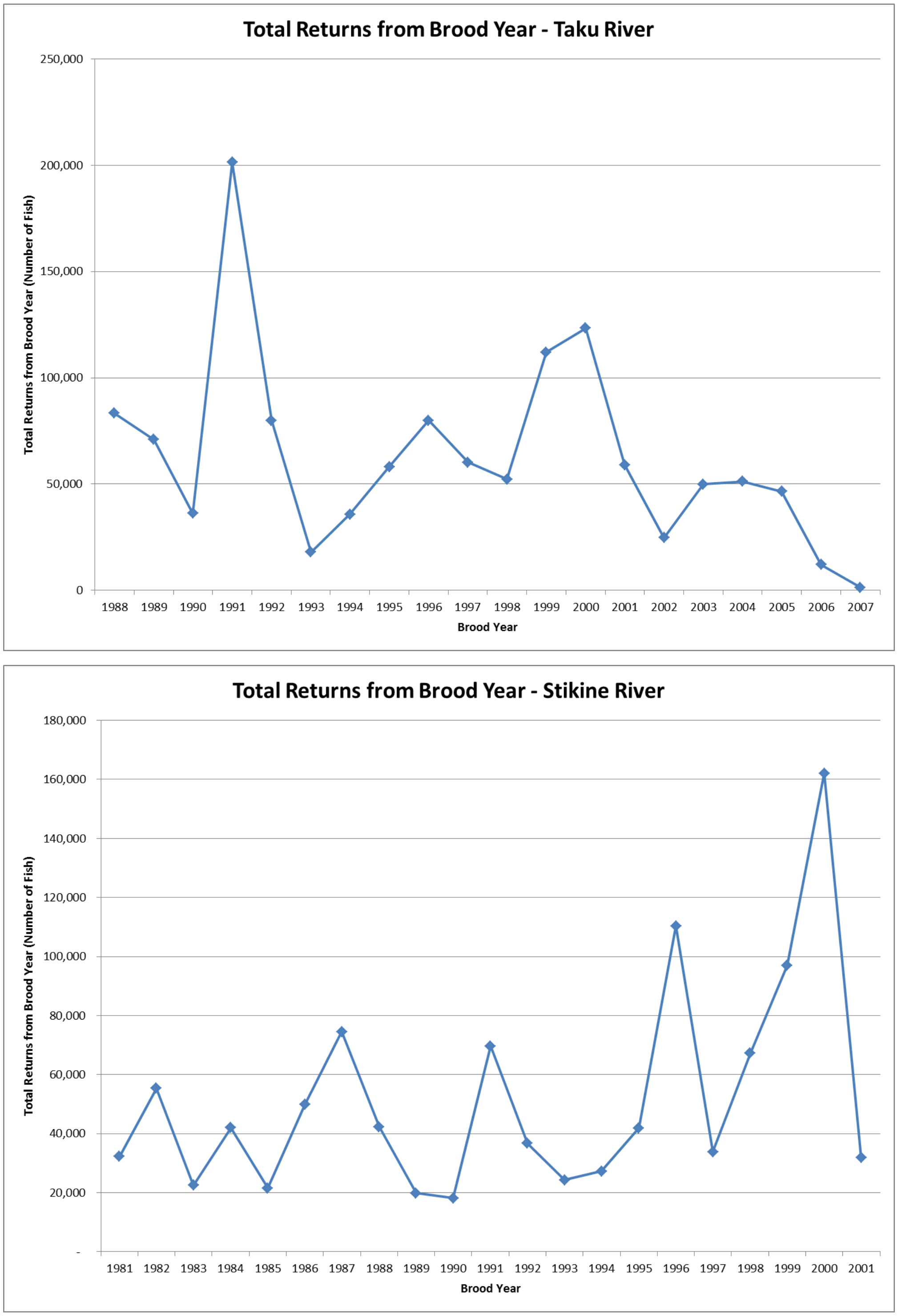
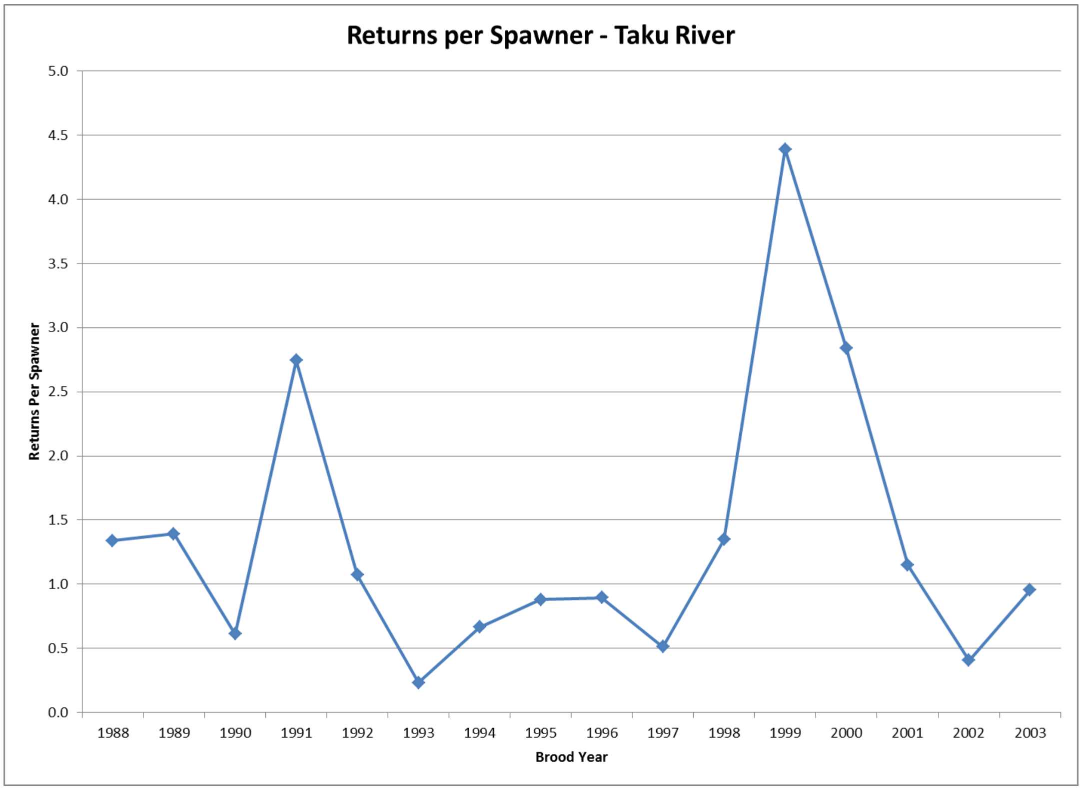


Figure 1. Total returns by brood year for the Taku (top) and Stikine (bottom) rivers.

Note: Taku returns for brood years 2005-2007 are based on incomplete age-class data and were not used in the analysis.



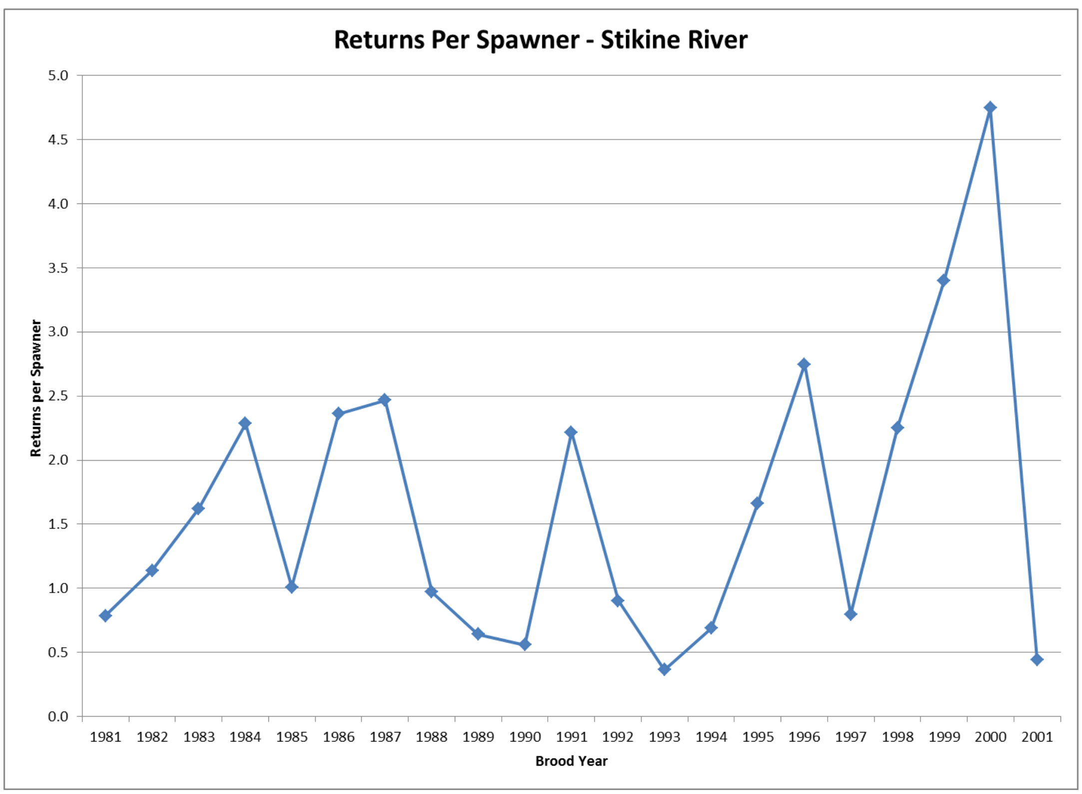
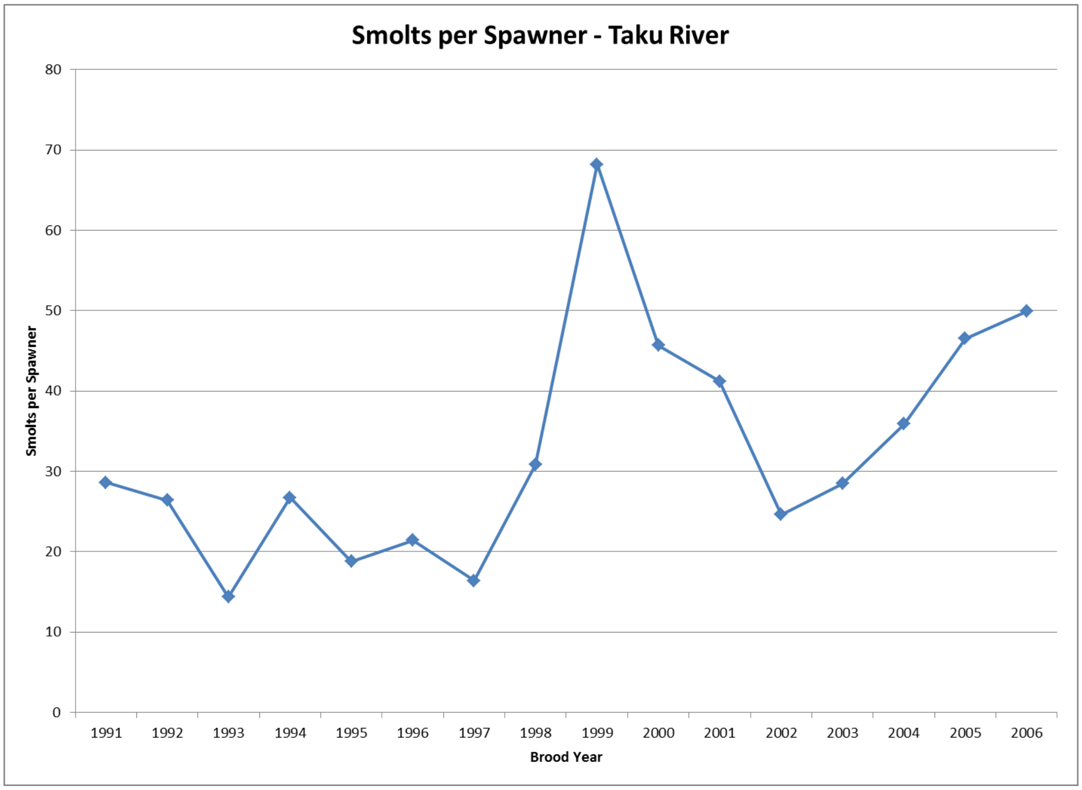


Figure 2. Chinook salmon returns per spawner for the Taku (top) and Stikine (bottom) rivers.



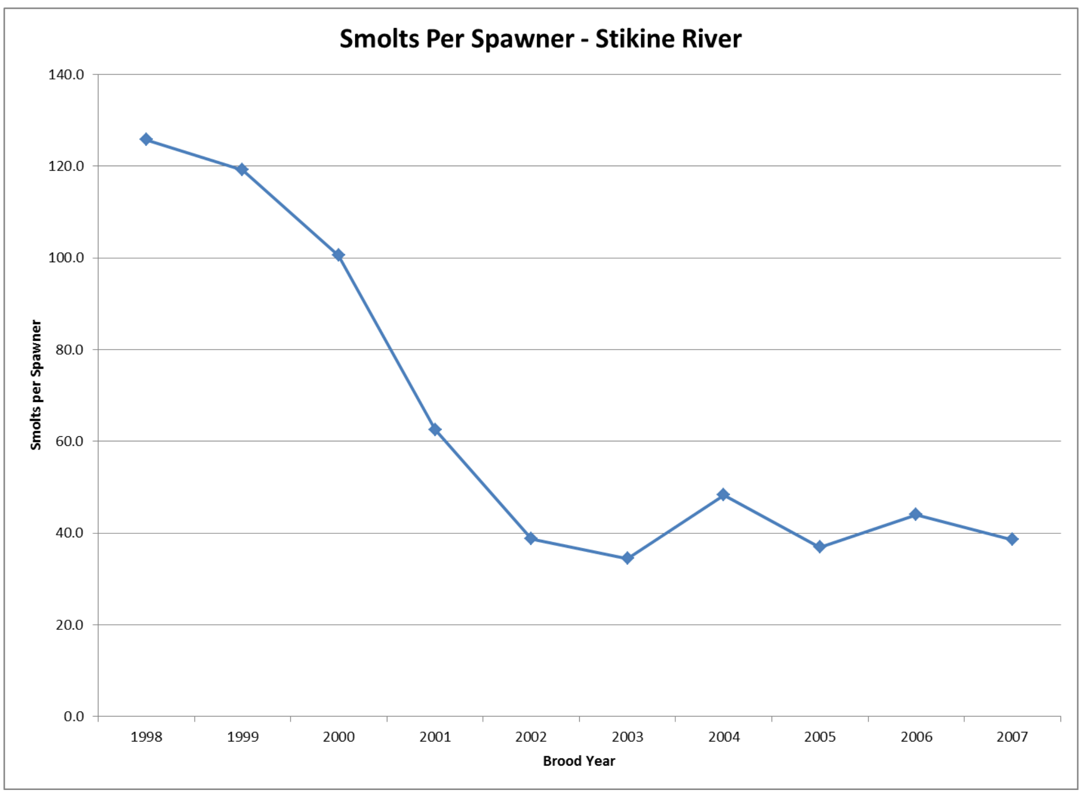


Figure 3. Chinook salmon smolts per spawner for the Taku (top) and Stikine (bottom) rivers.

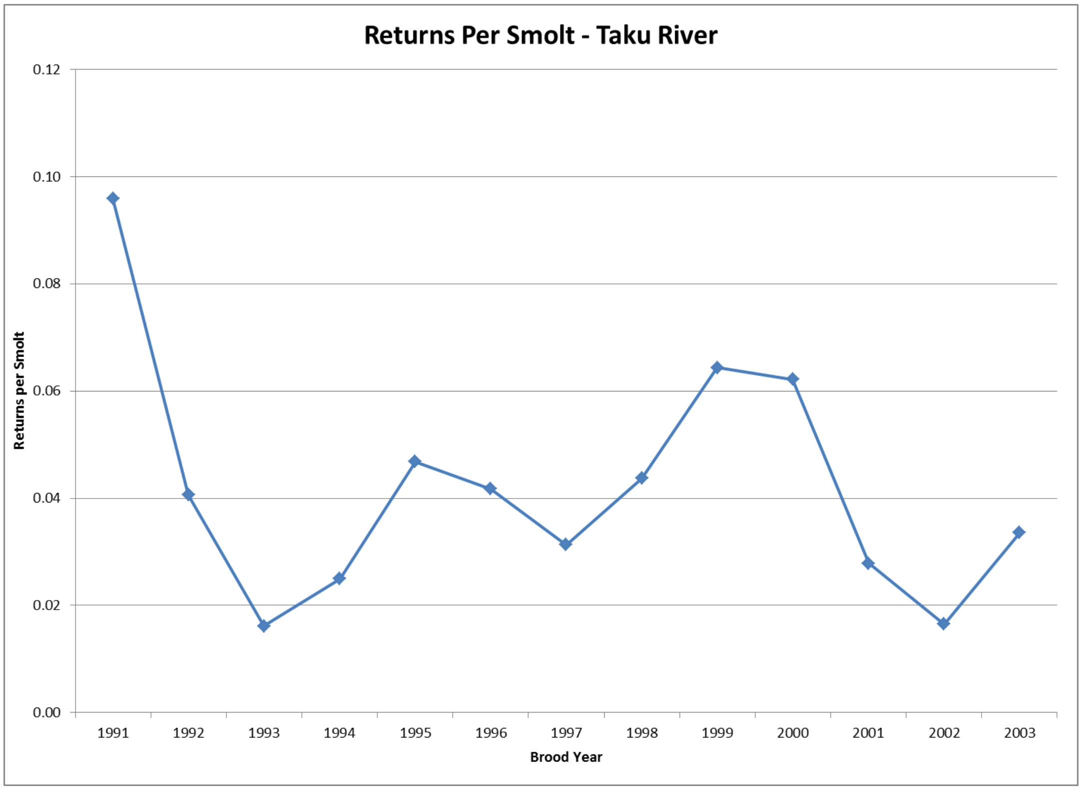
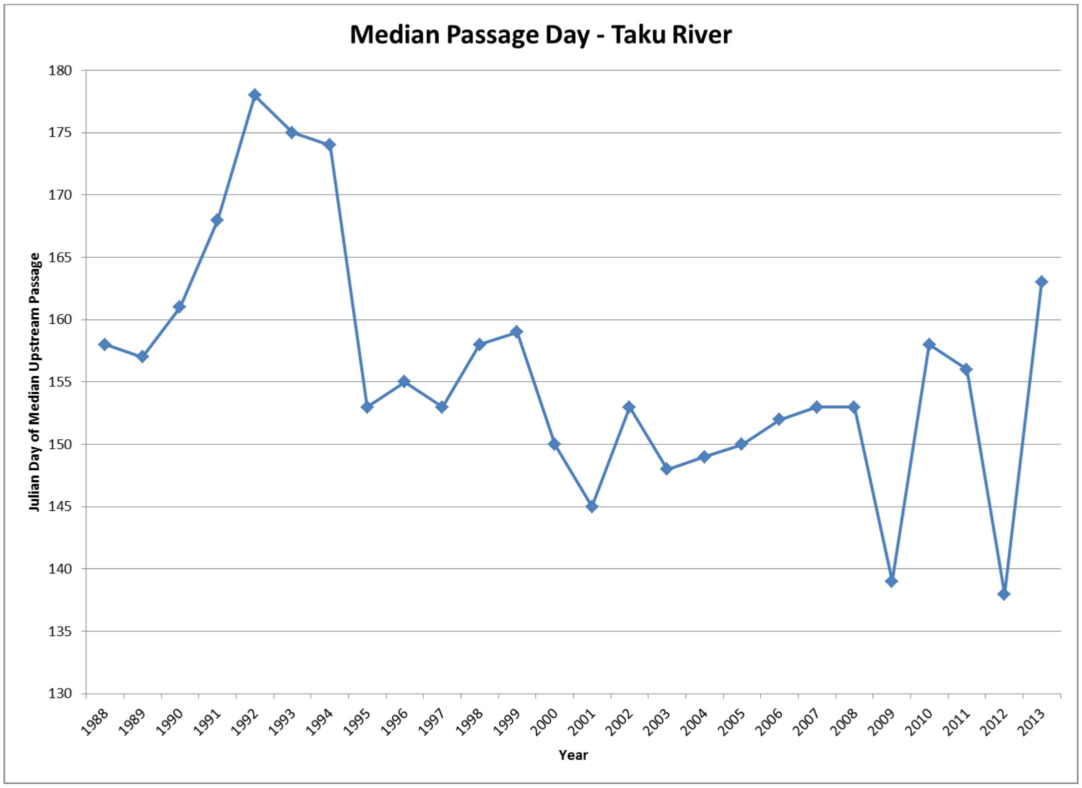


Figure 4. Chinook salmon returns per smolt for the Taku River.



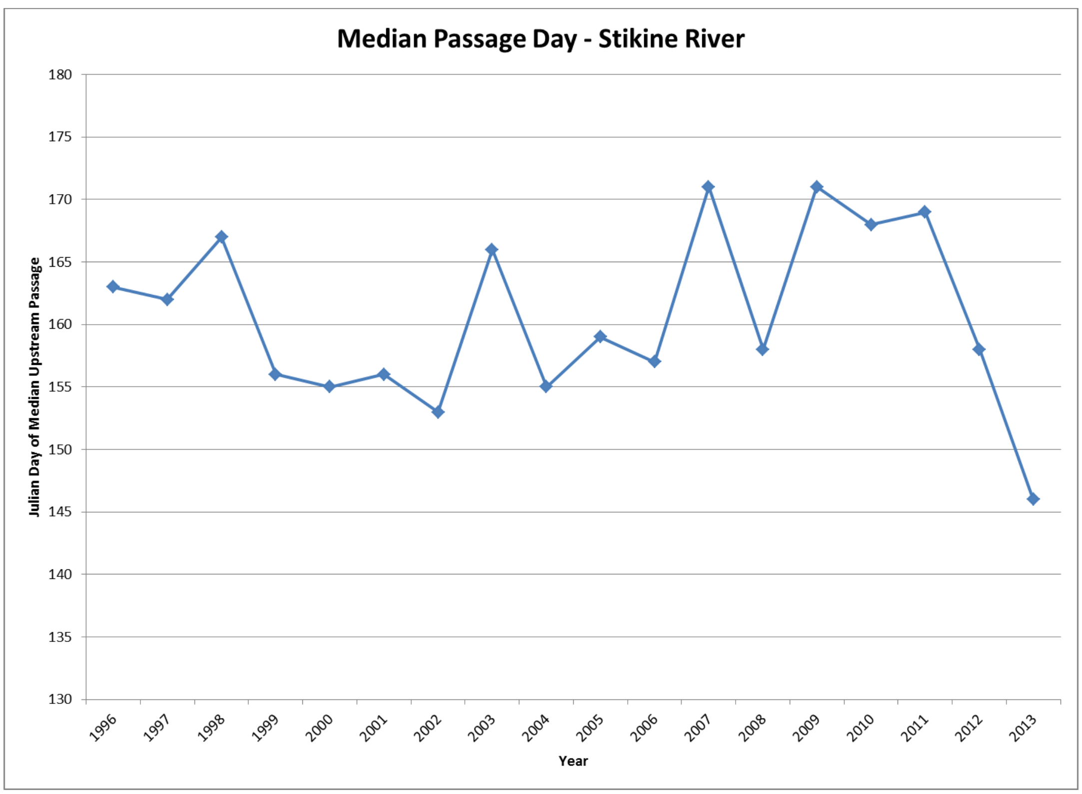
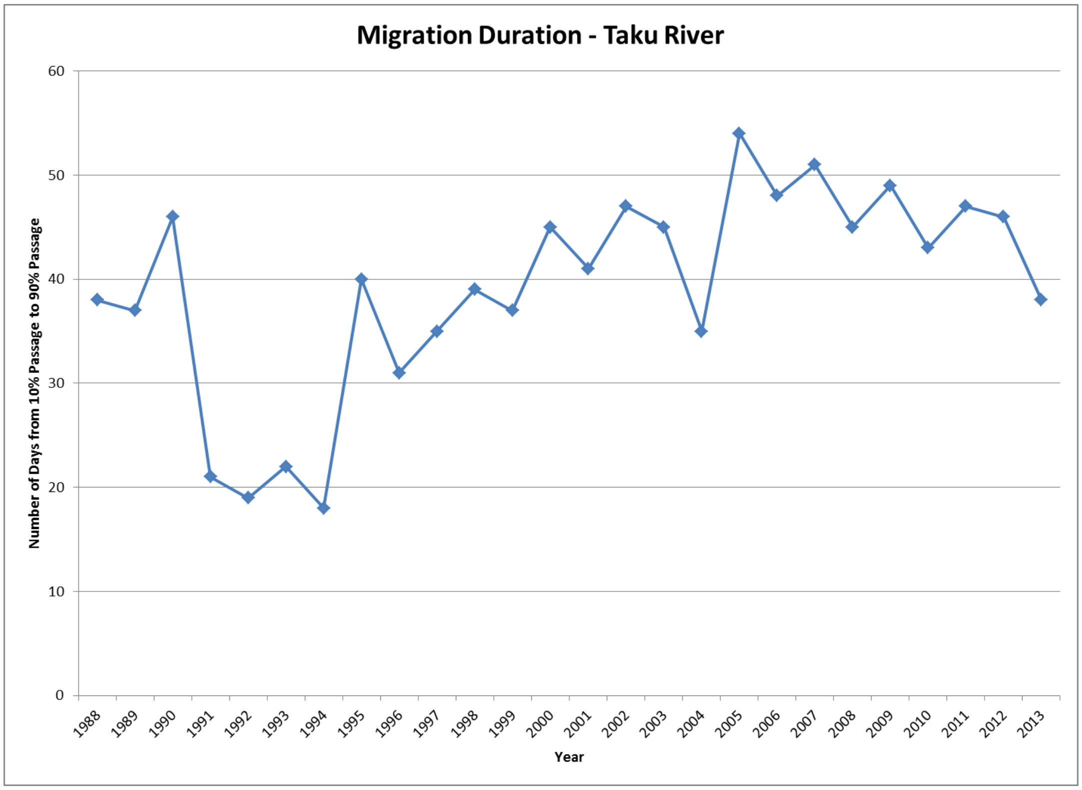


Figure 5. Median passage day for the Taku (top) and Stikine (bottom) Rivers.

Notes:

1. Julian Day 130 is May 10 and Julian Day 180 is June 29.



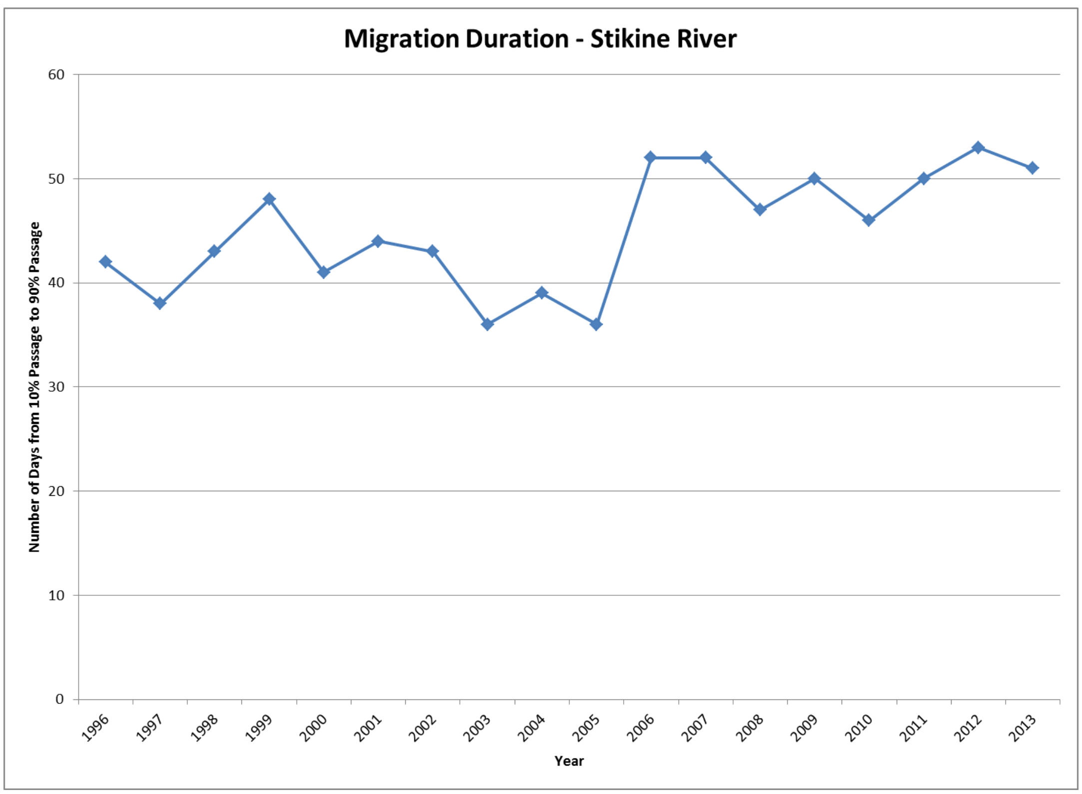


Figure 6. Upstream migration duration from 10% passage to 90% passage for the Taku (top) and Stikine (bottom) rivers.

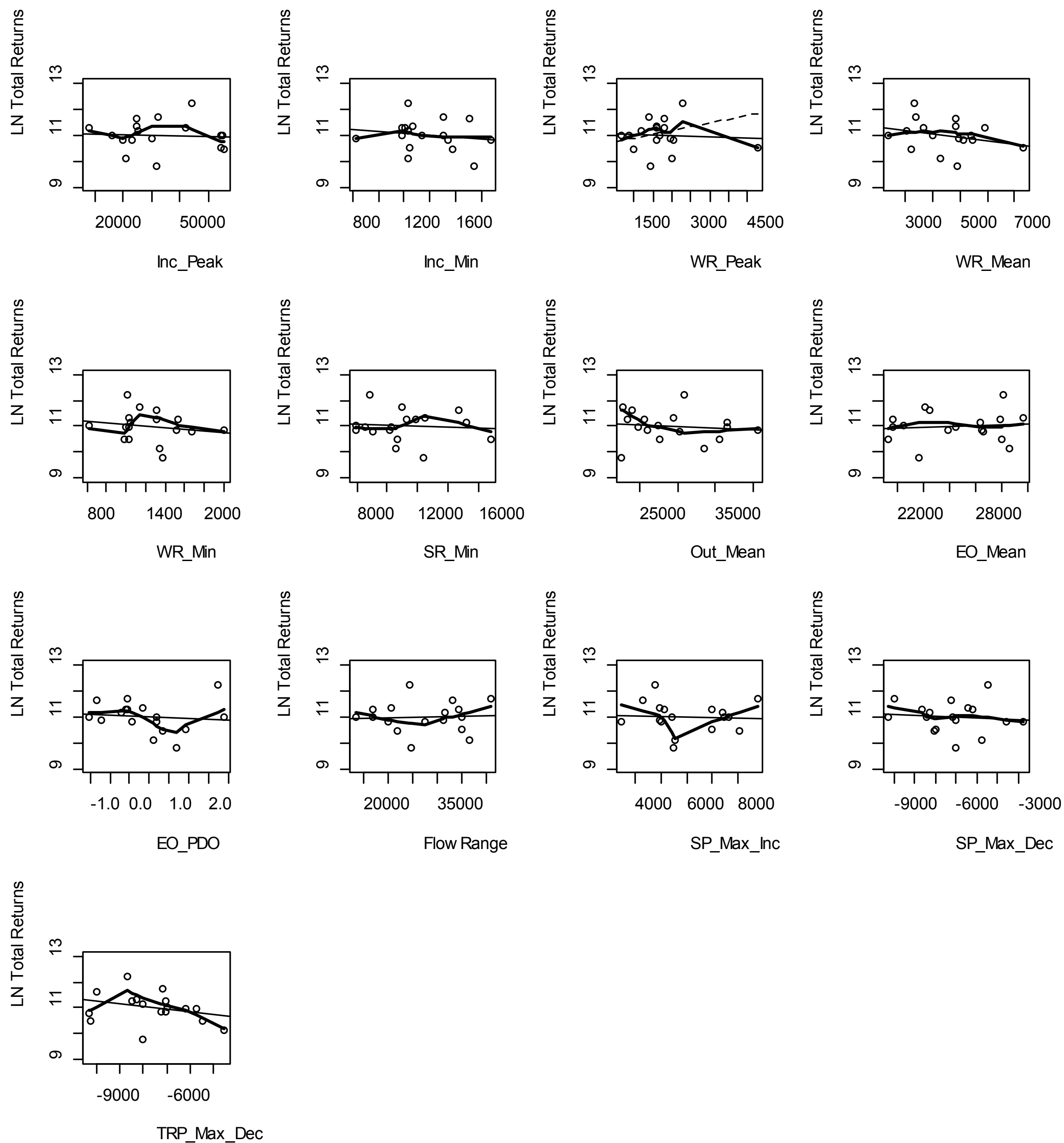


Figure 7. Total returns (natural log transformed to approximate normal response distribution) plotted as a function of full set of predictor variables for the Taku River.

Notes:

1. Straight line is least-squares linear fit. Heavy line is local regression smoother. Dotted lines, if present, are fit without heavily influential points.

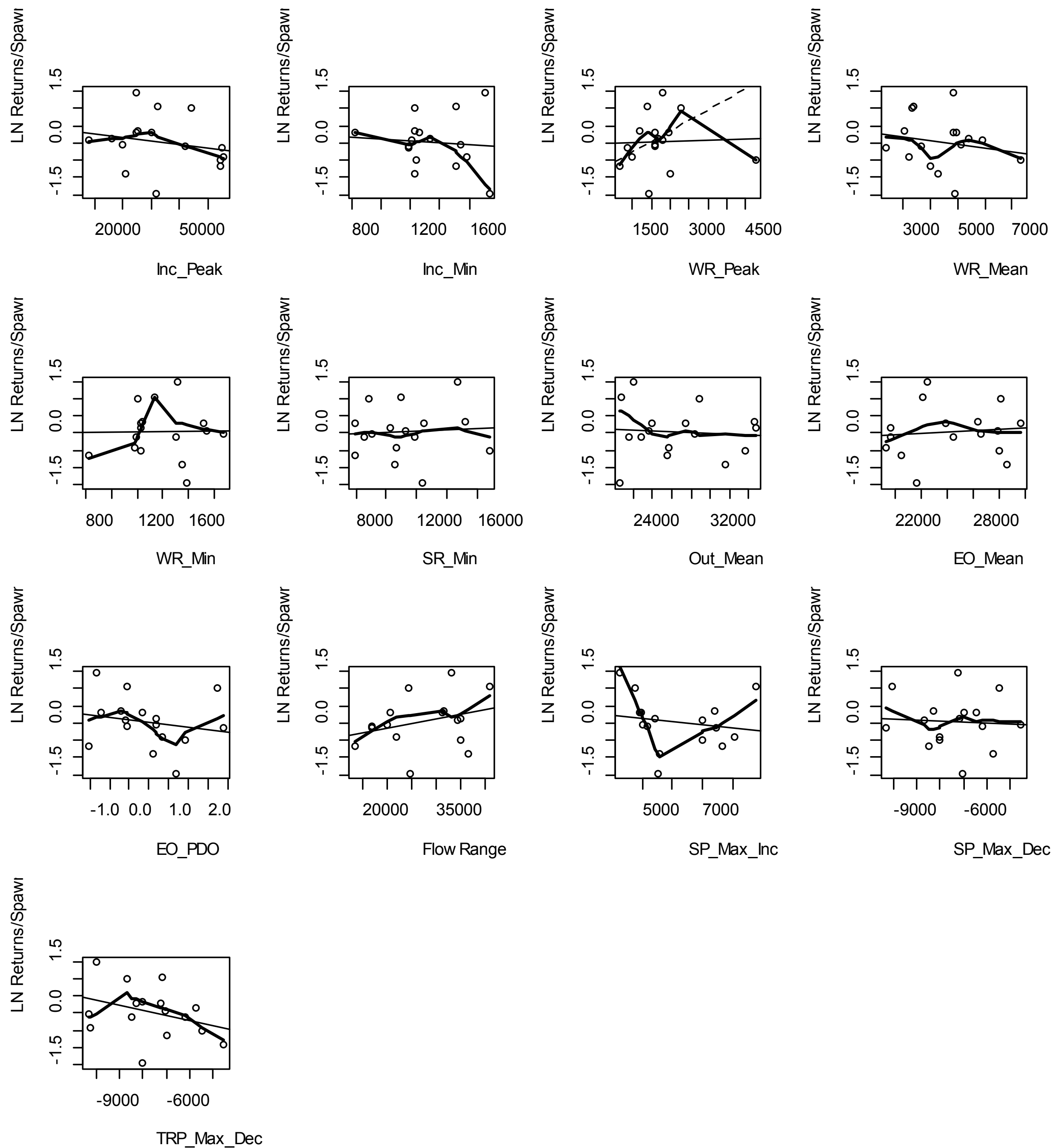


Figure 8. Returns per spawner (natural log transformed to approximate normal response distribution) plotted as a function of full set of predictor variables for the Taku River.

Notes:

1. Straight line is least-squares linear fit. Heavy line is local regression smoother. Dotted lines, if present, are fit without heavily influential points.

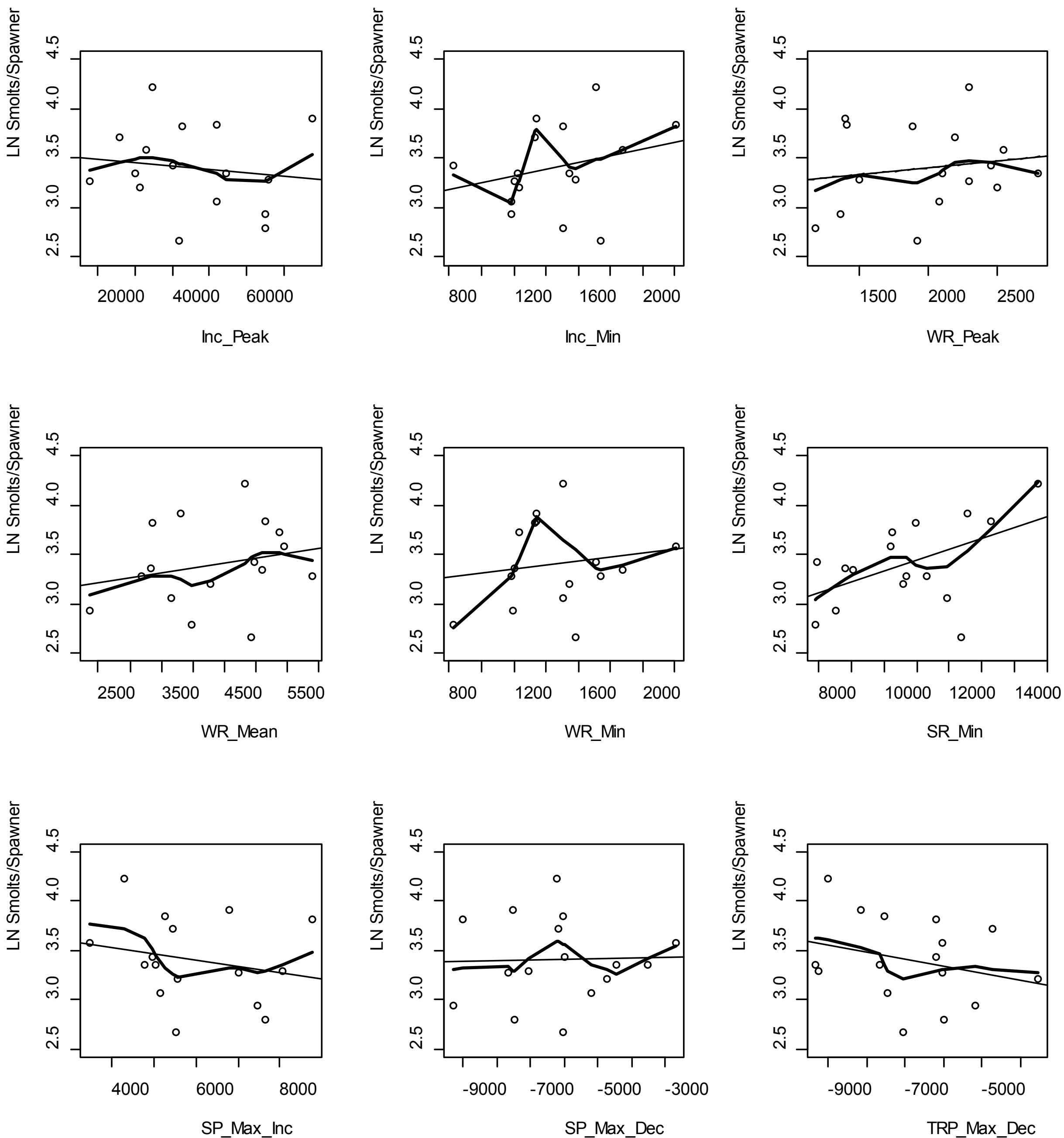


Figure 9. Smolts per spawner (natural log transformed to approximate normal response distribution) plotted as a function of full set of predictor variables for the Taku River.

Notes:

1. Straight line is least-squares linear fit. Heavy line is local regression smoother.

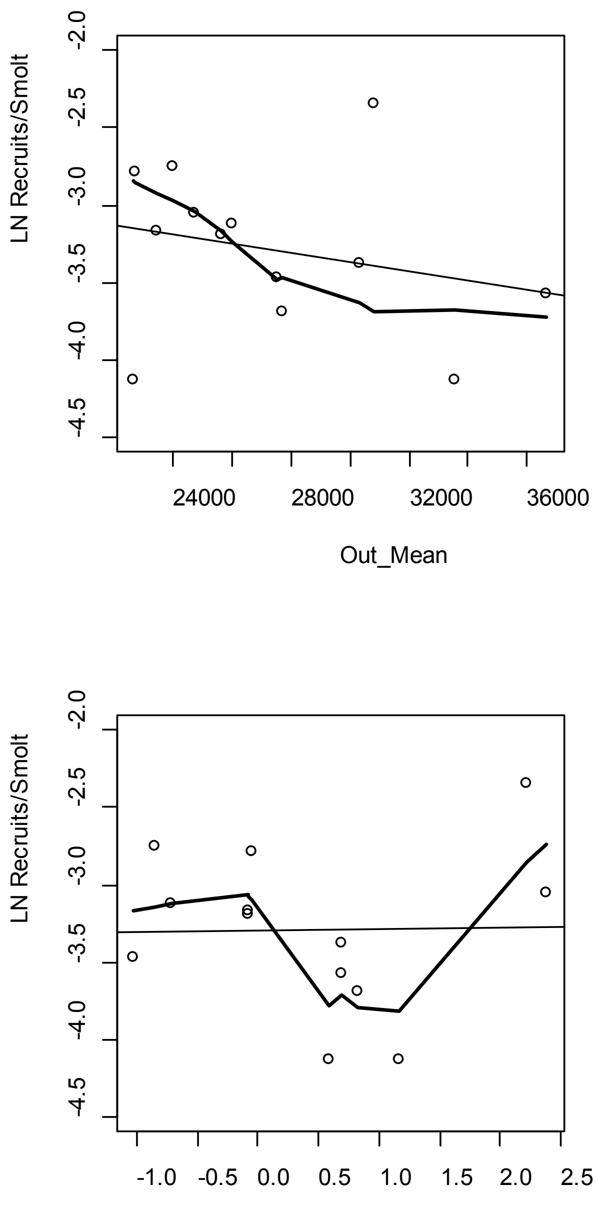


Figure 10. Smolt to adult returns (SAR; natural log transformed to approximate normal response distribution) plotted as a function of relevant predictor variables for the Taku River.

Notes:

1. Straight line is least-squares linear fit. Heavy line is local regression smoother.

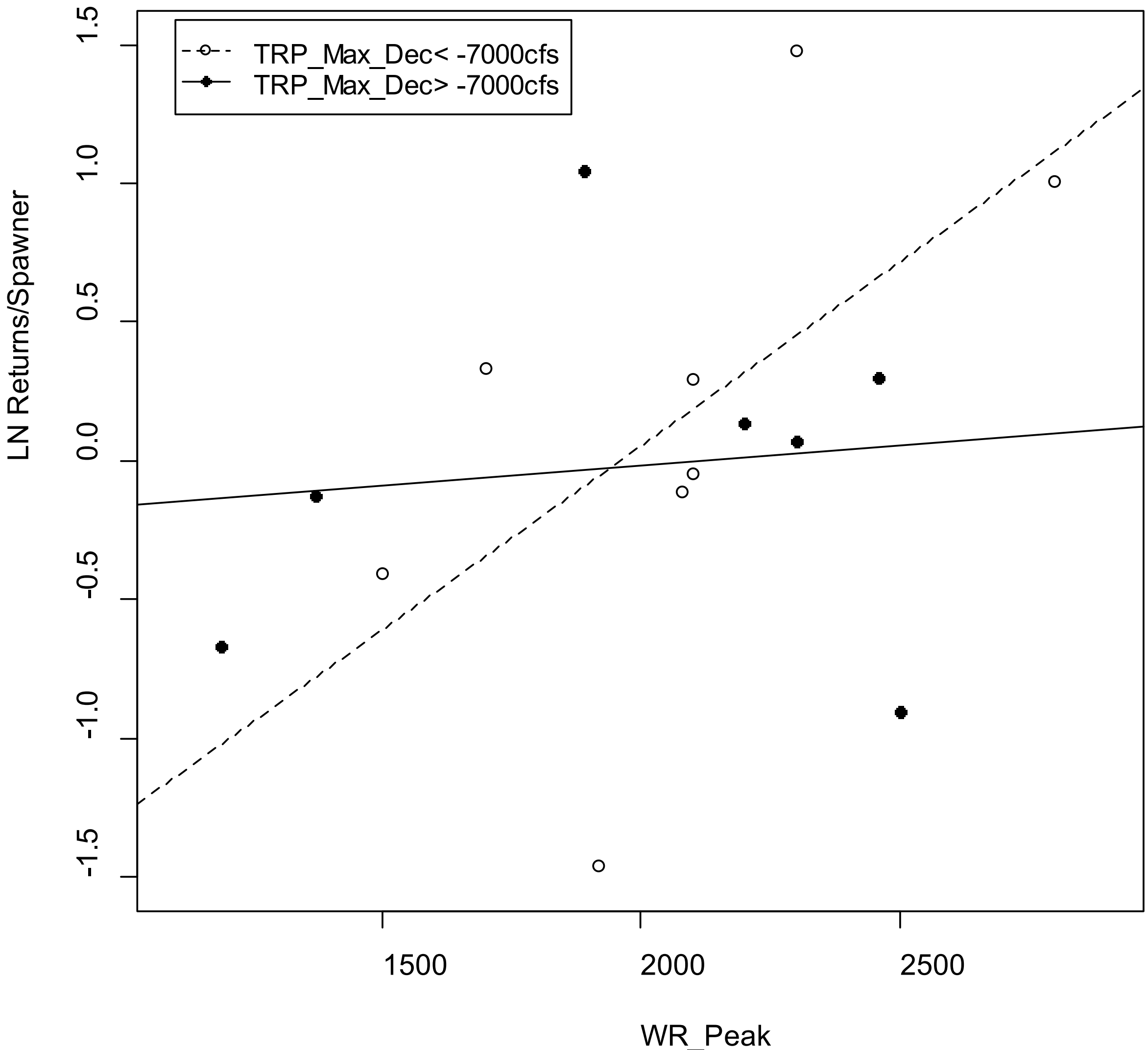


Figure 11. Plot showing interaction between winter-rearing peak flow and trapping maximum flow decrease for returns per spawner for the Taku River.

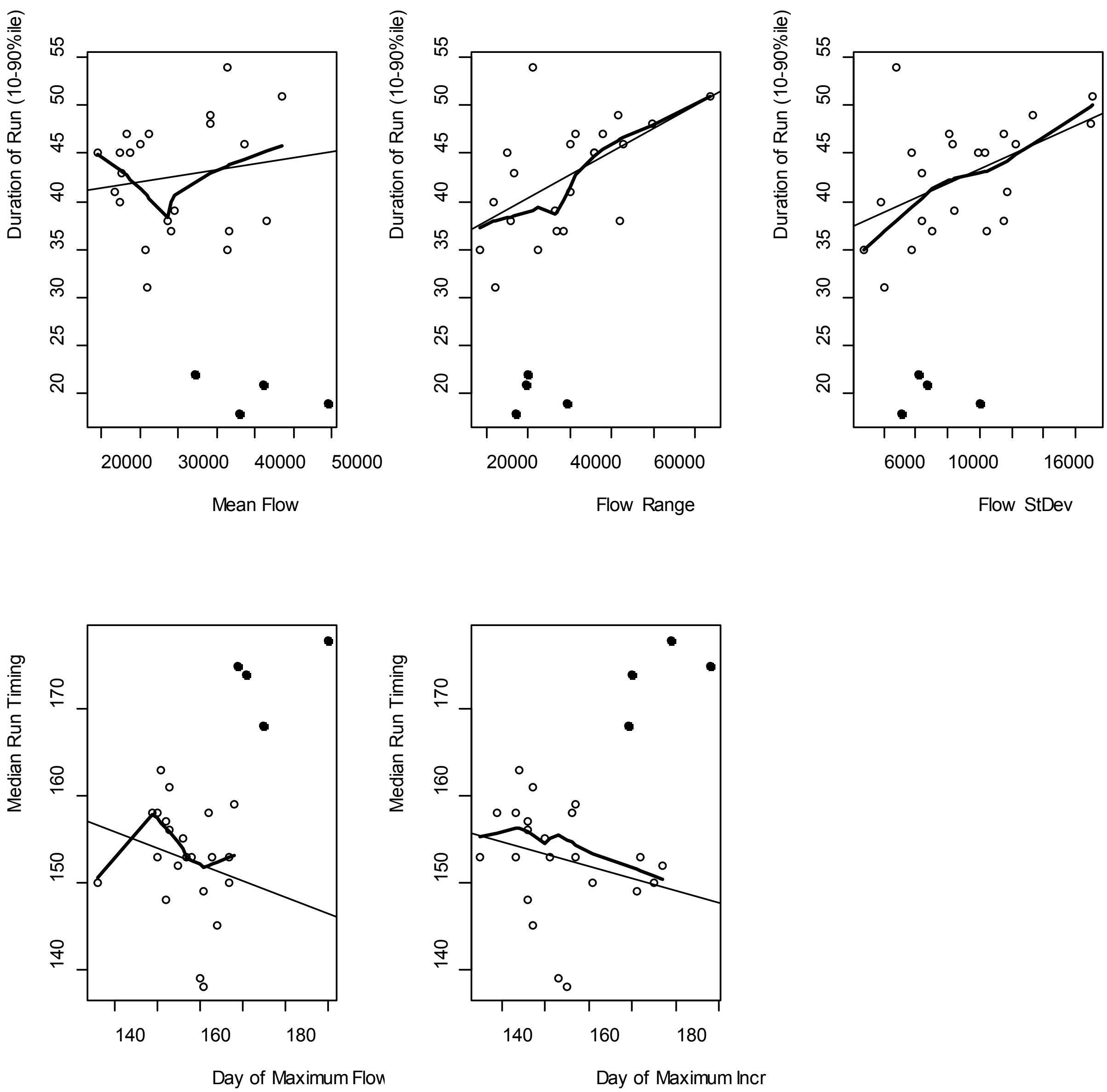


Figure 12. Scatterplots of potential run-timing relationships for the Taku River.

Notes:

1. Black points are for years 1991-1994 when the beginning of migration was possibly missed. These points are not included in analyses. Straight line is least-squares linear fit. Heavy line is local regression smoother.

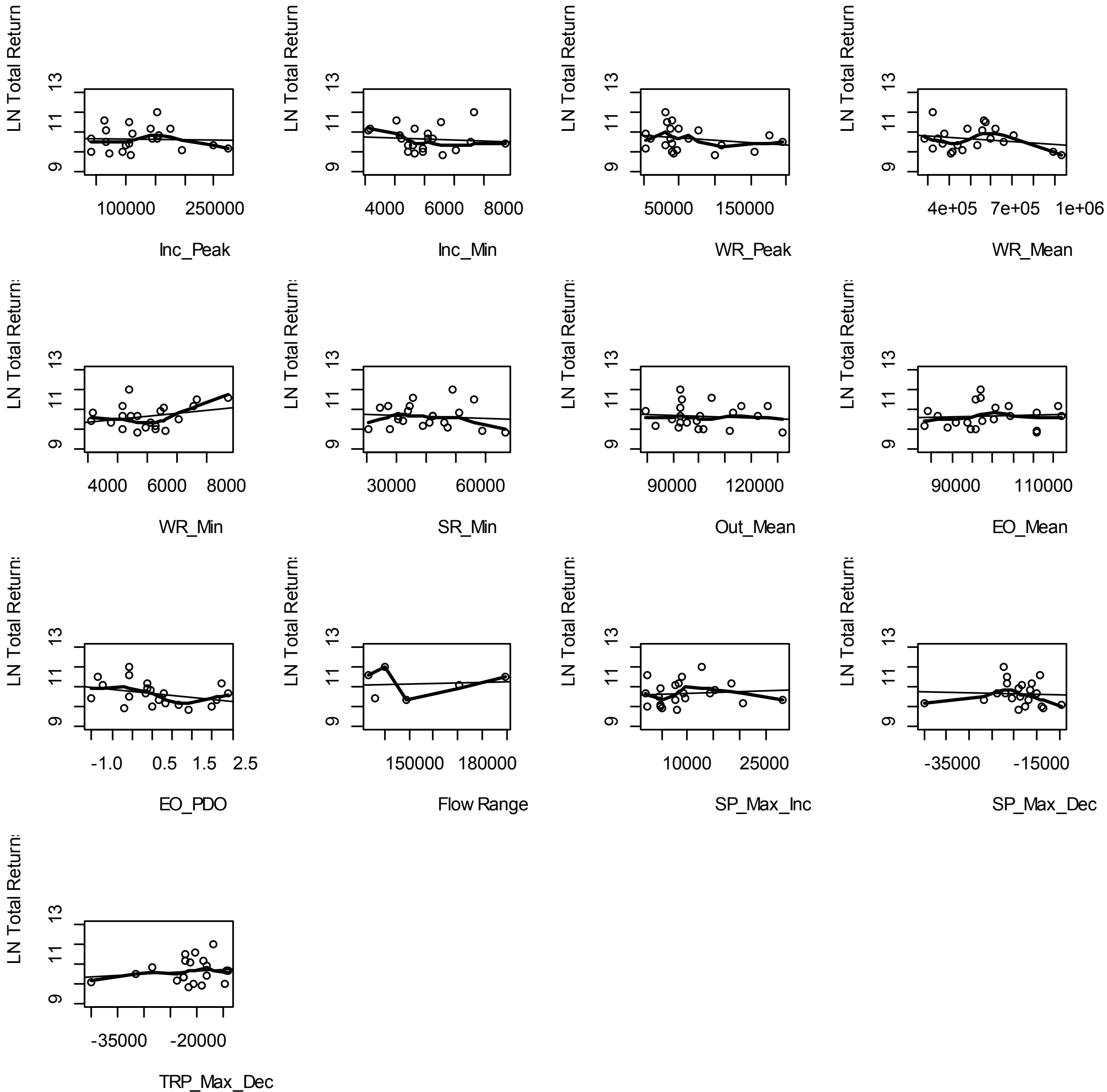


Figure 13. Total returns (natural log transformed to approximate normal response distribution) plotted as a function of full set of predictor variables for the Stikine River.

Notes:

1. Straight line is least-squares linear fit. Heavy line is local regression smoother.

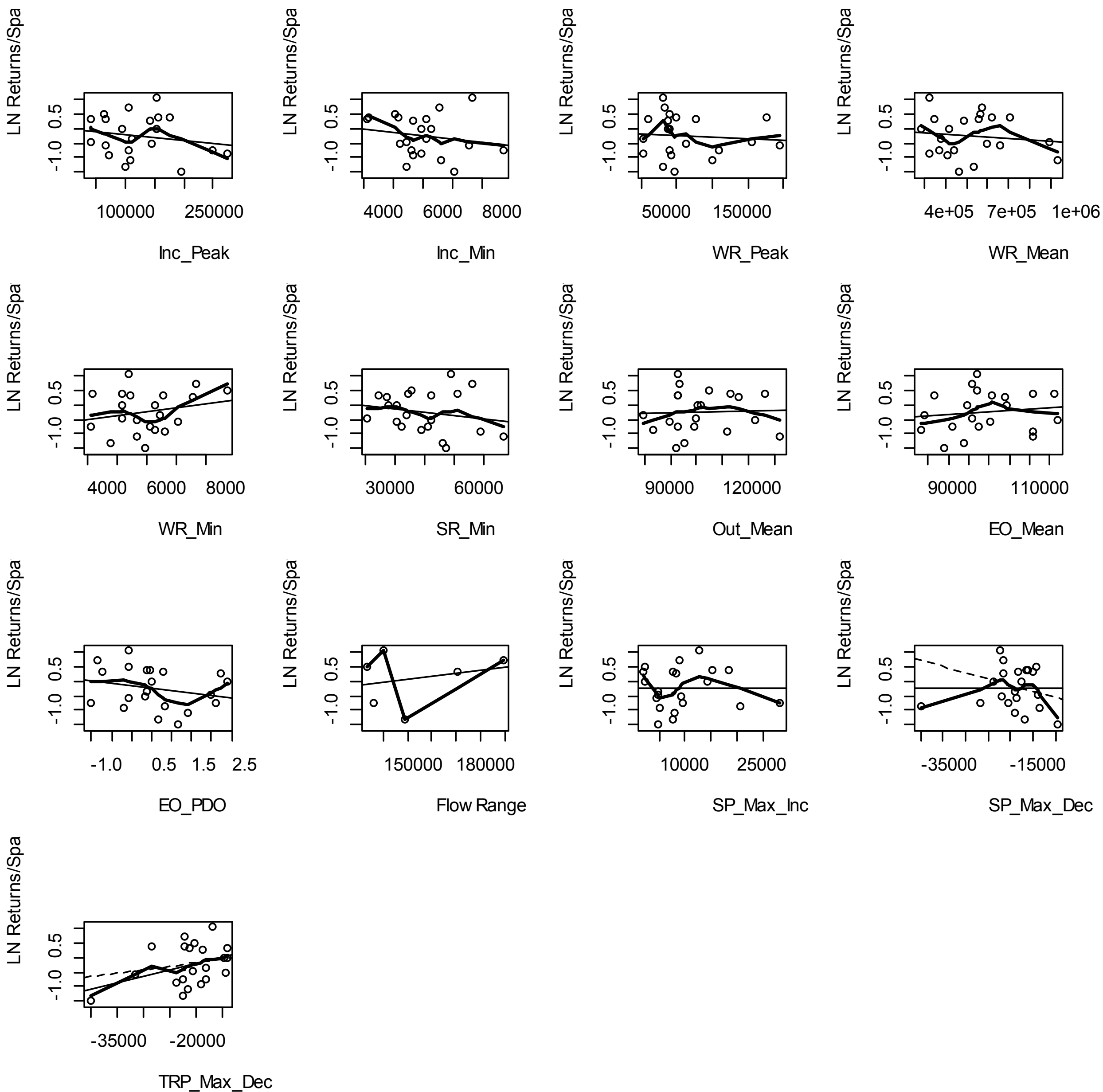


Figure 14. Returns per spawner (natural log transformed to approximate normal response distribution) plotted as a function of full set of predictor variables for the Stikine River.

Notes:

1. Straight line is least-squares linear fit. Heavy line is local regression smoother. Dotted lines, if present, are fit without heavily influential points.

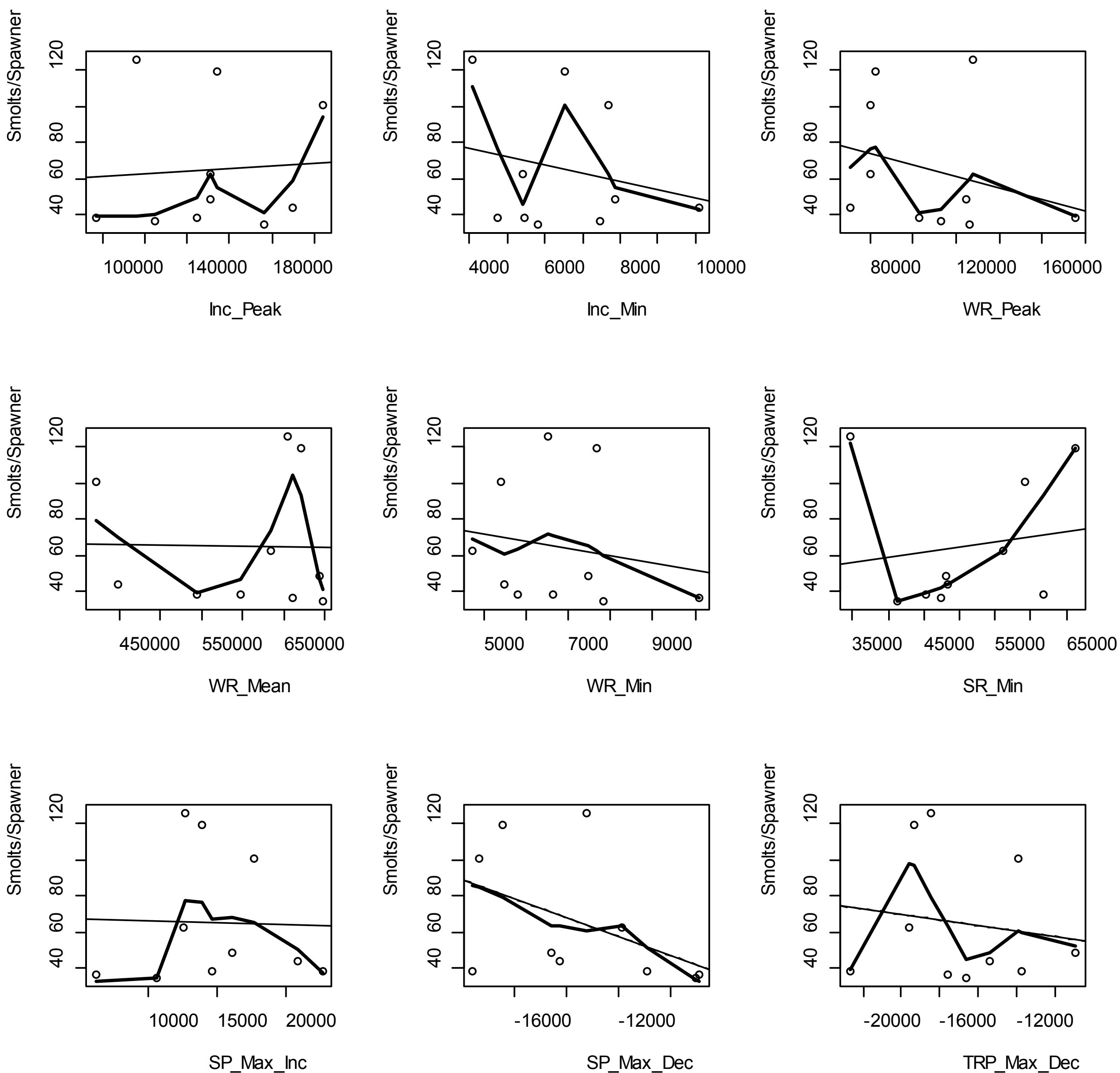


Figure 15. Smolts per spawner plotted as a function of full set of predictor variables for the Stikine River.

Notes:

1. Straight line is least-squares linear fit. Heavy line is local regression smoother. Note that smolts per spawner has a non-normal bimodal distribution.

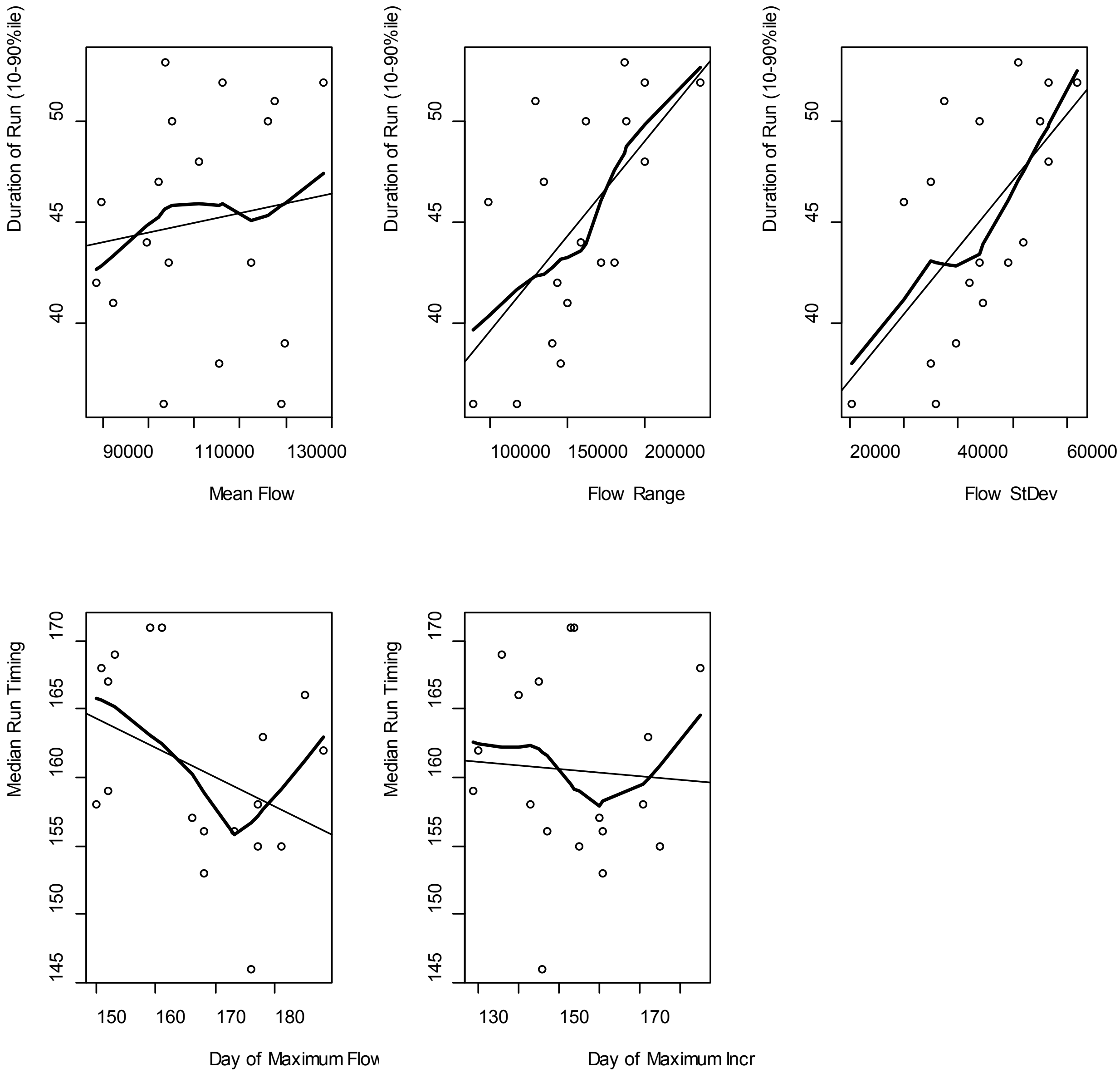


Figure 16. Scatterplots of potential run-timing relationships for the Stikine River.

Notes:

1. Straight line is least-squares linear fit. Heavy line is local regression smoother.

Susitna-Watana Hydroelectric Project

(FERC No. 14241)

Fish and Aquatics Instream Flow Study (8.5)

Part A - Appendix C
2013 Moving Boat ADCP Measurements

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Brailey Hydrologic

R2 Resource Consultants

Geovera

GWS

June 2014

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXHIBITS

LIST OF ACRONYMS AND SCIENTIFIC LABELS

Abbreviation	Definition
1-D	1-Dimensional
2-D	2-Dimensional
ADCP	Acoustic Doppler Current Profiler
AEA	Alaska Energy Authority
cfs	cubic feet per second
ft/s	feet per second
FA	Focus Area
FERC	Federal Energy Regulatory Commission
GGA	National Marine Electronics Association – 0183 GGA data sentence
GPS	Global Positioning System
IFS	Instream Flow Study
NEPA	National Environmental Policy Act
PRM	Project River Mile
RTK	Real-Time Kinematic

1. INTRODUCTION

This report provides 2013 moving-boat acoustic Doppler current profiler (ADCP) measurements performed as part of the Instream Flow Study (IFS) and Fluvial Geomorphology Modeling Study (Studies 8.5 and 6.6) for the Susitna-Watana Hydroelectric Project (Project). These studies are required by the Federal Energy Regulatory Commission (FERC) under the National Environmental Policy Act (NEPA). The studies were commissioned by the Alaska Energy Authority (AEA) to support the license application for the proposed Project.

2. STUDY OBJECTIVES

The goals of the IFS and Fluvial Geomorphology Modeling studies include development of hydraulic models to quantify potential impacts from the proposed Project (AEA 2012). The 2013 ADCP measurements will be used for calibration and verification of 1- and 2-dimensional (1-D and 2-D) hydraulic models developed by the IFS and Geomorphology Modeling teams.

3. STUDY AREA

As shown on Figure 1, the Susitna River can be divided into Upper, Middle, and Lower segments separated by the proposed dam site and the three rivers confluence. ADCP measurements were performed at two locations on the Upper River, 98 locations on the middle river, and 62 locations on the Lower River. The Upper and Middle river work included repeated measurements in 7 Focus Areas, at 7 mainstem and tributary gages, and at 3 locations required for 1-D modeling. The Lower River work included discharge measurements at 6 high-flow and 5 low-flow locations, each comprised of 3 to 11 channels. A total of 250 measurements were conducted during three field campaigns in June/July, August, and September 2013.

Throughout the study area, discharge measurements were limited to areas outside of Cook Inlet Regional Working Group (CIRWG) lands. As a result, no discharge measurements were performed between Project River Mile (PRM) 146 and PRM 225.

4. METHODS

Discharge measurements were conducted following current USGS guidance for moving-boat ADCP measurements. ADCP instruments utilize the Doppler effect to measure the velocity of moving water bodies by emitting acoustic signals at a given frequency and measuring the change in frequency after reflecting off particles (i.e. sediment) throughout the water. By deploying an ADCP from a moving-boat and plotting a course back and forth across a river, the velocity distribution of the river relative to the moving-boat is measured (not the absolute velocity of the river).

In order to account for the velocity of the moving boat, an ADCP can track the moving-boat movement and velocity by either bottom tracking, or GPS. With bottom tracking, an ADCP emits an acoustic signal directly down to the streambed to obtain the boat's velocity. When river flows are high, sediment transport along the streambed can be significant enough to bias the bottom tracking. In this case, the velocity of the boat must be corrected for, most commonly using the loop test method. In a loop test, an ADCP on a moving boat is brought back and forth across a river cross-section and returned to the exact same location. If bottom tracking correctly shows the moving-boat to have returned to the beginning location, no moving-bed correction is required. However, if bottom tracking results erroneously show that the moving-boat has not returned to the original location, the measured difference in distance can be used to correct for moving-bed conditions. Alternatively, an ADCP can be linked with a GPS system that tracks the movement of the boat, independent of moving-bed conditions.

Knowing the velocity distribution throughout a river cross-section, discharge is computed as the product of the cross-sectional area and the water velocity. Deviations from current USGS guidance are identified in Section 4.1.

4.1. Deviations from the Study Plan

Deviations from current USGS guidance included aspects of compass calibration (Section 5.1.1), moving bed tests (Sections 4.5.2 and 5.1.2), and velocity profile extrapolations (Section 5.1.3).

4.2. Instrument Selection

The depth range of the 2013 measurement locations (up to 25 feet) limits the choice of ADCPs to the Teledyne/RDI (TRDI) Rio Grande, the TRDI RiverRay, or the Sontek M9. With similar capabilities, the Sontek M9 was selected by the IFS and Geomorphology study teams because of its shallower measurement depth (as little as 0.5 feet) and greater vertical resolution (as small as 2 cm). This was despite documented compass calibration issues that compromised some of the 2012 Project results (R2 et al. 2013).

On November 18, 2013, USGS issued OSW Technical Memorandum No. 2014.02 (OSW 2013a), which increased the minimum blanking distance for the Sontek M9 (see Section 4.5.2.2). Using the M9 trimaran hull and the revised blanking distance, the minimum measurement depth for the M9 is 0.8 feet. Assuming the same transducer depth (0.25 feet), the minimum measurement depth for the TRDI RiverRay is 1.6 feet, and the TRDI Rio Grande is 2.6 feet.

4.3. Measurement Platform

The 2013 ADCP measurements were performed from a 12-foot solo cataraft powered by an outboard motor (Figure 2 and Figure 3). The ADCP was mounted in the center hull of an M9 trimaran at the forward end of the cataraft. A pivoting mount limits lateral roll to that of the cataraft, but allows fore-aft pitch to vary independently. The cataraft’s light weight permits a small (8-horsepower) motor that can be raised in shallow water. The cataraft’s shallow draft and floorless design allow it to be walked or held stationary with the operator’s feet in shallow water. These features allow measurements in water less than 1 foot deep, resulting in small edge estimates. An on-board computer avoids shore-based communication issues, and allows the boat operator to simultaneously monitor boat navigation and ADCP data quality.

4.4. Pre-Field Instrument Preparation

Although a backup M9 was maintained throughout the field program, all of the 2013 discharge measurements were made using a newly-manufactured Sontek M9 ADCP (serial no. 3936). Both units had current M9 firmware installed (v. 3.00), had their custom beam transformation matrices re-loaded, and passed factory beam alignment tests (Macone, Sontek Technical Support, personal communication, May 20, 2013). Although a firmware update became available on September 13, 2013, the update was not installed to avoid re-setting the custom beam transformation matrices.

4.5. Field Procedures

4.5.1. Compass Calibration

Compass calibrations were performed daily in accordance with the USGS *Best Practice for Calibrating RiverSurveyor S5/M9* (OSW 2012a). Although occasional passing scores were obtained, more than 90 percent of the calibrations failed. These results are discussed further in Section 5.1.1.

4.5.2. Moving Bed Tests

Except where low velocities (< 0.8 ft/s) resulted in loop test error messages, loop moving bed tests were performed at all 1-D model measurement locations. This was despite predominantly unsuccessful compass calibrations. As described in detail in Section 5.1.1, the failed compass calibrations are attributed to magnetic interference from the outboard motor. At most measurement locations, valid loop tests were obtained by maintaining a nearly-constant boat orientation. This resulted in stationary or upstream loop closures with out-back flow direction differences less than 5 degrees. These results are discussed further in Section 5.1.2.

For the 2-D model measurements, loop tests were limited to representative locations within each Focus Area. Again, valid loop test closures were obtained by maintaining a nearly-constant boat orientation.

4.5.3. 1-D Model Measurements

One-dimensional model flow measurements were performed at single-channel locations on the middle and Upper River and multiple-channel locations on the Lower River. These measurements included at least four reciprocal transects with a combined exposure time of at least 720 seconds (12 minutes). Except where low velocities resulted in loop test error messages, loop tests were performed at each measurement location. Edge estimates included at least 10 seconds of valid velocity data from at least two good bins.

4.5.4. 2-D Model Measurements

Two-dimensional model flow measurements were performed at 7 Middle River Focus Areas that do not include CIRWG lands. Measurement locations were selected to quantify flow splits among various channels and sloughs, resulting in 10 to 14 measurements per Focus Area. If possible, the modeling team preferred that the measurements were completed in a single day. Considering travel to and from the work site, this timeframe did not allow moving bed tests and

12 minutes of exposure time at each location. As a result, moving bed tests were performed at representative main channel locations, and each measurement consisted of at least two reciprocal transects (except where precluded by standing waves). As described in Section 5.1.9, the uncertainty of 2-D model flow measurements was evaluated using streamwise summations of riverwide flow.

4.6. Data Review and Post-Processing

4.6.1. Field Data Review

Upon completion of each 1-D model measurement, the results were reviewed to ensure that:

- System settings were correct;
- Valid moving bed tests were completed;
- An even number of reciprocal transects were recorded;
- The transects did not show significant bottom tracking errors;
- The velocity profiles did not include missing or corrupted data;
- At least 12 minutes of exposure time were recorded;
- Measurement precision was acceptable; and
- Directional bias was acceptable.

A similar review was performed upon completion of the 2-D model measurements, except that each transect consisted of two reciprocal passes, and moving bed tests were limited to representative main channel locations.

The field review identified additional issues related to compass calibration, bottom-tracking errors, GPS data quality, and heading errors. These issues are described in Section 5.1.6.

4.6.2. Data Post-Processing

4.6.2.1. Data Reprocessing

ADCP data reprocessing was performed to verify system settings, to check for data quality issues, and to identify heading corrections and velocity profile extrapolation settings. After the initial field data review, reprocessing was performed by Brailey Hydrologic, followed by R2 Resource Consultants. Results of the reprocessing efforts are described in Section 5.1.6.

4.6.2.2. Blanking Distance Settings

Due to interference from the outgoing signal, most ADCPs cannot measure velocity within a certain "blanking distance" from the transducer head. In addition, displacement of water by the ADCP can cause flow disturbance around the instrument. As documented by Mueller et al. (2007), the flow disturbance is greatest for unfaired mountings such as the USGS 'Kentucky mount'. However, it was assumed that flow disturbance is minimal for streamlined fairings such as the M9 trimaran hull (Figure 3). As a result, the ADCP data were collected and reprocessed using the default (0.2-foot) blanking distance.

On November 18, 2013, USGS issued OSW Technical Memorandum No. 2014.02, which establishes a minimum blanking distance of 0.52 feet for the Sontek M9 (OSW 2013a). This is based on shallow-water flume studies on several mounts including the M9 trimaran hull. Results indicate a negative bias ranging up to 6 percent for shallow water conditions, attributed to flow disturbance around the transducer head.

Because the data were reprocessed before November 18, 2013, the recommended blanking distance was not included. Reprocessing of measured 2013 flows at four Middle River gaging stations (ESS40, ESS45, ESS50, and Gold Creek) indicates that the M9's default blanking distance results in a negative bias ranging from -0.5 to -2.3%. Measurement uncertainty is not expected to change as a result of the revised blanking distance.

4.6.2.3. Velocity Profile Extrapolation Settings

In shallow water, extrapolated areas can comprise more than half of the velocity profile used for discharge computations. Default settings in RiverSurveyorLive use the 1/6 power law to compute these estimates. As recommended by USGS, all transects were reprocessed using Extrap 3.22 (OSW 2012b) to identify empirical extrapolation settings for each location. However, the velocity profiles were extrapolated without the 0.52-foot blanking distance required by OSW Technical Memorandum No. 2013.02. Reprocessing of measured 2013 flows at four Middle River gaging stations (ESS40, ESS45, ESS50, and Gold Creek) indicates that the M9's default blanking distance results in a negative bias ranging from -0.5 to -2.3%. Measurement uncertainty is not expected to change as a result of the revised blanking distance.

4.6.2.4. Heading Corrections

If the local magnetic declination differs from the result entered in RiverSurveyorLive, the heading error will be manifested as directional disparities in GPS ship tracks and computed discharges. This effect can be reduced by adjusting the magnetic declination until the directional disparity in GPS discharge reaches a minimum. Using RiverSurveyorLive's Processing Toolbox, heading corrections were determined for all measurements that included at least four transects.

Heading corrections can also be an indicator of compass error. Results are discussed in Section 5.1.4.

5. RESULTS

5.1. ADCP Data Quality

5.1.1. Compass Calibrations

In August 2012, USGS issued a *Best Practice Recommendation* indicating that the M9's compass calibration score cannot be used to evaluate calibration accuracy (OSW 2012a). Instead, "the best that can be done is to follow good calibration procedures and to carefully observe the collected data for potential compass errors".

During 2012, a total of 214 measurements were conducted using the same measurement platform as the 2013 ADCP measurements (R2 et al. 2013). All of the calibrations exhibited failing scores, but successful loop tests and low directional biases initially indicated normal compass operation. Downstream (invalid) loop test closure occurred on the 13th measurement, and recurred for 8 of the next 22 measurements. Repeated compass calibrations did not result in successful loop tests. To determine whether off-boat calibrations would improve compass performance, subsequent measurements were performed with the ADCP removed from the boat. Although overall measurement quality improved, downstream loop closures persisted.

Analysis of the 2012 ADCP measurements indicates that the compass was affected by on-board interference, confirming the failed compass calibration scores (R2 et al. 2013). By process of elimination, field tests indicated that the outboard motor was the source of interference.

The 2012 results indicated that despite failed compass calibrations, successful loop tests are possible where fast current allows loop navigation with only a slight change in boat orientation. Where loop tests were successful, the close agreement between loop-corrected and GPS-based discharges indicated that 2012 GPS-based results were not compromised by compass errors.

During 2013, other techniques were developed for maintaining a constant boat orientation during loop tests (see Section 5.1.2). Although these techniques resulted in successful loop tests, they were not maintained during discharge measurement transects. As described in Section 5.1.5, failure to maintain a constant boat orientation resulted in spurious GPS-based discharges at some locations. The spurious results are attributed to compass errors resulting from on-board magnetic interference.

5.1.2. Moving Bed Tests

Due to compass calibration issues, USGS recommends stationary rather than loop moving bed tests for the Sontek M9 (OSW 2012a). Stationary moving bed tests require bottom-track data collection while maintaining an initial stationary mid-channel position for at least 5 minutes (Mueller and Wagner 2009). If the initial test indicates a moving bed, at least two additional 5-minute stationary moving bed tests should be performed on either side of the mid-channel position.

Swift current at most mainstem Susitna measurement locations requires use of an anchored buoy to maintain a stationary position. Under most conditions, a 16-lb anchor was adequate to mark loop test endpoints in shallow water. However, a much larger anchor would be needed to secure a mid-channel buoy during all flow conditions. Because of the difficulty of deploying and retrieving anchors in swift current, loop tests were conducted rather than stationary moving bed tests. Loop tests have the added benefit of providing distributed, rather than stepwise averaged moving bed corrections.

Loop tests measure the difference between the actual boat position and the bottom-track boat position after a two-way crossing of the river. If a moving bed is present, the bottom-track position will be upstream of the actual position upon return to the boat's starting point. The distance between the actual and bottom-track positions (termed loop closure) is used to compute the average bed velocity. Systematic errors limit the precision of bed velocity measurements to about 0.04 ft/s. Moving bed corrections at average bed velocities below 0.04 ft/s are generally within the precision of ADCP discharge measurements. As a result, average bed velocities equal or lower than 0.04 ft/s are commonly considered stationary.

Compass errors can cause erroneous loop tests manifested as downstream (rather than upstream) closures, or as both upstream or downstream closures during stationary bed conditions. Compass errors are also indicated by a difference in flow direction between the outgoing and return legs of the loop. The USGS LC software (OSW 2013b) computes the out-back difference as one of several loop test quality control measures.

Constant heading errors, such as entering the wrong magnetic declination, do not affect loop test results (Mueller and Wagner 2006). Based on this principle, if the changes in boat orientation are small enough, then the corresponding heading errors should be negligible. Although the 2012 loop tests were not performed with this in mind, post-season analyses indicated that successful loop tests were possible where fast current allowed loop navigation with only slight changes in boat orientation.

During 2013, other techniques were used to maintain a constant boat orientation during loop tests, including walking the boat and “crabbing”. Crabbing involves using an oar to steer the boat upstream while the motor propels the boat laterally. Changes in boat orientation can also be minimized using a small lateral rate of travel. This resulted in some 2013 loop tests with nearly twice the recommended minimum duration. The loop course can also be “rounded” to maintain a constant ferry angle in both fast and slow water. Finally, a half-channel loop was sometimes used in wide, symmetrical channels to allow smaller lateral boat speeds.

Results of 2013 loop tests are provided on Table 1. No downstream loop closures were obtained. Three of the 109 loop tests had out-back flow direction differences greater than 5 degrees; one was irrelevant due to stationary closure, another was confirmed with additional valid loops, and a third was accepted due to its rounded course. Based on these results, the 2013 loop tests do not appear to be compromised by the invalid compass calibrations.

In addition to compass errors, bad bottom-tracking can cause inaccurate loop tests. The USGS LC program issues a warning if the loop exceeds 5% bad bottom-track, and loop corrections are not performed at more than 20% bad bottom-track. More than 5% bad bottom-tracking was obtained at 13 of the 109 loop test locations. These loop tests were repeated to assess the variation in loop test corrections. As shown on Figure 4 and Figure 5, the standard deviation of loop corrections was less than 1% for 10 of the 13 locations, including one location with 25% bad bottom-tracking. As a result, loops with more than 5% bad bottom-track were repeated to assess the precision of the loop corrections. If the standard deviation of loop corrections was more the 1 percent, the measurement was downgraded by adding 1.5% of additional uncertainty (Table 2).

Fast current in narrow channels required an additional loop test modification. Maintaining a uniform lateral boat speed, slow enough to achieve the minimum loop test duration (5 minutes), can be difficult in narrow channels with fast current. In these cases, a more uniform boat speed was accomplished by navigating multiple complete loops. This technique was used at less than 5% of the loop test locations.

5.1.3. Velocity Profile Extrapolation Settings

Because ADCPs cannot measure velocities near the surface or the riverbed, discharge is calculated by extrapolating measured velocities in those regions. By default, RiverSurveyorLive uses the 1/6 power law for velocity profile extrapolation. Current guidance recommends reprocessing all measurements with the USGS Extrap program to identify empirical extrapolation settings, but only implementing those settings if they cause more than 1% change in discharge (OSW 2012b).

Upon reprocessing, most of the 2013 near-surface velocity profiles more closely matched Extrap's Constant/No Slip fit rather than empirical power law settings. Because the change in discharge was often greater than 1%, empirical extrapolation settings were computed for all 2013 measurements (Table 2).

On November 18, 2013, USGS issued OSW Technical Memorandum No. 2014.02, which establishes a minimum blanking distance of 0.52 feet for the Sontek M9 (OSW 2013a). This is based on shallow-water flume studies indicating a negative bias attributed to flow disturbance around the transducer head. This finding explains the unusual near-surface velocity profiles obtained with the Sontek M9, and invalidates the resulting extrapolation settings.

At the time of this writing, new extrapolation settings have not yet been developed for the 2013 discharge measurements. However, reprocessing of all 2013 measurements at four Middle River gaging stations (ESS40, ESS45, ESS50, and Gold Creek) indicates that the M9's default blanking distance results in a negative bias ranging from -0.5 to -2.3%. Measurement uncertainty is not expected to change as a result of the revised blanking distance.

5.1.4. Heading Corrections

As described in Section 4.6.2.4, the RSL software includes a "heading correction" that can be used to minimize directional disparities in GPS-based ship tracks and computed discharges. RSL was used to determine heading corrections for all measurements with at least four reciprocal transects. The resulting heading corrections ranged from -3.9 to 4.1 degrees, with an average of 0.4 degrees. The heading corrections did not follow spatial patterns as expected for magnetic anomalies, and adjacent channels often showed widely disparate values. As a result, the heading corrections are believed to reflect on-board magnetic interference.

5.1.5. GPS Data Quality

Although an accurate compass is needed for GPS-based discharge measurements, the Sontek M9's calibration score may not be a reliable indicator of compass accuracy (OSW 2012a). To evaluate the accuracy of GPS-based discharges, Wagner and Mueller (2011) compared bottom-track vs. GGA-based discharges for 30 stationary-bed measurements in the United States, Canada, and New Zealand. The results were considered of sufficient quality to support the use of GPS positioning without real-time kinematic (RTK) corrections. As shown on Figure 6, the accuracy of 2012 stationary bed measurements was equivalent to Wagner and Mueller's results, indicating that the 2012 GGA results were acceptable for stationary bed conditions (R2 et al. 2013).

Figure 7 provides the same comparison for 2013 stationary bed measurements. The 2013 results are less precise, suggesting another source of interference. The 2012 measurements were performed using the same ADCP model, measurement platform, and boat operator. However, 2012 loop tests were conducted using boat speeds and track positions that closely mimicked the measurement transects. Due to varying boat orientations, some of the 2012 loop tests failed, and the resulting data were excluded from Figure 6. The remaining 2012 results reflect sites where fast current allowed loop navigation with only slight changes in boat orientation. Because they were conducted using similar track positions, changes in boat orientation during the 2012 measurement transects were small enough to preclude significant impacts on GPS data quality.

In contrast, 2013 loop tests were performed with particular emphasis on maintaining a constant boat orientation. After successful loop tests were obtained, measurement transects were performed without the same attention to boat orientation. This apparently caused heading errors that compromised the precision of GPS-based discharge data (Figure 7).

Considering the results shown on Figure 7, either bottom-tracking or loop-corrected bottom-tracking was selected as the final track reference for all 2013 discharge data. Although GPS results are useful for establishing transect positions, GPS-based velocity and discharge values include additional variance caused by on-board compass interference.

5.1.6. Data Review and Post Processing

Field data review identified loop test quality issues such as excessive bad bottom-tracking and out-back flow direction differences. These issues were addressed by performing additional loop tests. Field data review also indicated poor measurement quality at some Focus Area transects where lateral standing waves caused surfing of the cataraft. Here unidirectional transects provided more consistent results than reciprocal transects.

Office review identified GPS quality issues such as inconsistent heading corrections (Section 5.1.4) and poor measurement precision (Figure 7). Loop tests were examined for potential heading errors, and the impact of bad bottom-tracking was evaluated (Figure 4 and Figure 5). Measurement statistics were compiled, identifying incomplete exposure times and loop test quality control issues.

Peer review identified several data entry errors including the use of outdated magnetic declinations. Complete reprocessing of all 2013 data was performed using updated declinations. Although declination reprocessing caused little change in discharge values, other miscellaneous errors were identified including the accidental enabling of ‘composite tracks’ (automatic substitution of GPS for bad bottom-tracking). The errors were corrected and the data were annotated with relevant qualifiers (Table 1 and Table 2).

During peer review, bottom-tracking errors were noted for about 15 percent of the 2013 measurements. The errors ranged from noisy ship tracks to bad bottom-tracking indicated by a yellow icon for individual 1-second “samples”. Unfortunately, RiverSurveyorLive only quantifies bad bottom-tracking for loop tests, not measurement transects. However, loop tests were performed at nearly all sites, and repeated loop tests were performed at sites with more than 5% bad bottom-tracking. Interestingly, the results shown on Figure 4 and Figure 5 indicate acceptable precision for some loop tests with up to 25% bad bottom-tracking. Considering that most loop tests with over 5% bad bottom tracking had acceptable precision, the 2013 results were not qualified for bad bottom-tracking except where loop test precision exceeded 1%. Similarly, because the GPS track reference was not used for final discharge values, the results provided in this report are not qualified for GPS quality issues.

5.1.7. ADCP Check Measurements

The three field campaigns allowed four check measurements at the USGS Gold Creek gage (USGS no. 15292000) and one check measurement at the Sunshine gage (USGS no. 15292780).

Results are summarized on Table 4, indicating that measurements reprocessed using Sontek's default blanking distance (0.2 ft) and empirical extrapolation settings ranged from 5.6 to 7.7% lower than provisional online values for the Gold Creek gage. The discrepancy is reduced using the 0.52-ft blanking distance recommended by OSW (2013a), but still ranges from -3.6 to -6.3% using the 1/6 power law.

Although they show a gradual downstream increase attributed to tributary and base flow accretion, all of the Middle River discharge measurements appear biased low relative to the Gold Creek gage (Figure 8). The magnitude of the bias is consistent with the ~5% negative bias indicated by the Gold Creek check measurements. Interestingly, an August 15, 2013 rating measurement by USGS (no. 305) was also 5% lower than the Gold Creek gage (Table 4).

An August 3, 2013 check measurement using Sontek's default blanking distance was 2.6% lower than the provisional online value for the Sunshine gage. Use of OSW's recommended blanking distance (0.52 ft) and the 1/6 power law reduces the difference to 1.6% (Table 4).

5.1.8. Rating of 1-D Model Flow Measurements

USGS discharge measurements are rated as Excellent, Good, Fair or Poor corresponding to levels of uncertainty ranging from 0-2%, 2-5%, 5-8%, and over 8%, respectively. Current guidance (OSW 2012c), approximates 95% uncertainty as 0.5% for systematic errors plus the variation between repeated transects multiplied by a coefficient related to the number of transects. If known, other uncertainties can be added to obtain the 95% uncertainty.

Based on Figure 4 and Figure 5, 1.5% of uncertainty was added for loop tests with standard deviations over 1 percent, and an additional 0.5 percent of uncertainty was added for the following conditions:

- Loop test duration <300 seconds
- Total measurement duration <720 seconds
- Loop test with 5-7% bad bottom-track but no repeated loop test

The resulting 95% uncertainties are shown on Table 2. Although 95% of the 1-D flow measurements would rate as Excellent or Good, numerical uncertainties are provided instead of the four rating categories. This is partly because the data have not been reprocessed as required by OSW's November 18, 2013 technical memorandum (OSW 2013a). Preliminary results indicate a 0.5 to 2.3% increase in discharge values, but no appreciable increase in measurement uncertainty.

5.1.9. Rating of 2-D Model Flow Measurements

Because they consist of a large number of closely-spaced measurements, the methodology for 2-D model flow measurements differed from 1-D model measurements. Instead of recording at least 12 minutes of reciprocal passes at each transect, generally only two passes (ideally reciprocal) were recorded at each transect. Moving bed tests were limited to representative main-channel locations, and data quality was evaluated by comparing the total discharge at streamwise locations where discharge could be summed across all channels. The combined flows are provided on Table 5 and Table 6 for the June/July and September field campaigns, respectively. Using the USGS methodology (OSW 2012c), 95% uncertainties were calculated for deviations from the average and the best fit line. Results indicate 95% uncertainties ranging from 1.3 to 2.7% for the June-July measurements, and from 0.9 to 2.6% for the September measurements (Table 5 and Table 6).

The best fit lines are shown on Figure 9 through Figure 15 (June/July field campaign) and Figure 16 through Figure 22 (September field campaign), together with provisional Gold Creek flows adjusted for the travel time shift from Gold Creek to the measurement location. The Gold Creek data were used to confirm the overall trend and to eliminate spurious transects from the best fit line determination. As noted in Section 5.1.7, check measurements indicate that Middle River flow measurements are biased approximately 5% low relative to provisional Gold Creek discharge values.

The spurious transects identified on Figure 9 through Figure 22 correspond to poor measurement locations characterized by high velocities and standing waves. Poor boat navigation/ performance issues affected several July 1, 2013 transects at FA-138 (Gold Creek), resulting only one acceptable total discharge measurement (Figure 11). Correction of these issues resulted in 3 to 6 acceptable total discharge measurements at the remaining Focus Areas.

The best fit lines on Figure 9 through Figure 22 show that precision and accuracy vary considerably within each Focus Area. Better precision is obtained in reaches with lower average velocities, more uniform velocity distributions, and fewer channels.

5.1.10. Other Data Quality Checks

Comparison against provisional online flows for the Gold Creek and Sunshine gages provides an additional quality assurance check for the 2013 ADCP measurements. As shown on Figure 8, most of the Middle River ADCP measurements support the approximate 5% negative bias indicated by check measurements against provisional Gold Creek discharge data (Table 4). The gradual downstream flow increase is attributed to tributary and base flow accretion.

The Lower River ADCP measurements show a similar downstream flow increase, but a smaller negative bias when compared against provisional Sunshine flows (Figure 23). This raises the possibility that the 5% negative bias indicated for Middle River ADCP measurements could be exaggerated. This hypothesis is supported by the close agreement between August 15, 2013 flow measurements by USGS and Brailey Hydrologic (Table 4).

Of the Lower River measurements, the August 2-3, 2013 measurement at PRM 94.8 appears to show a larger negative bias than the rest. This could reflect lower measurement quality for wide, shallow cross-sections with numerous channels as compared with narrow cross-sections containing a few channels.

5.2. 1-D Model Flow Measurements

Results of the 1-D model flow measurements are provided on Table 2 and Table 3. Including additional uncertainty for bad bottom tracking, short exposure durations and shortened loop tests, about 95% of the 1-D model flow measurements had 95% uncertainties less than 5%. Of the five remaining 1-D model flow measurements, three had flows less than 120 cfs, and the other two comprised less than 20% of the total flow.

The results shown on Table 2 and Table 3 include a recently-discovered bias resulting from flow disturbance around the transducer head (OSW 2013a). Although the bias can be removed by reprocessing, this work has not been completed for all of the 2013 ADCP measurements. Reprocessing of measured 2013 flows at four Middle River gaging stations (ESS40, ESS45, ESS50, and Gold Creek) indicates that the bias ranges from -0.5 to -2.3%. Measurement uncertainty is not expected to change as a result of reprocessing.

5.3. 2-D Model Flow Measurements

The 2-D model flow measurements are summarized on Table 7, and the flow measurement locations are illustrated on Figure 24 through Figure 30. The measurements are provided as total flows computed using the best-fit lines illustrated on Figure 9 through Figure 22, and flow splits calculated using results for individual channels. Because streamwise flow summations differ from the best-fit lines (Figure 9 through Figure 22), results for individual channels were adjusted to match the best-fit total flows. This was performed using the measured flow proportions provided on Table 7.

For transects included in streamwise flow summations, measurement uncertainty was calculated using variations between measured flow totals and the best-fit line. The uncertainty of other transects was calculated using variations between repeated passes. Because only two passes were used to compute the flow splits, their 95% uncertainty is relatively high (Table 7). Lower uncertainties are indicated for the total flow measurements, where between 4 and 12 passes were used to calculate precision.

The 2-D model flow measurements included the longitudinal velocity profiles shown on Figure 24 through Figure 30. Because the longitudinal profiles have no associated discharge, they are not tabulated in this report. Instead, longitudinal velocity profiles are illustrated graphically in Exhibit 1. These profiles can be viewed in greater detail using RiverSurveyorLive (Sontek 2013).

6. DISCUSSION AND CONCLUSION

Despite documented compass calibration issues (OSW 2012a, R2 et al. 2013), the Sontek M9 was chosen for 2013 ADCP measurements because of its shallow measurement depth and greater vertical resolution than other ADCPs. Compass calibration scores, loop test results, and GPS data quality indicate that the Sontek M9 was affected by magnetic interference from the outboard motor. Anticipating that compass errors might compromise GPS-based velocities, procedures were developed to maintain a constant boat orientation during loop tests. These procedures resulted in successful loop tests, allowing valid velocity and discharge measurements where the proportion of bad bottom-tracking was less than 5%. Where the proportion of bad bottom-tracking exceeded 5%, repeated loop tests were used to quantify loop test uncertainty. Results indicate that 95% of the 1-D model flow measurements had overall uncertainties less than 5%.

During 2012, acceptable GPS accuracy was obtained at sites with valid loop tests (R2 et al. 2013). This was because 2012 loop tests and measurement transects followed the same course. During 2013, loop test procedures were modified to maintain more consistent boat orientations than the associated measurement transects. As a result, some of the 2013 measurements had compass errors that compromised the precision of GPS-based velocities.

Check measurements indicate an approximate 5% negative bias for Middle River flow measurements relative to provisional Gold Creek discharge values. An August 15, 2013 rating measurement by USGS (no. 305) was also 5% lower than the provisional online value. An August 3, 2013 check measurement at the Sunshine gage was only 1.6% below the provisional online value.

In addition to the 1-D model flow measurements, 2-D model flow measurements were performed in 7 Focus Areas. The 2-D model flow measurements consisted of closely-spaced transects to quantify flow splits between various channels and sloughs. Results from individual transects were added to obtain streamwise flow summations throughout each Focus Area. Whereas the uncertainty of the streamwise summations ranged from 0.9 to 2.7%, the uncertainty of individual flow splits ranged from 3.5 to over 50%. When transect flow splits within 2-D Focus Areas exhibited high levels of uncertainty, flow splits were provisionally determined based on adjacent 2-D transect measurements.

The low level of uncertainty identified using repeated loop tests, and the consistency of flow measurements relative to provisional USGS values, support the use of the data for Susitna River modeling purposes.

7. REFERENCES

AEA (Alaska Energy Authority). 2012. Revised Study Plan: Susitna-Watana Hydroelectric Project FERC Project No. 14241. December 2012. Prepared for the Federal Energy Regulatory Commission by the Alaska Energy Authority, Anchorage, Alaska. http://www.susitna-watanahydro.org/study-plan.

Mueller, D.S., Abad, J.D., García, C.M., Gartner, J.W., García, M.H., and Oberg, K.A. 2007. Errors in acoustic Doppler profiler velocity measurements caused by flow disturbance. Journal of Hydraulic Engineering, v. 133, no. 12, p. 1411–1420.

Mueller, D.S. and Wagner, C.R. 2006. Application of the Loop Method for Correcting Acoustic Doppler Current Profiler Discharge Measurements Biased by Sediment Transport. U.S. Geological Survey Scientific Investigations Report 2006-5079, 18 p.

Mueller, D.S. and Wagner, C.R. 2009. Measuring Discharge with Acoustic Doppler Current Profilers from a Moving Boat. U.S. Geological Survey Techniques and Methods 3A-22, 72 p.

OSW (U.S. Geological Survey, Office of Surface Water). 2012a. Best practice for calibrating SonTek RiverSurveyor M9/S5 compass. USGS Best Practice Recommendation, August 30, 2012.

OSW (U.S. Geological Survey, Office of Surface Water). 2012b. Introduction to Extrap 3.X. OSW Hydroacoustics Podcast, September 2012.

OSW (U.S. Geological Survey, Office of Surface Water). 2012c. Review and rating of moving-boat ADCP Q measurements. OSW Hydroacoustics Webinar, October 4, 2012.

OSW (U.S. Geological Survey, Office of Surface Water). 2013a. Policy on Required Minimum Screening Distance for the RiverSurveyor M9. Office of Surface Water Technical Memorandum No. 2014.02, November 18, 2013.

OSW (U.S. Geological Survey, Office of Surface Water). 2013b. Get Acquainted with the Latest Versions of LC and SMBA. OSW Hydroacoustics Webinar, April 2013.

R2 (R2 Resource Consultants, Inc.), GW Scientific, Brailey Hydrologic, and Geovera. 2013. Technical Memorandum, Open-water HEC-RAS Flow Routing Model. Susitna-Watana Hydroelectric Project, FERC No. P-14241. Prepared for Alaska Energy Authority, Anchorage, Alaska. 234 pp. January 2013. http://www.susitna-watanahydro.org/wp-content/uploads/2013/02/Att-A-Flow-Routing-Model.pdf.

Sontek. 2013. RiverSurveyor S5/M9 System Manual Firmware Version 3.50.

Wagner, C.R. and Mueller, D.S. 2011. Comparison of bottom-track to global positioning system referenced discharges measured using an acoustic Doppler current profiler. Journal of Hydrology v. 401, pp. 250-258.

8. TABLES

Table 1. 2013 Loop Test results. (page 1)

Date	Start time	DMG[2] ft	Duration, s	Velocity, ft/s		Direction, deg			Estimated % Corr[3].	% bad BT[4]	out-back difference[5]	% Add'l Uncert[6].	Comments
				Bed	Flow	Bed	Flow	Diff					
6/29/2013	1242	54.8	248	0.22	7.53	8.3	212.5	204.1	2.94	3.63	1.3	0.5	
6/30/2013	1111	3.4	318	0.01	7.24	322.1	221.3	-100.8	0.00	5.05	2.6		Stationary: bed v ≤ 0.04
7/1/2013	1339	43.3	350	0.12	6.49	21.5	193.7	172.3	1.91	2.57	3.9		bed v <1% of mean v - no correction
7/2/2013	1039	16.1	277	0.06	6.86	29.2	228.6	199.4	0.85	1.44	0.8	0.5	bed v <1% of mean v - no correction
7/9/2013	1310	6.3	264	0.02	6.45	206.2	201.7	-4.4	0.00	1.52	0.2	0.5	Stationary: bed v ≤ 0.04
7/9/2013	1400	2.4	303	0.01	6.76	311.0	221.7	-89.3	0.00	2.64	6.1		Stationary: bed v ≤ 0.04
7/9/2013	1533	25.1	376	0.07	6.94	360.0	184.1	-175.9	0.96	1.86	1.1		bed v <1% of mean v - no correction
7/9/2013	1657	6.0	350	0.02	6.81	340.4	216.1	-124.3	0.00	0.57	2.1		Stationary: bed v ≤ 0.04
7/10/2013	1110	5.5	341	0.02	4.11	6.2	179.5	173.3	0.00	0.59	358.7		Stationary: bed v ≤ 0.04
7/10/2013	1216	23.0	307	0.07	5.52	9.2	180.4	171.2	1.36	0.33	358.7		
7/11/2013	1133	25.5	307	0.08	6.9	348.6	162.6	-186.0	1.20	0.98	2.5		
7/11/2013	1342	19.7	301	0.07	7.16	285.0	141.3	-143.7	0.91	0.33	0.6		bed v <1% of mean v - no correction
7/11/2013	1640	7.7	287	0.03	6.29	1.6	183.2	181.6	0.00	1.39	1.2	0.5	Stationary: bed v ≤ 0.04
7/12/2013	1121	5.5	302	0.02	4.43	249.2	232.7	-16.5	0.00	1.32	3.6		Stationary: bed v ≤ 0.04
7/12/2013	1202	8.6	304	0.03	6.78	56.4	210.0	153.6	0.00	0.99	2.5		Stationary: bed v ≤ 0.04
8/1/2013	1525	15.0	309	0.05	7.86	35.0	206.7	171.7	0.62	5.18	1.6		bed v <1% of mean v - no correction
8/1/2013	1615	36.1	321	0.11	6.89	22.5	200.4	177.8	1.63	1.25	0.0		
8/2/2013	1225	141.8	337	0.42	7.69	351.9	172.9	179.1	5.47	27	0.1		> 20% bad bottom track but stdev of % corr. < 1%
8/2/2013	1233	174.3	371	0.47	7.55	357.2	172.6	184.6	6.22	24.53	0.6		> 20% bad bottom track but stdev of % corr. < 1%
8/2/2013	1240	121.4	347	0.35	7.78	342.6	174.4	168.1	4.49	24.5	3.6		> 20% bad bottom track but stdev of % corr. < 1%
8/2/2013	1321	49.0	379	0.13	3.49	338.1	155.8	182.3	3.70	13.98	1.7		> 10% bad bottom track but stdev of % corr. < 1%
8/2/2013	1328	39.5	314	0.13	3.74	1.3	157.5	156.1	3.37	15.65	1		> 10% bad bottom track but stdev of % corr. < 1%
8/2/2013	1333	38.8	296	0.13	3.75	341.1	157.4	183.7	3.49	14.19	0.1	0.5	> 10% bad bottom track but stdev of % corr. < 1%
8/2/2013	1718	2.0	345	0.01	3.00	15.9	198.6	182.7	0.00	0.58	0.2		Stationary: bed v ≤ 0.04
8/3/2013	1245	65.5	349	0.19	7.02	12.2	202.0	189.8	2.67	1.72	5.7		Out-back difference OK due to loop path
8/3/2013	1403	1.2	303	0.00	3.71	74.0	238.3	164.2	0.00	6.29	1.6		Stationary: bed v ≤ 0.04
8/3/2013	1501	34.5	305	0.11	4.05	3.2	194.6	191.5	2.79	2.95	2.3		
8/3/2013	1551	87.1	439	0.20	7.12	17.2	210.8	193.6	2.79	8.88	3.3		> 5% bad bottom track but stdev of % corr. < 1%
8/3/2013	1600	75.7	411	0.18	7.01	24.8	209.8	185.0	2.63	9.02	0.3		> 5% bad bottom track but stdev of % corr. < 1%
8/3/2013	1607	96.8	442	0.22	7.04	21.1	210.1	189.0	3.11	10.18	2.9		> 5% bad bottom track but stdev of % corr. < 1%
8/4/2013	1220	16.3	304	0.05	7.32	50.0	233.7	183.7	0.73	1.98	0.4		bed v <1% of mean v - no correction
8/4/2013	1247	9.4	309	0.03	6.81	347.6	184.3	163.3	0.00	2.6	0.9		Stationary: bed v ≤ 0.04
8/4/2013	1400	77.8	389	0.20	5.54	7.1	177.0	169.9	3.61	6.94	3.2	0.5	> 5% bad bottom track but no additional loops
8/4/2013	1445	11.9	310	0.04	6.98	334.0	165.9	168.1	0.00	1.29	0.1		Stationary: bed v ≤ 0.04
8/4/2013	1524	2.4	357	0.01	4.72	129.8	159.3	29.5	0.00	1.12	0.5		Stationary: bed v ≤ 0.04

1 highlighted cells indicate loop test durations less than 300 s and other quality issues (see Comments).
2 DMG = distance made good.
3 Estimated % correction using loop test path. Actual corrections based on measurement transects.
4 BT = bottom tracking.
5 Difference in flow direction between the outgoing and return legs of the loop.
6 1.5% added for loop test bottom-tracking errors (Figure 4 and Figure 5), 0.5% for loop durations < 300 s, 0.5% for failure to repeat loops with >5% bad BT.

Table 1. 2013 Loop Test results. (page 2)

Date	Start time	DMG[2] ft	Duration, s	Velocity, ft/s		Direction, deg			Estimated % Corr[3].	% bad BT[4]	out-back difference[5]	% Add'l Uncert[6].	Comments
				Bed	Flow	Bed	Flow	Diff					
8/5/2013	1314	11.6	337	0.03	7.16	50.5	231.4	180.9	0.00	0.3	0.5		Stationary: bed v ≤ 0.04
8/5/2013	1400	5.3	316	0.02	5.45	335.0	177.6	157.4	0.00	0.63	0.1		Stationary: bed v ≤ 0.04
8/5/2013	1435	7.2	391	0.02	4.37	336.4	168.1	168.3	0.00	0.51	1.4		Stationary: bed v ≤ 0.04
8/5/2013	1530	41.2	318	0.13	7.05	311.5	133.9	177.6	1.84	0	4.9		
8/6/2013	1404	8.1	345	0.02	2.11	321.7	136.1	185.6	0.00	2.32	1.3		Stationary: bed v ≤ 0.04
8/6/2013	1544	13.5	305	0.04	7.05	4.5	208.4	203.9	0.63	1.97	0.7		bed v <1% of mean v - no correction
8/7/2013	1217	13.0	273	0.05	7.15	26.6	189.7	163.1	0.67	0.74	3	0.5	bed v <1% of mean v - no correction
8/7/2013	1242	140.4	315	0.45	6.40	19.8	213.3	193.5	6.96	15.87	2.3		> 7-16% bad bottom track but stdev of % corr. < 1%
8/7/2013	1250	134.0	304	0.44	6.36	9.9	197.1	187.2	6.92	7.26	4.7		> 7-16% bad bottom track but stdev of % corr. < 1%
8/8/2013	1453	56.1	303	0.19	6.56	48.0	213.0	165.0	2.82	5.61	2.7	0.5	> 5% bad bottom track but no additional loops
8/9/2013	1135	5.2	304	0.02	3.77	290.7	7.7	282.9	0.00	1.32	0.1		Stationary: bed v ≤ 0.04
8/10/2013	1525	12.8	305	0.04	4.88	39.7	188.7	149.1	0.86	4.26	0		bed v <1% of mean v - no correction
8/10/2013	1623	17.0	411	0.04	7.21	12.4	183.8	171.4	0.57	1.46	0.3		bed v <1% of mean v - no correction
8/11/2013	1211	9.4	303	0.03	5.66	35.5	205.7	170.3	0.00	1.32	0.4		Stationary: bed v ≤ 0.04
8/11/2013	1313	6.5	308	0.02	5.50	41.5	217.3	175.8	0.00	2.6	0.3		Stationary: bed v ≤ 0.04
8/14/2013	1344	12.3	448	0.03	6.14	13.5	189.6	176.1	0.00	0	0.3		Stationary: bed v ≤ 0.04
8/14/2013	1555	19.8	517	0.04	5.08	6.0	189.8	183.8	0.00	0.58	1.6		Stationary: bed v ≤ 0.04
8/15/2013	1237	31.7	409	0.08	5.36	0.5	194.0	193.6	1.45	0.98	0		
8/15/2013	1541	17.6	331	0.05	6.37	10.0	184.4	174.3	0.83	1.81	1.5		bed v <1% of mean v - no correction
9/3/2013	1250	131.8	355	0.37	6.84	41.3	212.0	170.7	5.43	17.05	3.5	1.5	> 15% bad bottom track and stdev of % corr. = 1.1%
9/3/2013	1311	70.8	321	0.22	7.13	33.9	211.8	177.9	3.10	17.13	1.8	1.5	> 15% bad bottom track and stdev of % corr. = 1.1%
9/3/2013	1316	95.6	325	0.29	7.12	31.0	211.6	180.7	4.13	16.31	4	1.5	> 15% bad bottom track and stdev of % corr. = 1.1%
9/3/2013	1631	19.1	316	0.06	4.12	174.2	350.2	176.0	1.47	1.3	4.5		Multi-pass loop in narrow fast channel
9/7/2013	1258	34.4	307	0.11	7.59	71.4	230.1	158.7	1.47	4.56	3		
9/8/2013	1219	51.4	318	0.16	7.21	18.4	218.0	199.5	2.24	5.68	1	0.5	> 5% bad bottom track but no additional loops
9/8/2013	1525	32.9	354	0.09	7.71	86.3	240.2	153.8	1.20	6.78	4.6		> 5% bad bottom track but stdev of % corr. < 1%
9/8/2013	1532	45.3	340	0.13	7.83	76.4	239.5	163.1	1.70	8.24	1.4		> 5% bad bottom track but stdev of % corr. < 1%
9/9/2013	1102	39.1	308	0.13	8.51	125.3	269.1	143.8	1.49	6.51	2		> 5% bad bottom track but stdev of % corr. < 1%
9/9/2013	1115	39.6	309	0.13	8.47	120.9	271.6	150.6	1.51	7.12	2.2		> 5% bad bottom track but stdev of % corr. < 1%
9/9/2013	1254	47.8	442	0.11	7.04	1.4	194.2	192.8	1.54	5.22	3.4	0.5	> 5% bad bottom track but no additional loops
9/10/2013	1123	8.0	382	0.02	6.95	223.6	232.9	9.3	0.00	1.57	5		Stationary: bed v ≤ 0.04
9/12/2013	1625	51.4	400	0.13	7.58	19.9	207.2	187.3	1.69	11.75	0.2	1.5	> 10% bad bottom track and stdev of % corr. = 1.2%
9/12/2013	1634	27.4	308	0.09	7.34	19.1	205.4	186.2	1.21	14.94	2.2	1.5	> 10% bad bottom track and stdev of % corr. = 1.2%
9/12/2013	1641	76.1	349	0.22	7.23	7.7	207.3	199.6	3.02	14.61	1.6	1.5	> 10% bad bottom track and stdev of % corr. = 1.2%
9/12/2013	1722	56.8	313	0.18	7.78	30.8	217.1	186.3	2.33	10.22	1.8		> 5% bad bottom track but stdev of % corr. < 1%
9/12/2013	1727	59.9	338	0.18	7.84	51.2	217.8	166.6	2.26	7.72	0.6		> 5% bad bottom track but stdev of % corr. < 1%
9/13/2013	1153	10.9	394	0.03	7.56	19.6	185.3	165.7	0.00	5.08	3.3		Stationary: bed v ≤ 0.04

1 highlighted cells indicate loop test durations less than 300 s and other quality issues (see Comments)
2 DMG = distance made good
3 Estimated % correction using loop test path. Actual corrections based on measurement transects.
4 BT = bottom tracking
5 Difference in flow direction between the outgoing and return legs of the loop
6 1.5% added for loop test bottom-tracking errors (Figure 4 and Figure 5), 0.5% for loop durations < 300 s, 0.5% for failure to repeat loops with >5% bad BT.

Table 1. 2013 Loop Test results. (page 3)

Date	Start time	DMG[2] ft	Duration, s	Velocity, ft/s		Direction, deg			Estimated % Corr[3].	% bad BT[4]	out-back difference[5]	% Add'l Uncert[6].	Comments
				Bed	Flow	Bed	Flow	Diff					
9/14/2013	1113	44.1	379	0.12	7.19	355.0	166.3	188.7	1.62	1.32	0.9		
9/14/2013	1556	33.9	501	0.07	6.33	0.8	189.9	-189.1	1.07	0.8	1.4		
9/15/2013	1154	3.9	477	0.01	6.67	154.1	182.0	-27.9	0.00	2.73	2.3		Stationary: bed v ≤ 0.04
9/15/2013	1227	4.7	393	0.01	5.9	7.6	231.9	-224.4	0.00	2.54	0.8		Stationary: bed v ≤ 0.04
9/16/2013	1402	7.3	312	0.02	3.57	36.2	243.2	-207.0	0.00	1.61	1.2		Stationary: bed v ≤ 0.04
9/16/2013	1500	93.9	355	0.26	4.46	11.9	192.7	-180.9	5.93	2.25	5		
9/16/2013	1551	31.8	317	0.1	4.89	76.4	228.8	-152.5	2.05	5.38	1	0.5	> 5% bad bottom track but no additional loops
9/16/2013	1644	92.5	342	0.27	4.91	18.9	196.8	-177.9	5.50	7.33	1.5		> 5% bad bottom track but stdev of % corr. < 1%
9/16/2013	1651	72.2	312	0.23	4.84	9.8	196.6	-186.8	4.78	6.75	4.5		> 5% bad bottom track but stdev of % corr. < 1%
9/17/2013	1253	8.5	320	0.03	2.17	15.0	199.9	-184.8	0.00	1.25	3.2		Stationary: bed v ≤ 0.04
9/17/2013	1339	2.2	318	0.01	1.93	29.2	218.7	-189.5	0.00	0.95	2.6		Stationary: bed v ≤ 0.04
9/17/2013	1422	61.6	443	0.14	5.71	18.0	196.6	-178.7	2.44	2.03	1		
9/17/2013	1456	41.4	419	0.1	3.88	327.4	153.8	173.6	2.54	0.95	2.4		
9/17/2013	1610	3.2	310	0.01	4.74	355.5	152.0	203.5	0.00	1.61	1.1		Stationary: bed v ≤ 0.04
9/17/2013	1709	2.3	303	0.01	3.79	317.8	156.5	161.2	0.00	1.65	4.4		Stationary: bed v ≤ 0.04
9/18/2013	1214	55.4	409	0.14	3.59	25.2	206.9	-181.7	3.77	3.18	1.5		
9/18/2013	1350	43.7	316	0.14	6.98	12.5	184.3	-171.8	1.98	2.85	0.2		
9/18/2013	1424	11.9	327	0.04	1.98	43.7	204.4	-160.7	0.00	2.75	4.3		Stationary: bed v ≤ 0.04
9/18/2013	1556	19.0	347	0.05	2.33	25.3	194.1	-168.8	2.35	0.86	4.8		
9/18/2013	1643	111.6	525	0.21	4.78	145.8	312.8	-167.0	4.45	0.19	0.1		
9/19/2013	1223	5.9	323	0.02	1.7	71.4	232.8	-161.4	0.00	0.62	1.7		Stationary: bed v ≤ 0.04
9/19/2013	1250	17.6	478	0.04	2.41	36.1	228.9	-192.8	0.00	1.26	3.7		Stationary: bed v ≤ 0.04
9/19/2013	1340	170.5	444	0.38	5.7	22.3	204.3	-181.9	6.74	7.45	5.8		> 5% bad bottom track but stdev of % corr. < 1%
9/19/2013	1350	137.0	367	0.37	5.7	28.8	205.7	-176.9	6.55	6.56	3.7		> 5% bad bottom track but stdev of % corr. < 1%
9/19/2013	1357	153.0	354	0.43	5.7	19.6	205.0	-185.3	7.59	8.5	1.7		> 5% bad bottom track but stdev of % corr. < 1%
9/20/2013	1303	30.8	322	0.1	5.61	45.3	228.0	-182.6	1.71	2.49	1.2		
9/20/2013	1354	10.8	434	0.02	2.94	353.6	196.0	-157.6	0.00	1.38	3.8		Stationary: bed v ≤ 0.04
9/20/2013	1442	214.6	420	0.51	4.87	16.4	195.9	179.5	10.48	14.29	4.7		> 10% bad bottom track but stdev of % corr. < 1%
9/20/2013	1450	187.4	391	0.48	4.91	14.8	195.7	180.8	9.75	12.28	2.5		> 10% bad bottom track but stdev of % corr. < 1%
9/20/2013	1457	194.7	394	0.49	5	11.0	195.7	184.7	9.89	11.68	3		> 10% bad bottom track but stdev of % corr. < 1%
9/21/2013	1207	3.5	329	0.01	5.32	39.7	211.5	171.8	0.00	1.22	0.3		Stationary: bed v ≤ 0.04
9/21/2013	1242	21.8	382	0.06	3.55	21.4	210.5	189.1	1.60	1.31	0.9		
9/21/2013	1407	142.8	301	0.47	5.14	338.1	169.2	-168.9	9.24	6.31	3.1	1.5	> 6-12% bad bottom track and stdev of % corr. = 1.8
9/21/2013	1413	123.6	282	0.44	5.17	351.2	167.9	-183.3	8.49	11.7	1.6	2	> 6-12% bad bottom track and stdev of % corr. = 1.8
9/21/2013	1419	123.6	305	0.41	5.24	346.3	168.6	-177.7	7.73	12.17	3.3	1.5	> 6-12% bad bottom track and stdev of % corr. = 1.8
9/21/2013	1426	170.6	304	0.56	5.1	346.9	168.1	-178.9	11.00	8.91	3.8	1.5	> 6-12% bad bottom track and stdev of % corr. = 1.8

1 highlighted cells indicate loop test durations less than 300 s and other quality issues (see Comments)
2 DMG = distance made good
3 Estimated % correction using loop test path. Actual corrections based on measurement transects.
4 BT = bottom tracking
5 Difference in flow direction between the outgoing and return legs of the loop
6 1.5% added for loop test bottom-tracking errors (Figure 4 and Figure 5), 0.5% for loop durations < 300 s, 0.5% for failure to repeat loops with >5% bad BT.

Table 2. 1-D Model ADCP Measurements. (page 1)

Date	Mid-point time	Site	Transect or Channel	Compass Cal. Score[2]	Loop Test Results[3] See Table 5.1-1 for QC		Mmt duration, s	No. of Passes	Mean velocity, ft/s	Extrap-olation settings[4]	% Top & Bottom Est's.	% Edge Est's.	Discharge, cfs	Coeff. of Variation	95% Uncert[5]. (%)	Added Uncert[6]. (%)
					Start time	Est. % corr										
6/29/13	13:55	FA144	T2-5	M255Q8	1242	2.94	1929	8	Multiple channels - see Table 5.1-5				26,020	0.027	3.2	0.5
6/30/13	12:56	FA141	T1-5	M255Q8	1111	mbv ≤ 0.04	1491	8	Multiple channels - see Table 5.1-5				25,144	0.018	2.0	
7/1/13	13:51	FA138	T2	M255Q8	1339	1.91	657	4	Multiple channels - see Table 5.1-5				25,001	0.017	3.7	0.5
7/2/13	11:56	FA128	T1-5	M255Q8	1039	0.85	3681	12	Multiple channels - see Table 5.1-5				24,614	0.013	1.8	0.5
7/9/13	13:24	PRM 126.8	C1	M255Q8	1310	mbv ≤ 0.04	772	4	5.80	C/N-0.2480	19.41	0.018	23,082	0.010	2.6	0.5
7/9/13	14:14	PRM 124.1	C1	M255Q8	1400	mbv ≤ 0.04	712	4	5.81	C/N-0.2101	23.26	0.010	22,514	0.012	2.9	0.5
7/9/13	15:55	PRM 116.6	C1	M255Q8	1533	0.96	748	4	6.52	C/N-0.2303	22.43	0.146	22,932	0.001	0.7	
7/9/13	17:10	PRM 119.9	C1	M255Q8	1657	mbv ≤ 0.04	728	4	6.11	C/N-0.2358	24.26	0.097	22,745	0.007	1.6	
7/10/13	12:58	FA115	T2-5	M255Q8	1216	1.36	1931	8	Multiple channels - see Table 5.1-5				21,681	0.017	1.9	
7/11/13	13:23	FA113	T1-6	M255Q8	1133	1.20	2205	10	Multiple channels - see Table 5.1-5				19,777	0.012	1.4	
7/11/13	16:50	PRM 107.1	C1	M255Q8	1640	mbv ≤ 0.04	732	4	5.72	C/N-0.2268	22.09	0.117	19,719	0.006	2.0	0.5
7/12/13	12:14	FA104	T1-4	M255Q8	1121	mbv ≤ 0.04	2275	8	Multiple channels - see Table 5.1-5				17,498	0.022	2.3	
8/1/13	15:40	PRM 94.8	C2	M210Q8	1525	0.62	964	4	6.00	C/N-0.2263	26.3	0.07	25,470	0.017	3.2	
8/1/13	16:28	PRM 94.8	C1	M210Q8	1615	1.63	900	6	4.71	C/N-0.1193	25.1	0.50	5,745	0.040	4.5	
8/2/13	12:57	PRM 94.8	C3	M255Q8	1225	5.40	808	4	4.59	C/N-0.2751	24.4	0.57	12,020	0.019	3.5	
8/2/13	13:48	PRM 94.8	C4	M255Q8	1333	3.49	798	6	3.40	C/N-0.1513	28.4	0.24	2,055	0.019	2.9	0.5
8/2/13	14:35	PRM 94.8	C5	M255Q8	Assumed stationary		702	6	3.07	C/N-0.1799	29.8	1.03	2,092	0.023	3.3	0.5
8/2/13	15:46	PRM 94.8	C7	M255Q8	Note 7	mbv ≤ 0.04	716	4	2.75	C/N-0.1713	31.5	0.75	3,235	0.014	3.2	0.5
8/2/13	16:36	PRM 94.8	C8	M255Q8	Assumed stationary		780	6	1.80	C/N-0.2029	27.9	2.13	1,238	0.019	2.4	
8/2/13	17:30	PRM 94.8	C9	M255Q8	1718	mbv ≤ 0.04	804	6	2.83	C/N-0.1985	33.5	1.04	1,985	0.008	1.3	
8/3/13	13:00	PRM 90.2	C3	M255Q8	1245	2.67	1052	4	6.01	C/N-0.2158	26.0	0.01	47,216	0.009	1.9	
8/3/13	13:34	PRM 90.2	C2	M255Q8	Assumed stationary		748	4	0.80	C/N-0.2037	27.7	0.25	907	0.019	3.5	
8/3/13	14:16	PRM 90.2	C4	M255Q8	1403	mbv ≤ 0.04	808	8	3.36	C/N-0.05	48.3	3.52	357	0.035	3.3	
8/3/13	15:12	PRM 90.2	C1	M255Q8	1501	2.79	720	4	3.68	C/N-0.2247	25.0	0.32	3,416	0.021	3.9	
8/3/13	16:23	PRM 87.7	C1	M255Q8	1551	2.79	896	4	5.89	C/N-0.1937	20.1	0.06	52,697	0.006	1.5	
8/4/13	12:32	PRM 78.4	C4	M255Q8	1220	0.73	744	6	6.73	C/N-0.2093	24.5	0.90	9,015	0.009	1.4	
8/4/13	13:00	PRM 78.4	C5	M255Q8	1247	mbv ≤ 0.04	812	4	4.95	C/N-0.1835	22.5	0.00	20,249	0.009	2.4	0.5
8/4/13	14:13	PRM 78.4	C3	M255Q8	1400	3.61	768	4	5.14	C/N-0.2141	27.5	0.40	9,134	0.038	6.6	
8/4/13	14:55	PRM 78.4	C2	M255Q8	1445	mbv ≤ 0.04	732	4	6.34	C/N-0.2159	25.9	0.57	9,237	0.006	1.5	
8/4/13	15:51	PRM 78.4	C1	M255Q8	1524	mbv ≤ 0.04	916	4	2.87	C/N-0.1924	29.9	0.20	4,498	0.011	2.3	
8/5/13	13:28	PRM 73.1	C4	M255Q8	1314	mbv ≤ 0.04	940	4	4.37	C/N-0.1746	26.2	0.06	25,442	0.017	3.2	

1 highlighted cells indicate measurement durations less than 720 s and loop test data quality issues (see Table 1)
2 Compass calibration scores: M > 100 = failed magnetic score, Q > 7 = uniform magnetic field
3 mbv = moving bed velocity; no correction if estimated % corr. < 1% or mbv £ 0.04 ft/s
4 C/N = constant/no-slip, P/P = power/power fit, best-fit exponents shown
5 95% uncertainty calculated per OSW 2012c
6 1.5% added for loop test bottom-tracking errors (Figure 4 and Figure 5), 0.5% added for measurement durations < 720 s and loop durations < 300 s.
7 Moving bed v ≤ 0.04 ft/s on 6/13/13 at 4800 cfs, therefore stationary bed assumed on 8/2/13 (3200 cfs)

Table 2. 1-D Model ADCP Measurements. (page 2)

Date	Mid-point time	Site	Transect or Channel	Compass Cal. Score[2]	Loop Test Results[3] See Table 5.1-1 for QC		Mmt duration, s	No. of Passes	Mean velocity, ft/s	Extrap-olation settings[4]	% Top & Bottom Est's.	% Edge Est's.	Discharge, cfs	Coeff. of Variation	95% Uncert[5]. (%)	Added Uncert[6]. (%)
					Start time	Est. % corr										
8/5/13	14:12	PRM 73.1	C3	M255Q8	1400	mbv ≤ 0.04	788	4	4.37	P/P-0.1525	31.3	0.13	5,156	0.010	2.1	
8/5/13	14:49	PRM 73.1	C2	M255Q8	1435	mbv ≤ 0.04	780	4	2.44	C/N-0.1168	39.0	0.99	2,317	0.014	2.7	
8/5/13	15:44	PRM 73.1	C1	M255Q8	1530	1.84	996	4	4.89	C/N-0.1953	23.8	0.04	18,162	0.012	2.4	
8/6/13	13:11	PRM 67.2	C7	M255Q8	Assumed stationary		810	6	0.22	C/N-0.1967	35.1	2.46	18	0.098	10.3	
8/6/13	14:17	PRM 67.2	C6	M255Q8	1404	mbv ≤ 0.04	846	6	2.04	P/P-0.1754	29.3	0.17	1,446	0.012	1.7	
8/6/13	15:59	PRM 67.2	C5	M255Q8	1544	0.63	1268	4	3.55	C/N-0.2074	27.7	0.02	26,807	0.017	3.2	
8/6/13	16:26	PRM 67.2	C4	M255Q8	Assumed stationary		688	8	0.37	C/N-0.1080	24.4	2.34	151	0.044	4.5	0.5
8/7/13	12:28	PRM 67.2	C2	M255Q8	1217	0.67	808	4	5.14	C/N-0.1877	28.4	0.19	10,054	0.007	2.1	0.5
8/7/13	13:02	PRM 67.2	C3	M210Q8	1242	6.96	750	6	5.35	C/N-0.1715	25.2	0.66	6,587	0.085	9.0	
8/7/13	13:40	PRM 67.2	C1	M255Q8	Assumed stationary		696	8	0.46	C/N-0.2798	31.1	50.81	35	0.243	20.4	0.5
8/8/13	15:05	PRM 225	C1	M255Q8	1453	2.82	708	4	6.24	C/N-0.2617	23.9	0.06	11,912	0.007	2.6	1
8/9/13	12:03	Oshetna	~100m u/s	M74Q9	1135	mbv ≤ 0.04	848	8	3.01	P/P-0.2041	46.8	1.65	614	0.020	2.1	
8/10/13	15:40	PRM 139.0	C1	M255Q8	1525	0.86	820	4	4.85	C/N-0.2510	21.7	0.11	15,949	0.004	1.1	
8/10/13	16:51	PRM 137.6	C1	M255Q8	1623	0.57	872	4	5.46	C/N-0.2217	26.9	0.06	15,702	0.007	1.6	
8/11/13	12:26	PRM 126.8	C1	M255Q7	1211	mbv ≤ 0.04	784	4	4.32	C/N-0.2577	20.6	0.06	16,185	0.007	1.6	
8/11/13	13:32	PRM 124.1	C1	M255Q7	1313	mbv ≤ 0.04	764	4	4.60	C/N-0.2023	22.9	0.00	16,603	0.008	1.8	
8/14/13	14:00	PRM 116.6	C1	M255Q8	1344	mbv ≤ 0.04	776	4	5.82	C/N-0.2211	23.1	0.07	18,085	0.007	1.6	
8/14/13	16:12	PRM 113.6	C1	M255Q8	1555	mbv ≤ 0.04	724	4	4.74	C/N-0.2224	21.4	0.13	18,135	0.007	1.6	
8/15/13	12:53	PRM 138	T2	M255Q8	1237	1.45	792	4	4.95	C/N-0.2371	23.9	0.09	18,618	0.011	2.3	
8/15/13	15:53	PRM 107.1	C1	M255Q8	1541	0.83	732	4	5.67	C/N-0.2595	21.7	0.15	18,921	0.004	1.1	
9/3/13	13:32	PRM 225	C1	M51Q9	1316	4.13	756	4	6.85	C/N-0.2334	23.7	0.08	14,696	0.012	3.9	1.5
9/3/13	16:46	Oshetna	C1	M51Q9	1631	1.47	744	6	3.35	C/N-0.1046	46.03	1.71	1,107	0.020	2.5	
9/7/13	14:20	FA144	T1-5	M231Q8	1258	1.47	4524	6	Multiple channels - see Table 5.1-6				26,400	0.014	1.9	
9/8/13	13:36	FA141	T1-5	M255Q8	1219	2.24	1816	8	Multiple channels - see Table 5.1-6				29,491	0.010	1.8	0.5
9/9/13	12:30	FA138	T1-5	M97Q9	1102	1.49	3215	12	Multiple channels - see Table 5.1-6				28,926	0.011	1.1	
9/10/13	12:53	FA128	T1-5	M255Q7	1123	mbv ≤ 0.04	2228	8	Multiple channels - see Table 5.1-6				26,145	0.007	1.1	
9/12/13	16:52	PRM 126.8	C1	M255Q7	1625	1.69	776	4	6.36	C/N-0.2333	20.18	0.05	31,059	0.015	4.4	1.5
9/12/13	17:41	PRM 124.1	C1	M255Q7	1727	2.26	724	4	7.01	C/N-0.2030	24.53	0.02	30,632	0.016	3.1	
9/13/13	12:05	PRM 116.6	C1	M157Q8	1153	mbv ≤ 0.04	752	4	7.12	P/P-0.1912	23.54	0.02	30,796	0.012	2.4	
9/13/13	12:51	FA115	T1-5	M157Q8	1153	mbv ≤ 0.04	2101	8	Multiple channels - see Table 5.1-6				30,792	0.004	0.8	

1 highlighted cells indicate measurement durations less than 720 s and loop test data quality issues (see Table 1)
2 Compass calibration scores: M > 100 = failed magnetic score, Q > 7 = uniform magnetic field
3 mbv = moving bed velocity; no correction if estimated % corr. < 1% or mbv £ 0.04 ft/s
4 C/N = constant/no-slip, P/P = power/power fit, best-fit exponents shown
5 95% uncertainty calculated per OSW 2012c
6 1.5% added for loop test bottom-tracking errors (Figure 4 and Figure 5), 0.5% added for measurement durations < 720 s and loop durations < 300 s.
7 Moving bed v ≤ 0.04 ft/s on 6/13/13 at 4800 cfs, therefore stationary bed assumed on 8/2/13 (3200 cfs)

Table 2. 1-D Model ADCP Measurements. (page 3)

Date	Mid-point time	Site	Transect or Channel	Compass Cal. Score[2]	Loop Test Results[3] See Table 5.1-1 for QC		Mmt duration, s	No. of Passes	Mean velocity, ft/s	Extrap-olation settings[4]	% Top & Bottom Est's.	% Edge Est's.	Discharge, cfs	Coeff. of Variation	95% Uncert[5]. (%)	Added Uncert[6]. (%)
					Start time	Est. % corr										
9/14/13	13:39	FA113	T1-7	M200Q8	1113	1.62	3756	14	Multiple channels - see Table 5.1-6				25,652	0.009	1.1	
9/15/13	12:09	PRM 107.1	C1	M255Q8	1154	mbv ≤ 0.04	744	4	6.04	C/N-0.2267	22.73	0.23	21,713	0.009	1.9	
9/15/13	13:22	FA104	T1-4	M255Q8	1227	mbv ≤ 0.04	2921	10	Multiple channels - see Table 5.1-6				21,508	0.008	1.1	
9/16/13	14:14	PRM54.1	C1	M255Q8	1402	mbv ≤ 0.04	760	4	3.48	C/N-0.2089	24.13	0.69	4,415	0.014	2.7	
9/16/13	15:22	PRM54.1	C2	M255Q8	1500	5.93	792	4	4.12	C/N-0.1854	28.61	0.55	8,317	0.022	4.0	
9/16/13	16:02	PRM54.1	C3	M255Q8	1551	2.05	824	4	4.20	C/N-0.2115	30.04	0.32	5,701	0.011	2.8	0.5
9/16/13	17:02	PRM54.1	C4	M255Q8	1651	4.78	792	4	4.29	C/N-0.1831	25.69	0.17	15,187	0.019	3.5	
9/17/13	13:05	PRM54.1	C5	M255Q8	1253	mbv ≤ 0.04	762	6	1.70	C/N-0.1585	35.22	3.47	720	0.011	1.6	
9/17/13	13:52	PRM54.1	C6	M255Q8	1339	mbv ≤ 0.04	792	6	1.64	C/N-0.1741	26.30	1.73	1,123	0.009	1.4	
9/17/13	14:35	PRM54.1	C7	M255Q8	1422	2.44	756	4	5.36	C/N-0.1946	25.52	0.24	9,940	0.012	2.4	
9/17/13	15:10	PRM54.1	C8	M255Q8	1456	2.54	852	6	3.46	C/N-0.1844	33.03	1.08	1,770	0.026	3.1	
9/17/13	16:21	PRM54.1	C10	M255Q8	1610	mbv ≤ 0.04	744	6	4.00	C/N-0.2190	29.02	0.50	1,612	0.018	2.3	
9/17/13	16:46	PRM54.1	C9	M255Q8	Assumed stationary		704	8	1.31	C/N-0.2174	34.04	6.24	112	0.148	12.8	0.5
9/17/13	17:20	PRM54.1	C11	M255Q8	1709	mbv ≤ 0.04	744	6	2.97	C/N-0.2399	23.01	0.30	1,735	0.012	1.7	
9/18/13	12:26	PRM49.0	C7	M255Q7	1214	3.77	760	4	2.97	C/N-0.1610	23.92	0.03	9,844	0.022	4.0	
9/18/13	14:01	PRM49.0	C6	M255Q7	1350	1.98	796	4	5.80	C/N-0.1857	26.43	0.12	19,333	0.010	2.1	
9/18/13	14:37	PRM49.0	C4	M255Q7	1424	mbv ≤ 0.04	756	6	1.77	C/N-0.1379	26.60	0.09	1,223	0.034	3.9	
9/18/13	15:07	PRM49.0	C5	M255Q7	Assumed stationary		648	8	1.32	C/N-0.2057	32.83	7.85	350	0.008	1.6	0.5
9/18/13	16:09	PRM49.0	C3	M255Q7	1556	2.35	744	6	2.00	C/N-0.1736	34.24	1.62	987	0.022	2.7	
9/18/13	16:31	PRM49.0	C2	M255Q7	Assumed stationary		348	4	1.59	C/N-0.1879	33.29	2.01	129	0.015	3.9	1
9/18/13	16:58	PRM49.0	C1	M255Q7	1643	4.45	800	4	4.35	C/N-0.1642	26.50	0.09	12,204	0.012	2.4	
9/19/13	12:34	PRM40.3	C3	M255Q8	1223	mbv ≤ 0.04	716	4	1.35	C/N-0.1363	37.03	9.72	350	0.011	2.8	0.5
9/19/13	13:05	PRM40.3	C2	M255Q8	1250	mbv ≤ 0.04	844	4	1.80	C/N-0.2004	22.00	0.10	7,842	0.008	1.8	
9/19/13	14:12	PRM40.3	C1	M255Q7	1340	6.74	868	4	4.78	C/N-0.1517	25.27	0.03	36,327	0.016	3.1	
9/20/13	13:17	PRM36.4	C3	M255Q7	1303	1.71	748	4	3.09	C/N-0.1331	22.73	-0.06	12,813	0.008	1.8	
9/20/13	14:09	PRM36.4	C2	M255Q7	1354	mbv ≤ 0.04	880	4	1.67	C/N-0.1861	28.95	0.55	3,499	0.013	2.6	
9/20/13	15:15	PRM36.4	C1	M255Q7	1457	9.89	848	4	3.95	C/N-0.1792	25.80	0.04	24,546	0.014	2.7	
9/21/13	12:18	PRM34.8	C3	M255Q8	1207	mbv ≤ 0.04	744	4	4.58	C/N-0.1996	24.10	0.41	11,755	0.005	1.3	
9/21/13	12:55	PRM34.8	C2	M255Q8	1242	1.60	840	4	2.79	C/N-0.1973	23.97	0.16	6,752	0.011	2.3	
9/21/13	14:39	PRM34.8	C1	M255Q8	1407	9.24	888	4	3.52	C/N-0.1832	29.77	0.31	19,549	0.007	3.1	1.5

1 highlighted cells indicate measurement durations less than 720 s and loop test data quality issues (see Table 1)
2 Compass calibration scores: M > 100 = failed magnetic score, Q > 7 = uniform magnetic field
3 mbv = moving bed velocity; no correction if estimated % corr. < 1% or mbv £ 0.04 ft/s
4 C/N = constant/no-slip, P/P = power/power fit, best-fit exponents shown
5 95% uncertainty calculated per OSW 2012c
6 1.5% added for loop test bottom-tracking errors (Figure 4 and Figure 5), 0.5% added for measurement durations < 720 s and loop durations < 300 s.
7 Moving bed v ≤ 0.04 ft/s on 6/13/13 at 4800 cfs, therefore stationary bed assumed on 8/2/13 (3200 cfs)

Table 3. Lower River Summed Multi-Channel Flows.

PRM	Starting		Ending		Main channel midpoint		Discharge,	Weighted
	Date	Time	Date	Time	Date	Time	cfs	95% uncert[1].
94.8	8/1/13	15:34	8/2/13	17:36	8/1/13	15:40	53,839	3.3
90.2	8/3/13	12:54	8/3/13	15:17	8/3/13	13:00	51,896	2.1
87.7	8/3/13	16:17	8/3/13	16:29	8/3/13	16:23	52,697	1.5
78.4	8/4/13	12:26	8/4/13	16:30	8/4/13	13:00	52,133	2.6
73.1	8/5/13	13:22	8/5/13	15:50	8/5/13	13:28	51,077	2.8
67.2	8/6/13	13:11	8/7/13	13:40	8/6/13	15:59	45,099	2.9
54.1	9/16/13	14:14	9/17/13	17:20	9/16/13	17:02	50,634	3.2
49.0	9/18/13	12:26	9/18/13	16:58	9/18/13	14:01	44,070	2.7
40.3	9/19/13	12:34	9/19/13	14:12	9/19/13	14:12	44,519	2.8
36.4	9/20/13	13:17	9/20/13	15:15	9/20/13	15:15	40,858	2.4
34.8	9/21/13	12:18	9/21/13	14:39	9/21/13	14:39	38,056	1.6

1 Discharge-weighted average of 95% uncertainties from Table 2.

Table 4. 2013 ADCP Check Measurements.

Gold Creek ADCP Check Measurements, Sontek M9 S/N 3936								
Measurement Party		D. Brailey			Provisional	Percent difference from online Q		
Blanking Distance		0.2 ft[1]	0.52 feet[2]	0.52 feet[2]	online Q, cfs	0.2 ft[1]	0.52 feet[2]	0.52 feet[2]
Extrapolation Settings		C/N-0.1991	P/P-0.1966	P/P-0.1667	27,100	C/N-0.1991	C/N-0.2051	P/P-0.1667
7/1/2013	13:51:31	25,001	25,291	25,395		-7.74	-6.68	-6.29
Extrapolation Settings		C/N-0.2510	P/P-0.2104	P/P-0.1667	16,900	C/N-0.2510	P/P-0.2104	P/P-0.1667
8/10/2013	15:40	15,949	16,205	16,286		-5.63	-4.11	-3.63
Extrapolation Settings		C/N-0.2371	P/P-0.2081	P/P-0.1667	19,900	C/N-0.2371	P/P-0.2081	P/P-0.1667
8/15/2013	12:53	18,618	18,930	19,029		-6.44	-4.87	-4.38
USGS Rating Measurement no. 305 - J. Morse					19,900	RDI Rio Grande, VTG, P/P-0.1667		
8/15/2013	13:49	18,900				-5.03		
Extrapolation Settings		C/N-0.2145	P/P-0.2096	P/P-0.1667	30,600	C/N-0.2145	P/P-0.2096	P/P-0.1667
9/9/2013	13:10:10	28,719	28,928	29,097		-6.15	-5.46	-4.91
Sunshine ADCP Check Measurement, Sontek M9 S/N 3936								
Extrapolation Settings		C/N-0.1937	C/N-0.1877	P/P-0.1667	54,100	C/N-0.1937	C/N-0.1877	P/P-0.1667
8/3/2013	16:23	52,697	52,713	53,224		-2.59	-2.56	-1.62

Table 5. Focus Area Best Fit Flow Measurements – June & July 2013. (page 1)

Times listed for main channel transects.

Focus Area 144										
Date	Time	Transect	Pass	Duration, seconds	Measured flow (or sum), cfs				Constant average line Q = 26,020	
					Left	Middle	Right	Total	Flow	Error
6/29/2013	14:38	T2	R-L,L-R*	265	469		25,495	25,964	26,020	-56
6/29/2013	14:47	T2	L-R	256	492		26,200	26,692	26,020	672
6/29/2013	14:25	T3	R-L,L-R*	351	280	7,332	18,858	26,470	26,020	450
6/29/2013	14:28	T3	L-R	365	282	7,266	19,376	26,924	26,020	903
6/29/2013	13:24	T4	R-L,L-R*	230	55		25,025	25,080	26,020	-941
6/29/2013	13:28	T4	L-R	237	59		25,346	25,405	26,020	-616
6/29/2013	13:03	T5	R-L,L-R*	107				26,595	26,020	575
6/29/2013	13:06	T5	L-R	118				25,033	26,020	-988
mean	13:55		total duration	1929				26,020	26,020	
COV								0.027		0.027
95%U								2.69		2.69

Focus Area 141									
Date	Time	Transect	Pass	Duration, seconds	Measured flow (or sum), cfs			Best fit line Q = -3875*date[1] + 1.61e8	
					Left	Right	Total	Flow	Error
6/30/2013	13:49	T1	L-R	154			25,068	25,003	65
6/30/2013	13:57	T1	L-R	135			25,512	24,981	531
6/30/2013	13:15	T2	L-R	178			24,268	24,844	-576
6/30/2013	13:21	T2	L-R	148			24,158	24,826	-668
6/30/2013	13:07	T3	R-L,L-R*	259	12,166	13,085	25,251	24,865	387
6/30/2013	13:04	T3	L-R	272	12,420	12,812	25,232	24,873	359
6/30/2013	11:31	T5	R-L	171			25,543	25,124	419
6/30/2013	11:27	T5	L-R	174			24,768	25,135	-367
mean	12:56		total duration	1491			24,975	25,144	
COV							0.020		0.018
95%U							2.09		1.96

Focus Area 138									
Date	Time	Transect	Pass	Duration, seconds	Measured flow (or sum), cfs			Constant average line Q = 25,001	
					Left	Right	Total	Flow	Error
7/1/2013	13:46	T2	R-L	205			25,070	25,001	68
7/1/2013	13:49	T2	L-R	143			25,376	25,001	375
7/1/2013	13:52	T2	R-L	171			24,301	25,001	-700
7/1/2013	13:57	T2	L-R	138			25,258	25,001	257
mean	13:51		total duration	657			25,001	25,001	
COV							0.017		0.017
95%U							3.18		3.18

Focus Area 128										
Date	Time	Transect	Pass	Duration, seconds	Measured flow (or sum), cfs				Best fit line Q = 1905*date[1] + 7.90e7	
					Left	Middle	Right	Total	Flow	Error
7/2/2013	13:08	T1	R-L	271	7,694		17,457	25,151	24,710	441
7/2/2013	13:19	T1	R-L	247	7,615		17,550	25,165	24,724	441
7/2/2013	12:39	T2	R-L, R-L*	445	6,257	755	17,762	24,774	24,671	103
7/2/2013	12:53	T2	L-R, R-L*	429	6,445	757	17,170	24,373	24,690	-317
7/2/2013	12:10	T3	R-L	349	375	5,810	18,406	24,591	24,633	-42
7/2/2013	12:13	T3	L-R, R-L*	318	381	5,848	18,334	24,563	24,637	-74
7/2/2013	11:29	T4	R-L	510	3,066	12,540	8,610	24,216	24,578	-362
7/2/2013	11:24	T4	L-R	525	2,931	12,985	8,803	24,719	24,571	148
7/2/2013	10:55	T5	R-L	151				24,105	24,534	-429
7/2/2013	11:03	T5	R-L	134				24,528	24,544	-17
7/2/2013	10:53	T5	L-R	161				25,059	24,530	529
7/2/2013	11:01	T5	L-R	141				24,991	24,541	450
mean	11:56		total duration	3681				24,694	24,614	
COV					"Left" includes 2 channels at T2			0.014		0.013
95%U					and 3 channels at T4			1.33		1.31

[1] date and time in serial number format (datum = 1/0/1900)

* non-reciprocal pass in main channel due to swift current/standing waves

Table 5. Focus Area Best Fit Flow Measurements – June & July 2013. (page 2)

Times listed for main channel transects.

Focus Area 115					Measured flow (or sum), cfs			Best fit line Q = -664*date[1] + 2.75e7	
Date	Time	Transect	Pass	Duration, seconds	Left	Right	Total	Flow	Error
7/10/2013	14:07	FA113 T7	R-L	279	1,515	19,726	21,241	21,650	-408
7/10/2013	14:11	FA113 T7	L-R, R-L*	271	1,539	20,535	22,074	21,648	426
7/10/2013	12:52	T2	R-L	325	16,108	5,342	21,450	21,684	-234
7/10/2013	12:55	T2	L-R	281	16,373	5,452	21,825	21,683	142
7/10/2013	12:40	T4	R-L,L-R*	241	16,174	5,489	21,663	21,690	-27
7/10/2013	12:47	T4	L-R	231	15,969	5,523	21,492	21,687	-194
7/10/2013	12:09	T5	R-L	132			21,269	21,704	-435
7/10/2013	12:06	T5	L-R	171			22,386	21,705	680
mean	12:58		total duration	1931			21,675	21,681	
COV							0.017		0.017
95%U							1.88		1.88

Focus Area 113					Measured flow (or sum), cfs				Best fit line Q = -721*date[1] + 2.99e7	
Date	Time	Transect	Pass	Duration, seconds	Left	Middle	Right	Total	Flow	Error
7/11/2013	15:25	T1	R-L	148				19,359	19,716	-356
7/11/2013	15:27	T1	L-R	144				20,098	19,714	384
7/11/2013	14:47	T3	R-L	260	20,028		21	20,049	19,735	314
7/11/2013	14:51	T3	L-R, R-L*	284	19,379		27	19,406	19,732	-326
7/11/2013	13:16	T4	R-L	361	3,729	15,946	21	19,696	19,780	-85
7/11/2013	13:37	T4	L-R, R-L*	384	3,751	16,007	27	19,785	19,769	16
7/11/2013	11:58	T5	R-L	255	3,318		16,750	20,068	19,819	249
7/11/2013	11:53	T5	L-R	242	3,303		16,545	19,848	19,821	27
7/11/2013	11:15	T6	R-L	222	1,492		18,167	19,659	19,841	-182
7/11/2013	11:18	T6	L-R, R-L*	197	1,475		18,371	19,846	19,839	7
mean	13:23		total duration	2205				19,781	19,777	
COV								0.012		0.012
95%U								1.37		1.35

Focus Area 104					Measured flow (or sum), cfs				Constant average line Q = 17,498	
Date	Time	Transect	Pass	Duration, seconds	Left		Right	Total	Flow	Error
7/12/2013	13:42	T1	R-L	462	115	14,960	2,639	17,713	17,498	215
7/12/2013	13:46	T1	L-R, R-L*	491	118	15,178	2,731	18,027	17,498	529
7/12/2013	11:54	T2	R-L	244	13,934		2,809	16,742	17,498	-756
7/12/2013	11:57	T2	L-R	231	14,769		2,795	17,565	17,498	66
7/12/2013	11:42	T3	R-L,L-R*	269	17,140		149	17,289	17,498	-209
7/12/2013	11:46	T3	L-R	270	17,620		141	17,761	17,498	263
7/12/2013	11:31	T4	R-L	175				17,740	17,498	242
7/12/2013	11:36	T4	L-R	133				17,147	17,498	-351
mean	12:14		total duration	2275				17,498	17,498	
COV					"Left" = T1A plus T1B			0.022		0.022
95%U								2.27		2.27

[1] date and time in serial number format (datum = 1/0/1900)

* non-reciprocal pass in main channel due to swift current/standing waves

Table 6. 2013 Focus Area Best Fit Flow Measurements – September 2013. (page 1)

Times listed for main channel transects.

Focus Area 144									
		Transect	Pass	Duration, seconds	Measured flow (or sum), cfs			Best fit line Q = -4033*date[1] + 1.68e8	
Date	Time				Left	Right	Total	Flow	Error
9/7/2013	13:13	T5	R-L	180			25,980	26,587	-607
9/7/2013	13:16	T5	L-R	174			27,213	26,578	634
9/7/2013	14:33	T2	R-L	306	462	25,650	26,112	26,362	-250
9/7/2013	14:30	T2	L-R	345	472	25,980	26,452	26,370	82
9/7/2013	14:45	T1	R-L	255	2,354	23,996	26,350	26,329	21
9/7/2013	14:48	T1	L-R	248	2,125	24,316	26,441	26,321	120
mean	14:20	total duration		1508			26,425	26,400	
COV							0.015		0.014
95%U							1.98		1.93

Focus Area 141									
		Transect	Pass	Duration, seconds	Measured flow (or sum), cfs			Best fit line Q = 1234*date[1] - 5.12e7	
Date	Time				Left	Right	Total	Flow	Error
9/8/2013	12:28	T5	R-L	151			28,995	29,432	-437
9/8/2013	12:31	T5	L-R	158			29,839	29,435	404
9/8/2013	12:40	T4	R-L	283	24,572	4,884	29,456	29,443	13
9/8/2013	12:44	T4	L-R	314	24,580	4,904	29,484	29,446	39
9/8/2013	14:05	T3	R-L	297	14,789	15,047	29,836	29,516	320
9/8/2013	14:03	T3	L-R	307	14,814	14,990	29,804	29,513	291
9/8/2013	15:09	T1	R-L	147			30,909	30,550	359
9/8/2013	15:11	T1	L-R	159			30,849	30,552	297
mean	13:36	total duration		1816			29,897	29,491	
COV							0.021		0.010
95%U							2.59		1.53

Focus Area 138										
		Transect	Pass	Duration, seconds	Measured flow (or sum), cfs				Best fit line Q = -1778*date[1] +7.39e7	
Date	Time				Left	Middle	Right	Total	Flow	Error
9/9/2013	11:22	T5	R-L	178				28,929	29,072	-143
9/9/2013	11:25	T5	L-R	159				29,225	29,065	160
9/9/2013	11:46	T4	R-L	236	255		28,730	28,985	29,021	-36
9/9/2013	11:49	T4	L-R, R-L*	239	236		28,567	28,803	29,014	-211
9/9/2013	11:57	T3	R-L	372	4,383	23,401	895	28,680	28,998	-318
9/9/2013	12:01	T3	L-R	329	4,621	24,110	888	29,619	28,989	630
9/9/2013	13:04	T2	R-L	178				28,693	28,852	-159
9/9/2013	13:08	T2	L-R	188				28,969	28,844	125
9/9/2013	13:11	T2	R-L	187				28,717	28,837	-120
9/9/2013	13:15	T2	L-R	186				28,496	28,830	-334
9/9/2013	13:29	T1	R-L	493	4,330	4,267	20,711	29,308	28,799	509
9/9/2013	13:34	T1	L-R	470	4,462	4,119	19,860	28,441	28,787	-346
mean	12:30	total duration		3215				28,905	28,926	
COV					"Left" = sum of T6 and T7			0.011		0.011
95%U								1.19		1.14

Focus Area 128										
		Transect	Pass	Duration, seconds	Measured flow (or sum), cfs				Best fit line Q = -963*date[1] + 4.00e7	
Date	Time				Left	Middle	Right	Total	Flow	Error
9/10/2013	11:53	T5	R-L	187				25,978	26,185	-207
9/10/2013	11:50	T5	L-R	163				26,437	26,187	250
9/10/2013	11:59	T5	R-L	190				26,020	26,181	-161
9/10/2013	11:56	T5	L-R	191				26,305	26,183	122
9/10/2013	13:38	T2	R-L	521	6,884	1,145	17,854	25,883	26,115	-232
9/10/2013	13:43	T2	L-R	459	7,035	1,123	18,181	26,339	26,112	228
9/10/2013	14:01	T1	R-L	257	8,547		17,468	26,015	26,099	-85
9/10/2013	14:06	T1	L-R	260	8,548		17,637	26,186	26,097	89
mean	12:53	total duration		2228				26,145	26,145	
COV					"Middle" = T2B plus T2C			0.007		0.007
95%U								1.07		1.06

[1] date and time in serial number format (datum = 1/0/1900)

* non-reciprocal pass in main channel due to swift current/standing waves

Table 6. 2013 Focus Area Best Fit Flow Measurements – September 2013. (page 2)

Times listed for main channel transects.

Focus Area 115		Transect	Pass	Duration, seconds	Measured flow (or sum), cfs			Constant average line Q = 30,792	
Date	Time				Left	Right	Total	Flow	Error
9/13/2013	12:25	T5	R-L	156			30,772	30,792	-20
9/13/2013	12:28	T5	L-R	143			30,709	30,792	-83
9/13/2013	12:44	T4	R-L	280	21,875	9,057	30,932	30,792	140
9/13/2013	12:42	T4	L-R	276	21,853	9,029	30,882	30,792	90
9/13/2013	12:55	T2	R-L	340	21,687	9,105	30,793	30,792	1
9/13/2013	12:52	T2	L-R	338	21,794	8,953	30,747	30,792	-45
9/13/2013	13:23	T1	R-L	294	3,074	27,453	30,527	30,792	-265
9/13/2013	13:20	T1	L-R	274	3,073	27,904	30,977	30,792	185
mean	12:51	total duration		2101			30,792	30,792	
COV							0.004		0.004
95%U							0.85		0.85

Focus Area 113		Transect	Pass	Duration, seconds	Measured flow (or sum), cfs			Best fit line Q = -6531*date[1] + 2.71e8	
Date	Time				Left	Right	Total	Flow	Error
9/14/2013	11:24	T7	R-L	318	1,810	24,216	26,026	26,267	-240
9/14/2013	11:20	T7	L-R	330	1,793	24,797	26,591	26,281	309
9/14/2013	11:38	T6	R-L	306	1,840	24,473	26,313	26,201	111
9/14/2013	11:41	T6	L-R	277	1,813	24,588	26,400	26,188	212
9/14/2013	11:50	T5	R-L	307	5,087	20,682	25,769	26,147	-379
9/14/2013	11:47	T5	L-R	276	5,078	20,999	26,077	26,159	-82
9/14/2013	14:24	T4	R-L	289	5,643	19,838	25,481	25,447	34
9/14/2013	14:29	T4	L-R	256	5,459	20,064	25,524	25,425	98
9/14/2013	14:53	T3	R-L	309	25,231	152	25,383	25,318	65
9/14/2013	14:58	T3	L-R	286	25,211	152	25,363	25,293	70
9/14/2013	15:30	T1	R-L	220			24,894	25,148	-254
9/14/2013	15:44	T1	L-R	189			25,438	25,084	353
9/14/2013	15:38	T1	R-L	225			24,642	25,112	-471
9/14/2013	15:50	T1	L-R	168			25,173	25,061	113
mean	13:39	total duration		3756			25,648	25,652	
COV							0.022		0.009
95%U							1.79		1.06

Focus Area 104		Transect	Pass	Duration, seconds	Measured flow (or sum), cfs				Best fit line Q = -1621*date[1] + 6.74e7	
Date	Time				Left	Middle	Right	Total	Flow	Error
9/15/2013	12:43	T4	R-L	195				21,534	21,552	-18
9/15/2013	12:46	T4	L-R	180				21,805	21,548	257
9/15/2013	12:50	T4	R-L	185				21,623	21,544	78
9/15/2013	12:53	T4	L-R	171				21,514	21,541	-27
9/15/2013	13:03	T3	R-L	309	20,950		509	21,459	21,529	-70
9/15/2013	12:59	T3	L-R	291	21,294		519	21,813	21,534	279
9/15/2013	13:10	T2	R-L	306	17,318		3,893	21,211	21,521	-311
9/15/2013	13:13	T2	L-R	277	17,563		3,861	21,424	21,518	-94
9/15/2013	15:03	T1	R-L	495	375	17,227	3,683	21,284	21,394	-110
9/15/2013	14:59	T1	L-R	512	385	17,499	3,674	21,559	21,398	160
mean	13:22	total duration		2921				21,522	21,508	
COV					"Left" = T1A plus T1B			0.009		0.008
95%U								1.10		1.06

[1] date and time in serial number format (datum = 1/0/1900)

Table 7. 2013 Focus Area Flow Splits. (page 1)

Times correspond to main channel transects.

Focus Area 144			Proportion of Total Flow			Flow (cfs), adjusted to match Focus Area Total			Focus Area Total Flow, cfs	95% Uncertainty, percent
Date	Time	Transect	Left	Middle	Right	Left	Middle	Right		
6/29/2013	16:02	T1	0.0809		R	2,104		R	26,020	10.4
9/7/2013	14:46	T1	0.0849		0.915	2,234		24,091	26,325	3.5
6/29/2013	14:43	T2	0.0183		0.982	475		25,545	26,020	7.1
9/7/2013	14:32	T2	0.0178		0.982	469		25,897	26,366	7.1
6/29/2013	14:26	T3	0.0105	0.273	0.716	274	7,114	18,632	26,020	10.4
9/7/2013	14:05	T3	0.0092	0.258	0.733	244	6,825	19,374	26,442	7.1
6/29/2013	13:26	T4	0.0023		0.998	59		25,961	26,020	10.4
9/7/2013	13:25	T4	0.0009		0.999	23		26,529	26,552	7.1
6/29/2013	13:05	T5		single channel			26,020		26,020	2.7
9/7/2013	13:14	T5		single channel			26,583		26,583	1.9

Focus Area 141			Proportion of Total Flow		Flow (cfs), adjusted to match Focus Area Total		Focus Area Total Flow, cfs	95% Uncertainty, percent
Date	Time	Transect	Left	Right	Left	Right		
6/30/2013	13:53	T1	single channel		24,992		24,992	2.0
9/8/2013	15:10	T1	single channel		30,551		30,551	1.5
6/30/2013	13:18	T2	single channel		24,835		24,835	2.0
9/8/2013	15:04	T2	single channel		30,546		30,546	1.5
6/30/2013	13:05	T3	0.487	0.513	12,112	12,757	24,869	7.1
9/8/2013	14:04	T3	0.496	0.504	14,650	14,865	29,515	3.8
6/30/2013	11:51	T4	0.833	0.167	20,893	4,175	25,068	23.6
9/8/2013	12:42	T4	0.834	0.166	24,554	4,890	29,444	3.5
6/30/2013	11:29	T5	single channel		25,130		25,130	2.0
9/8/2013	12:30	T5	single channel		29,434		29,434	1.5
6/30/2013	14:27	T6	0.0583		1,437		24,650	3.8
9/8/2013	13:04	T6	0.0591		1,800		30,443	3.5
6/30/2013	14:36	T7	0.0992		2,443		24,625	3.8
9/8/2013	13:29	T7	0.0939		2,862		30,465	3.5
6/30/2013	15:30	T8	5.1E-05		1.24		24,481	>50
6/30/2013	15:45	T9	-3.2E-05		-0.78		24,441	>50
6/30/2013	15:59	T10	-2.6E-05		-0.63		24,402	>50
9/8/2013	14:35	T11	1.2E-04		3.76		30,521	>50

Table 7. 2013 Focus Area Flow Splits. **(page 2)**

Times correspond to main channel transects.

Focus Area 138			Proportion of Total Flow			Flow (cfs), adjusted to match Focus Area Total			Focus Area Total Flow, cfs	95% Uncertainty, percent
Date	Time	Transect	Left	Middle	Right	Left	Middle	Right		
7/1/2013	14:37	T1	see T6 & T7	0.141	R	see T6 & T7	3,520		25,001	3.8
9/9/2013	13:32	T1	0.152	0.145	0.703	4,383	4,181	20,228	28,793	7.1
7/1/2013	13:51	T2		single channel			25,001		25,001	3.2
9/9/2013	13:10	T2		single channel			28,841		28,841	1.1
7/1/2013	12:44	T3		0.817	0.0248		20,434	621	25,001	7.1
9/9/2013	11:59	T3	0.1544	0.815	0.0306	4,478	23,629	887	28,994	7.1
7/1/2013	12:28	T4	0.0066		0.993	165		24,837	25,001	23.6
9/9/2013	11:48	T4	0.0085		0.992	247		28,771	29,017	3.8
7/1/2013	11:57	T5		single channel			25,001		25,001	3.2
9/9/2013	11:24	T5		single channel			29,068		29,068	1.1
7/1/2013	14:52	T6		0.130			3,258		25,001	7.1
9/9/2013	14:08	T6		0.141			4,050		28,714	7.1
7/1/2013	15:03	T7		0.0073			183		25,001	26.9
9/9/2013	14:19	T7		0.0121			346		28,692	3.8
7/1/2013	15:18	T8		3.8E-04			9.59		25,001	>50
9/9/2013	14:01	T8		2.1E-04			5.91		28,729	>50

Focus Area 128			Proportion of Total Flow					Flow (cfs), adjusted to match Focus Area Total					Focus Area Total Flow, cfs	95% Uncertainty, percent
Date	Time	Transect	Far left	Left	Middle	Right	Far right	Far left	Left	Middle	Right	Far right		
7/2/2013	13:14	T1		0.304		0.696			7,520		17,197		24,717	7.1
9/10/2013	14:03	T1		0.327		0.673			8,547		17,551		26,098	3.5
7/2/2013	12:46	T2	0.010	0.251	0.0311	0.718		236	6,204	766	17,710		24,916	7.1
9/10/2013	13:40	T2		0.267	0.0434	0.690			6,960	1,134	18,019		26,113	7.1
7/2/2013	12:12	T3		0.0154	0.237	0.747			379	5,843	18,413		24,635	3.5
9/10/2013	13:13	T3		0.0181	0.242	0.740			473	6,331	19,328		26,132	7.1
7/2/2013	11:26	T4	3.7E-04	0.0152	0.107	0.522	0.356	9.10	374	2,629	12,818	8,745	24,575	3.8
9/10/2013	12:20	T4		0.0181	0.111	0.522	0.349		473	2,907	13,659	9,127	26,167	7.1
7/2/2013	10:58	T5			single channel					24,538			24,538	3.2
9/10/2013	11:54	T5			single channel					26,184			26,184	1.1
7/2/2013	12:24	T6			0.0094					231			24,651	4.0
9/10/2013	13:26	T6			0.0096					250			26,123	13.7
7/2/2013	15:36	T7			1.2E-04					2.95			24,905	>20
9/10/2013	15:10	T7			1.4E-04					3.68			26,053	7.1

Table 7. 2013 Focus Area Flow Splits. (page 3)

Times correspond to main channel transects.

Focus Area 115		Transect	Proportion of Total Flow			Flow (cfs), adjusted to match Focus Area Total			Focus Area Total Flow, cfs	95% Uncertainty, percent
Date	Time		Left	Middle	Right	Left	Middle	Right		
7/10/2013	14:09	T1	0.100		0.900	2,165		19,484	21,649	10.4
9/13/2013	13:21	T1	0.100		0.900	3,077		27,715	30,792	3.8
7/10/2013	12:53	T2	0.751		0.249	16,275		5,409	21,683	3.8
9/13/2013	12:53	T2	0.707		0.293	21,756		9,036	30,792	3.5
7/10/2013	11:23	T3	2.5E-04	0.253	3.8E-05	5.38	5,493	0.825	21,725	3.8
9/13/2013	14:07	T3	0.0135	0.986	7.5E-04	415	30,354	23.1	30,792	3.5
7/10/2013	12:43	T4	0.745		0.255	16,154		5,534	21,688	3.8
9/13/2013	12:43	T4	0.707		0.293	21,783		9,009	30,792	3.5
7/10/2013	12:08	T5		single channel			21,705		21,705	1.3
9/13/2013	12:26	T5		single channel			30,792		30,792	0.85

Focus Area 113		Transect	Proportion of Total Flow		Flow (cfs), adjusted to match Focus Area Total		Focus Area Total Flow, cfs	95% Uncertainty, percent
Date	Time		Left	Right	Left	Right		
7/11/2013	15:26	T1	single channel		19,715		19,715	1.4
9/14/2013	15:41	T1	single channel		25,101		25,101	1.1
7/11/2013	15:05	T2	0.999	0.0012	19,701	24.4	19,725	13.7
9/14/2013	15:08	T2	0.994	0.0059	25,101	150	25,251	7.1
7/11/2013	14:49	T3	0.999	0.0012	19,710	23.8	19,733	7.1
9/14/2013	14:56	T3	0.994	0.0060	25,154	152	25,306	3.5
7/11/2013	13:26	T4	0.189	0.0012	3,747	23.8	19,775	3.5
9/14/2013	14:27	T4	0.218	0.782	5,537	19,899	25,436	3.5
7/11/2013	11:56	T5	0.166	0.834	3,288	16,532	19,820	3.8
9/14/2013	11:49	T5	0.196	0.804	5,127	21,026	26,153	3.8
7/11/2013	13:48	T6	0.0751	0.925	1,490	18,350	19,840	3.8
9/14/2013	11:40	T6	0.0693	0.931	1,815	24,380	26,195	3.8
7/10/2013	14:09	T7	0.0705	0.929	1,526	20,122	21,649	7.1
9/14/2013	11:22	T7	0.0685	0.932	1,800	24,474	26,274	3.8

Focus Area 104		Transect	Proportion of Total Flow				Flow (cfs), adjusted to match Focus Area Total				Focus Area Total Flow, cfs	95% Uncertainty, percent
Date	Time		Far left	Left	Middle	Right	Far left	Left	Middle	Right		
7/12/2013	13:44	T1	8.5E-05	0.0064	0.843	0.150	1.48	113	14,756	2,629	17,498	7.1
9/15/2013	15:01	T1	1.3E-04	0.0176	0.811	0.172	2.74	377	17,345	3,675	21,396	3.8
7/12/2013	11:55	T2		0.837		0.163		14,640		2,858	17,498	10.4
9/15/2013	13:11	T2		0.818		0.182		17,606		3,914	21,520	3.8
7/12/2013	11:44	T3		0.992		0.008		17,353		145	17,498	3.8
9/15/2013	13:01	T3		0.976		0.0237		21,020		511	21,531	3.8
7/12/2013	11:34	T4		single channel				17,498			17,498	2.3
9/15/2013	12:51	T4		single channel				21,546			21,546	1.1
7/12/2013	13:34	T5		0.0052		8.1E-04		90.8		14.3	17,498	3.8
9/15/2013	14:46	T5		0.0110		2.9E-03		236		63.0	21,413	3.8
7/12/2013	12:20	T6		0.147			2,576				17,498	3.5
9/15/2013	13:26	T6	0.161				3,471				21,503	3.5

9. FIGURES

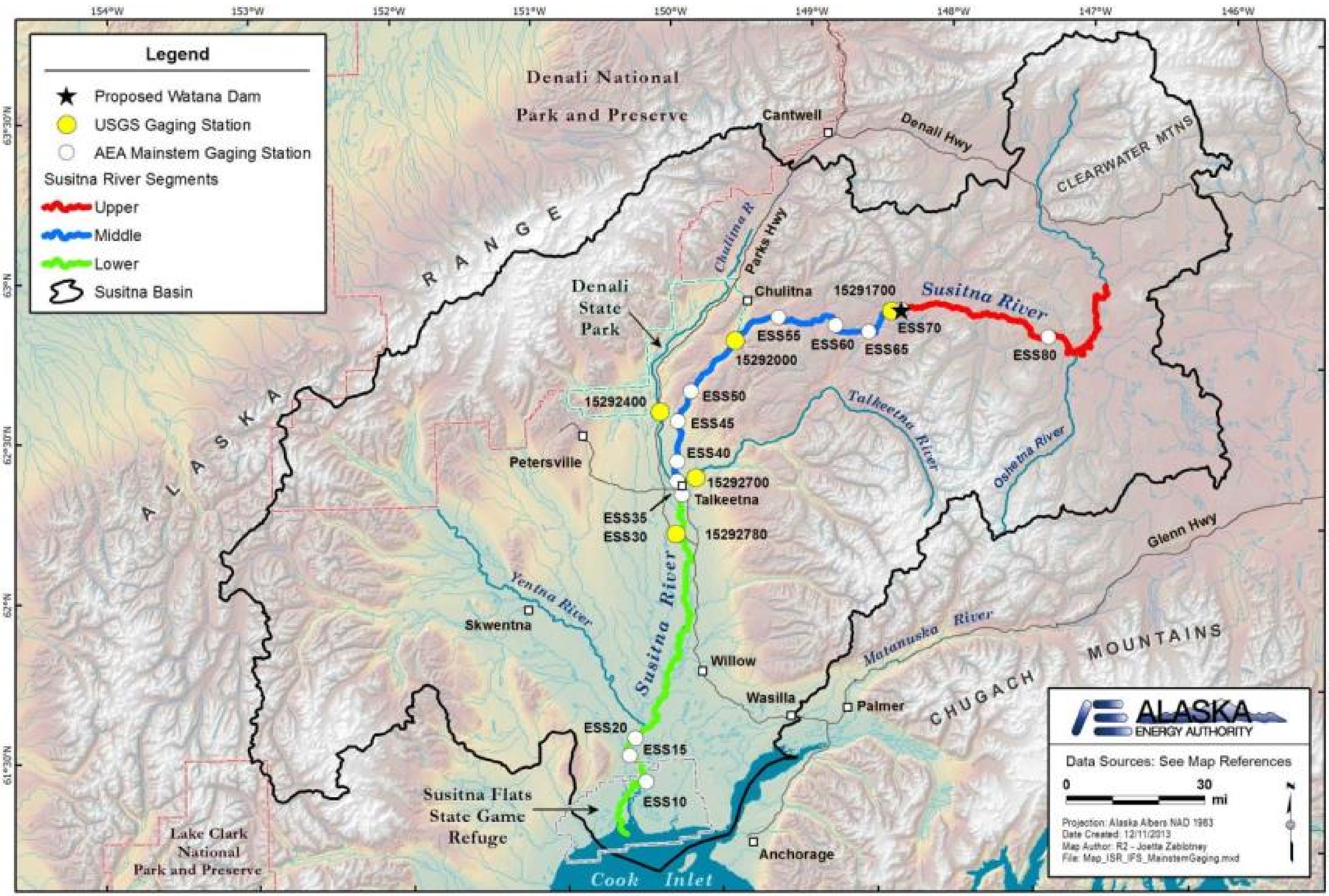


Figure 1. Susitna River watershed showing mainstem gaging stations and major river segments.

Figure 2. ADCP measurement platform.

Figure 3. M9 trimaran mount, inverted to show transducer head.

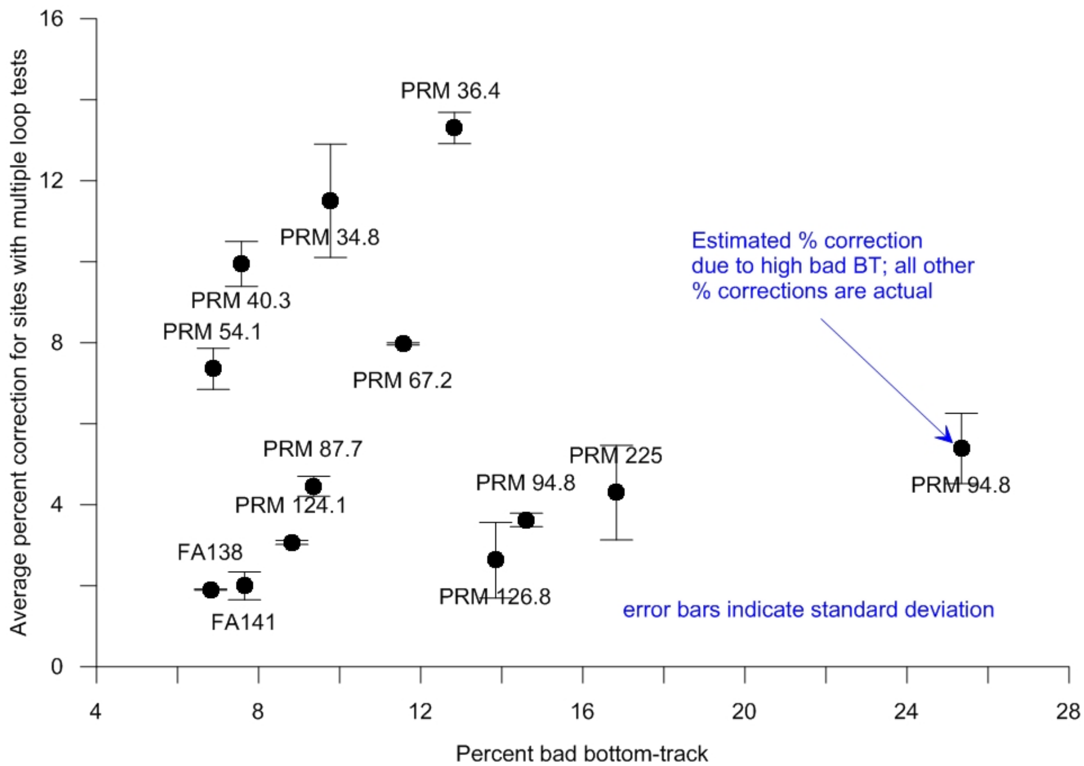


Figure 4. % Bad Bottom-Track vs. Loop Test % Correction.

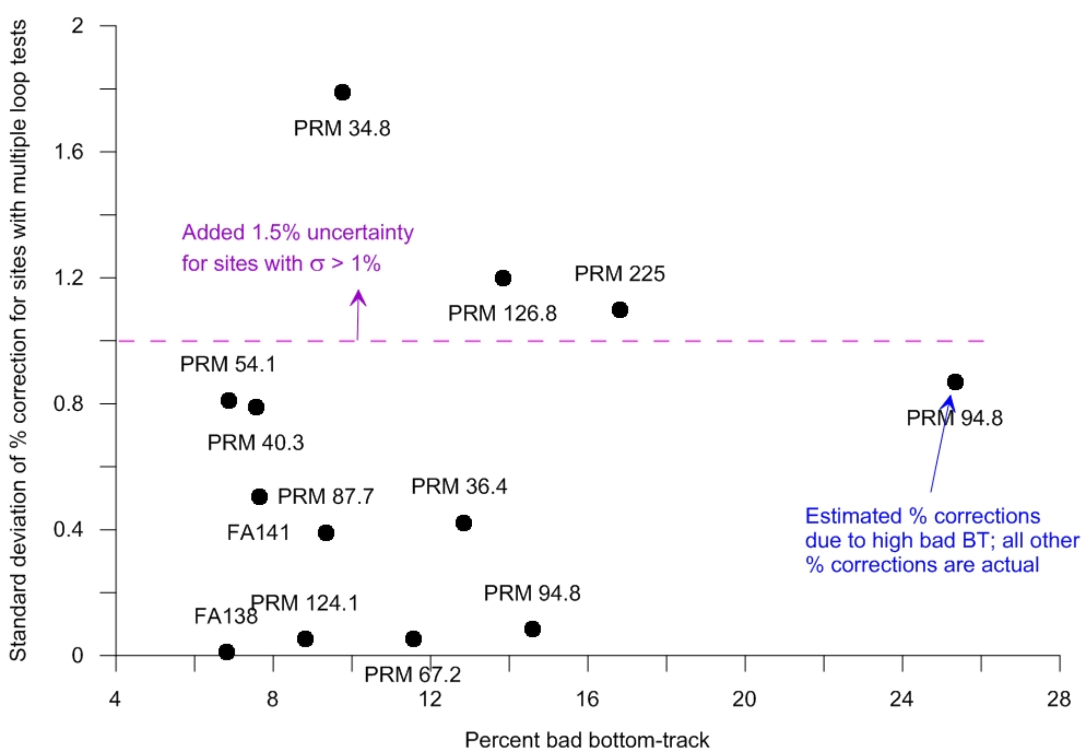


Figure 5. % Bad Bottom-Track vs. Standard Deviation of Loop Test % Correction.

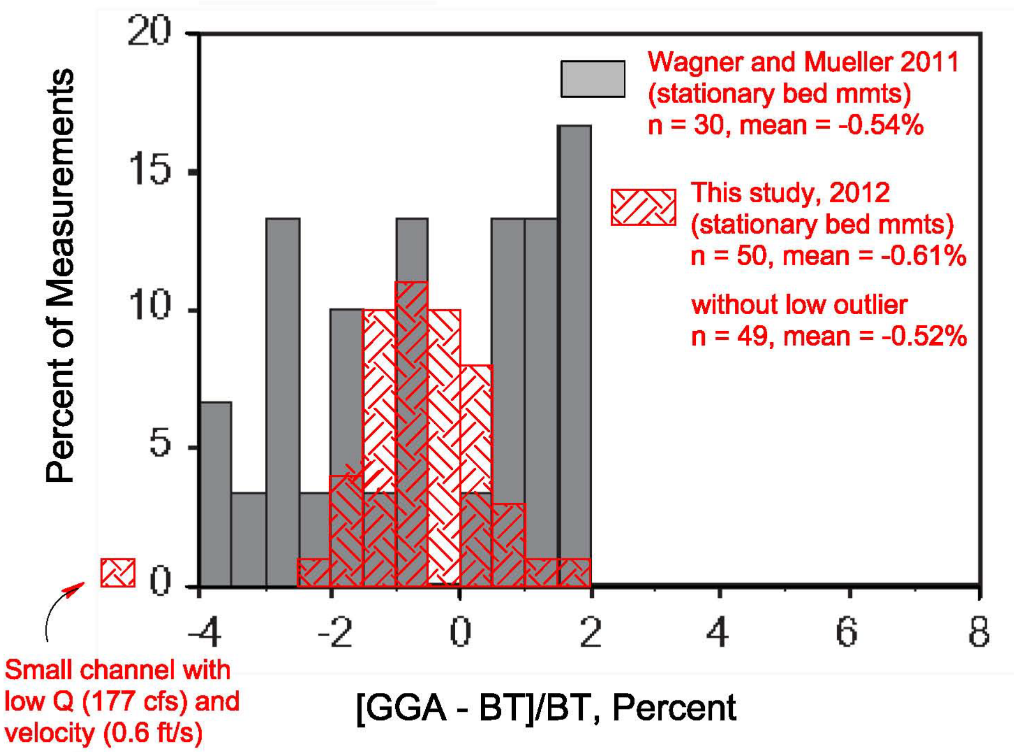


Figure 6. Accuracy of 2012 Stationary Bed GGA Measurements.

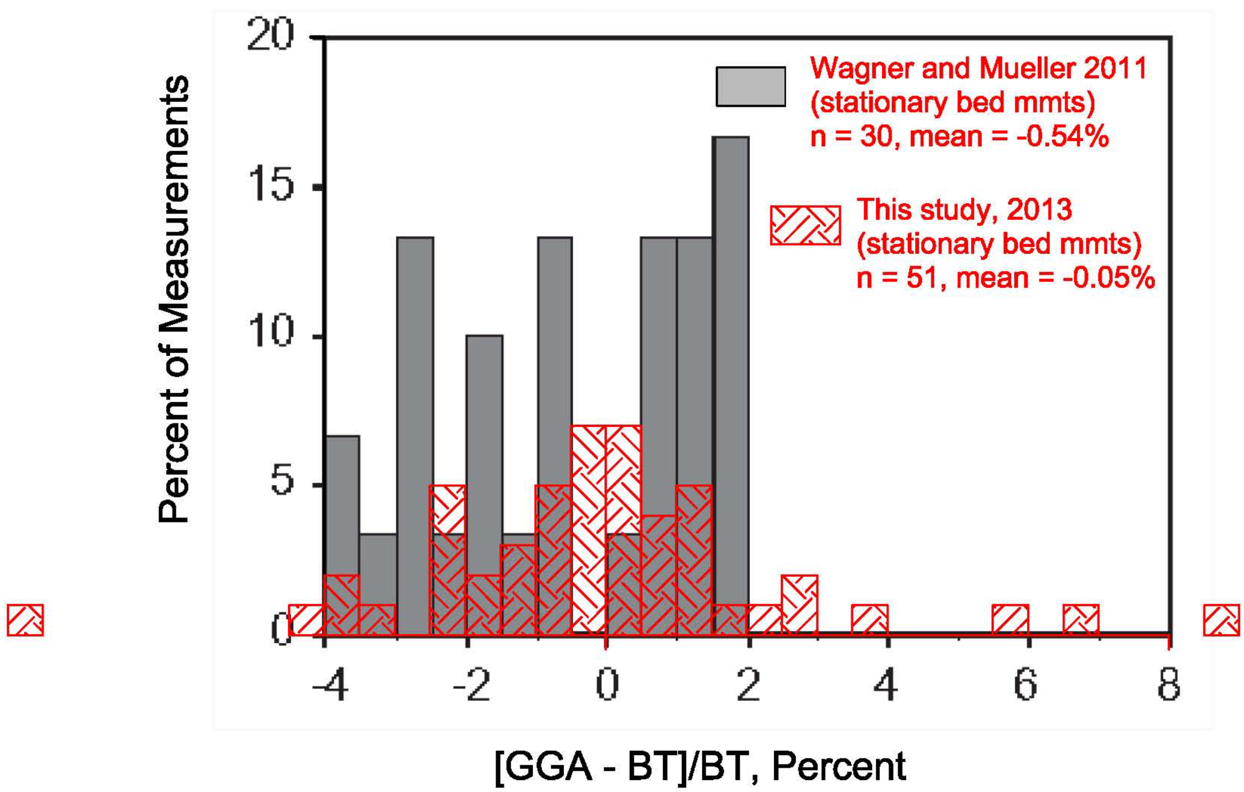


Figure 7. Accuracy of 2013 Stationary Bed GGA Measurements.

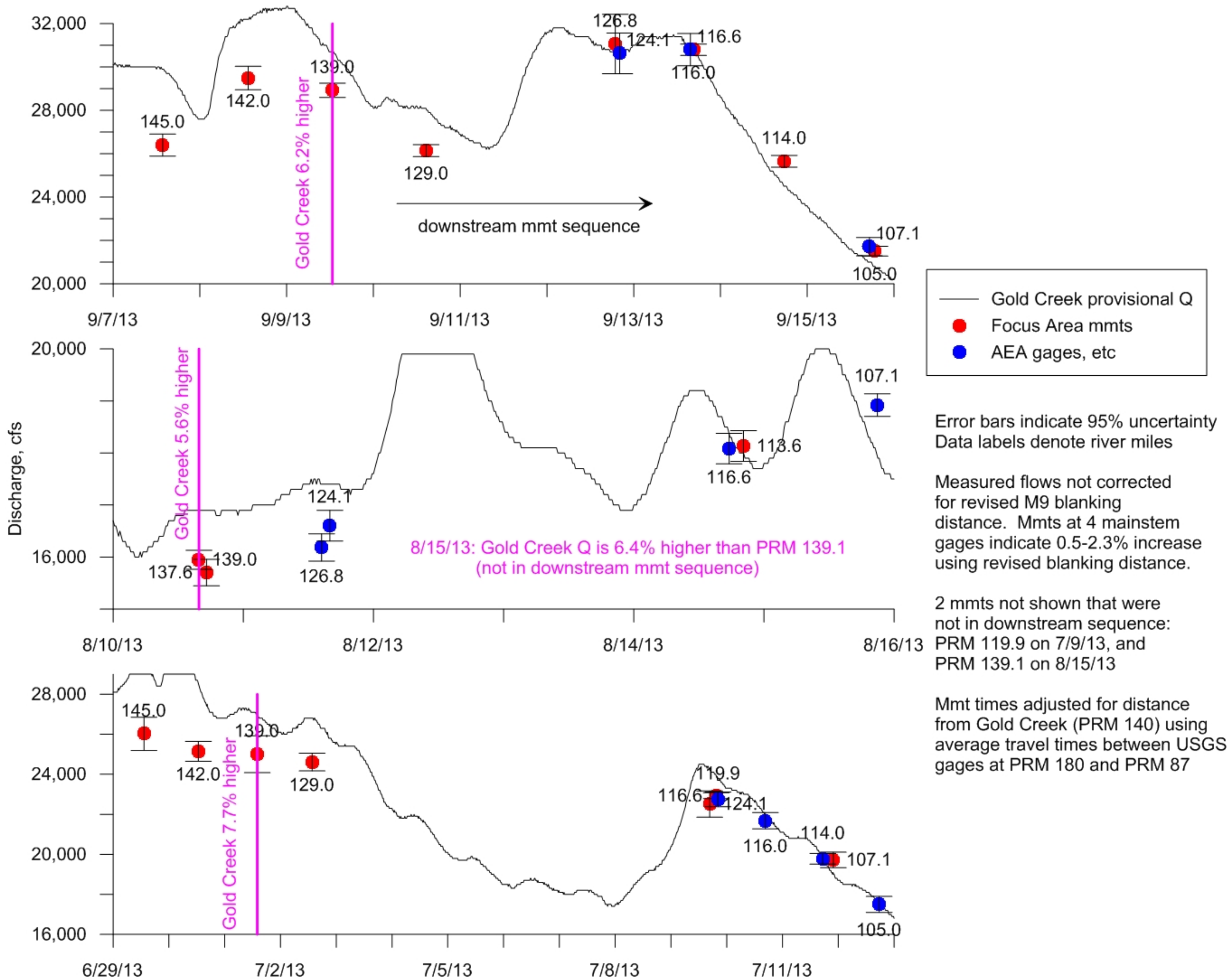


Figure 8. Gold Creek vs. Middle River Discharge Measurements.

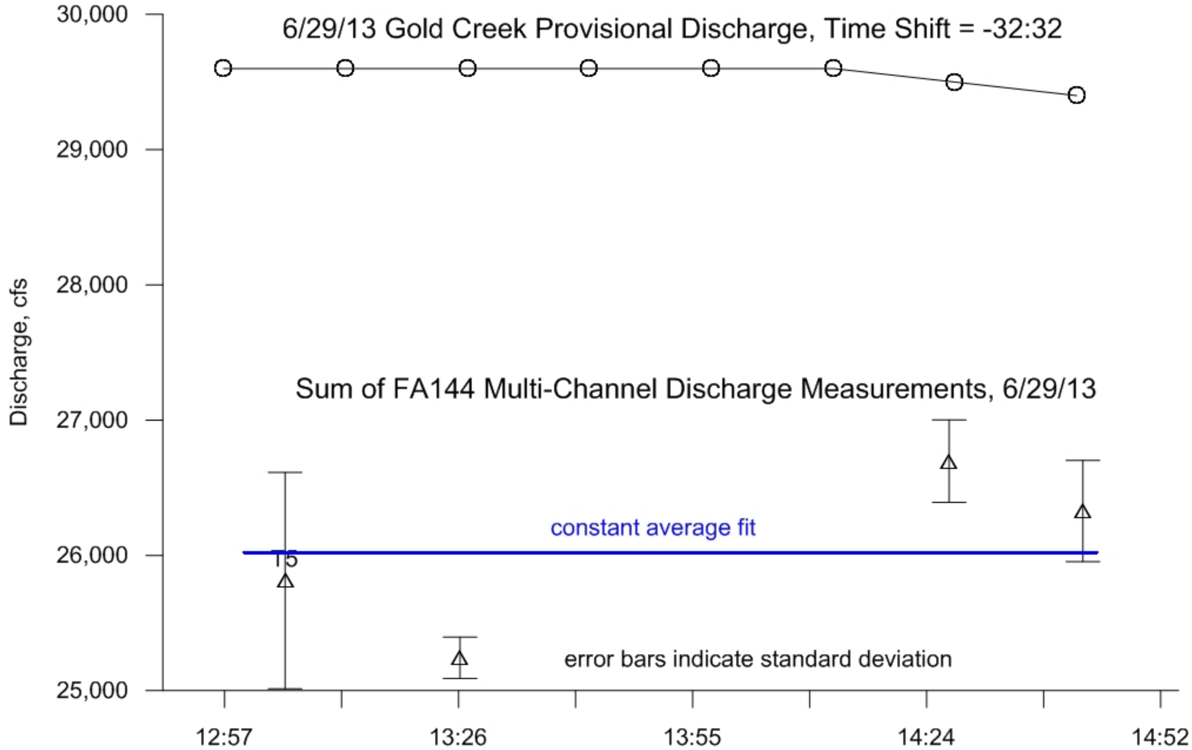


Figure 9. FA-144 (Slough 21) Best Fit Lines, June/July Field Campaign.

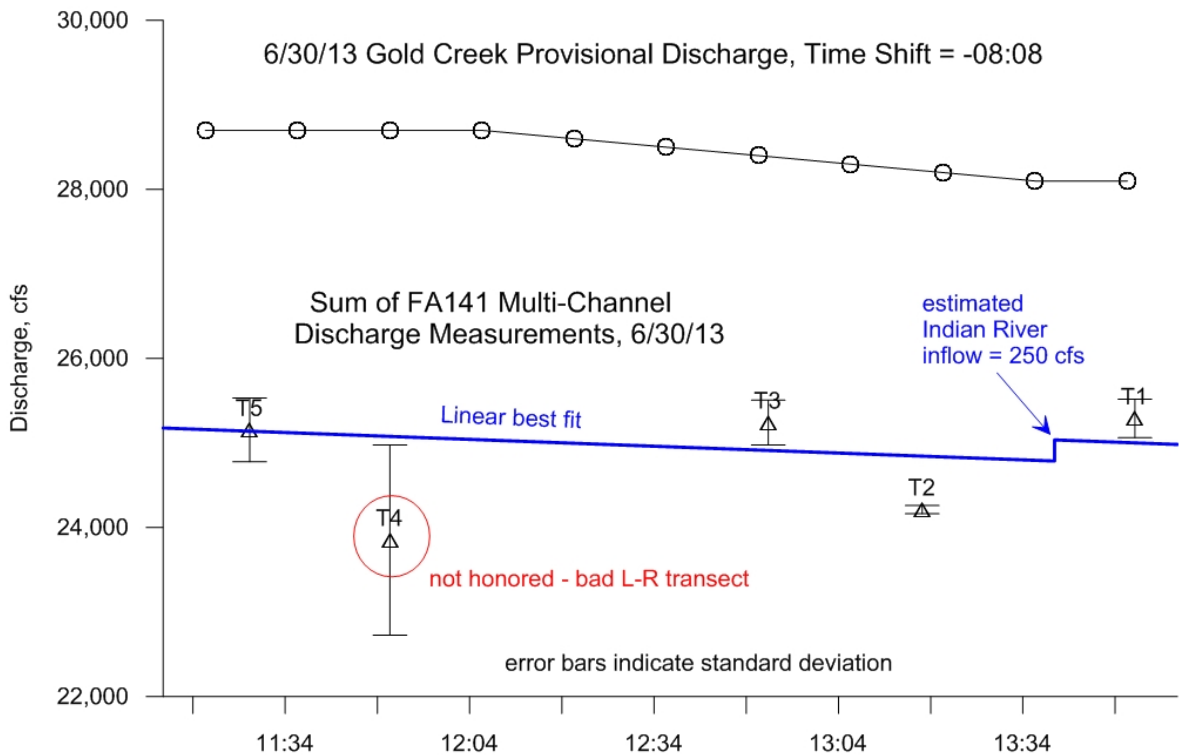


Figure 10. FA-141 (Indian River) Best Fit Lines, June/July Field Campaign.

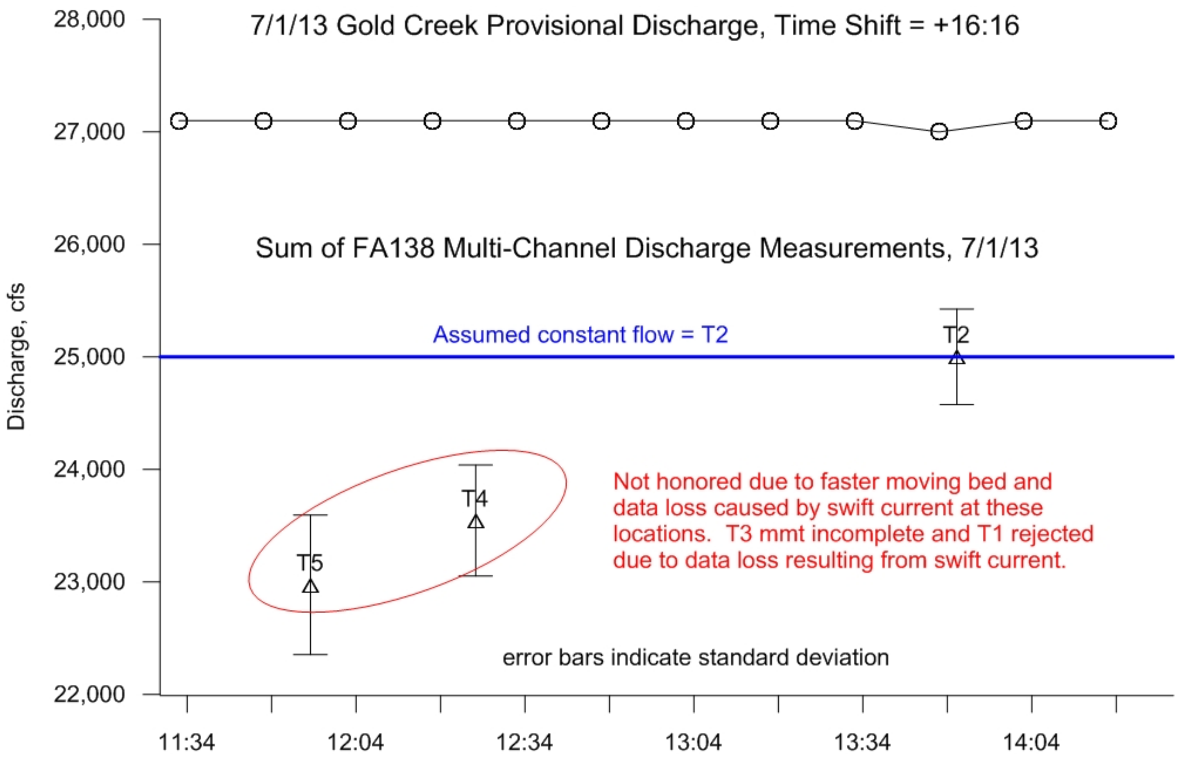


Figure 11. FA-138 (Gold Creek) Best Fit Lines, June/July Field Campaign.

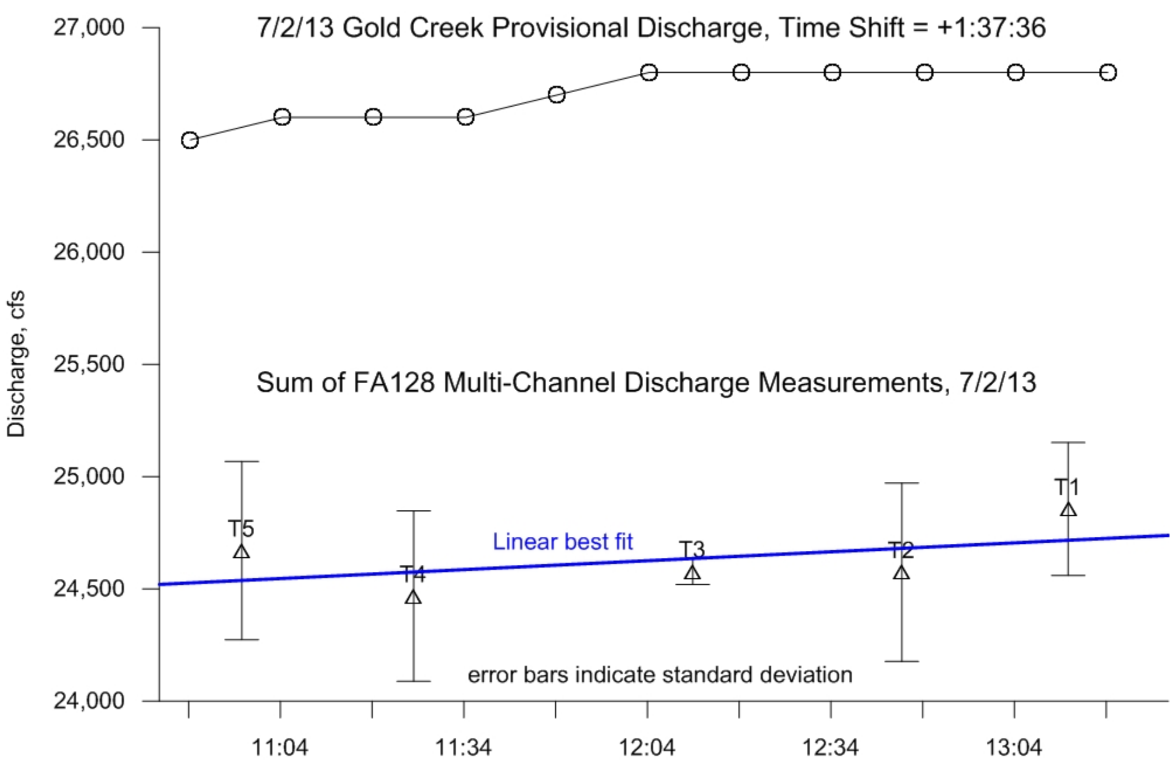


Figure 12. FA-128 (Slough 8A) Best Fit Lines, June/July Field Campaign.

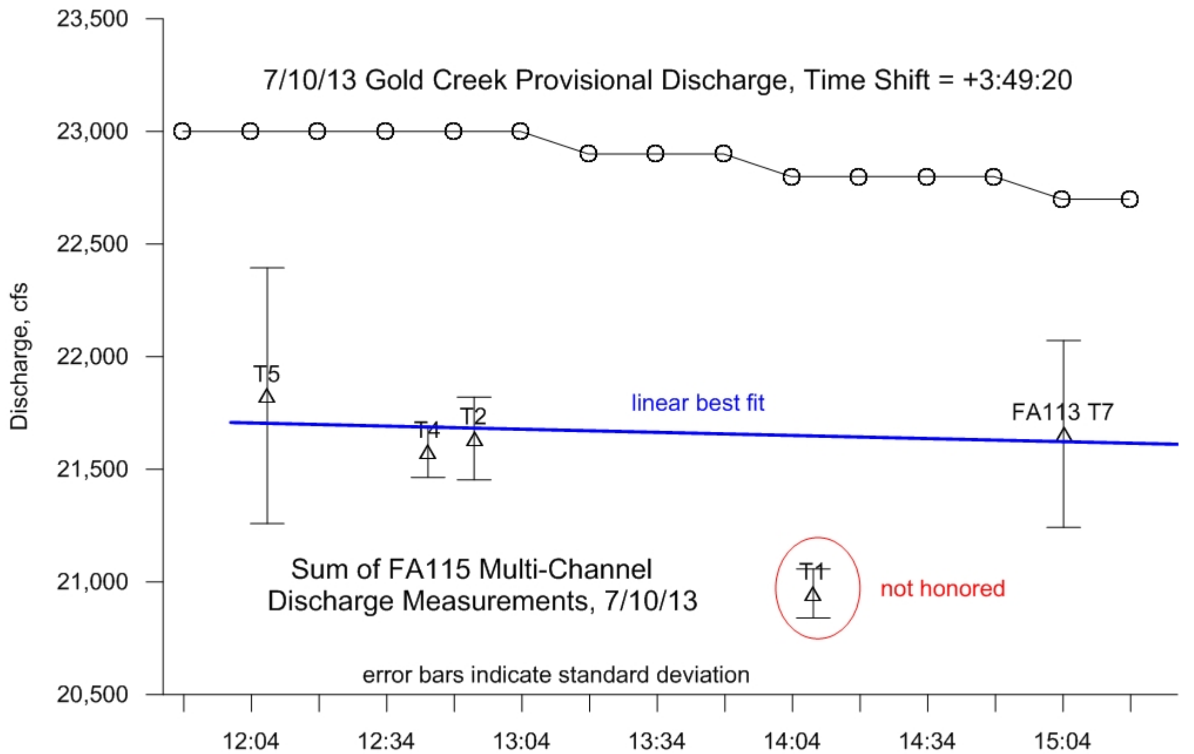


Figure 13. FA-115 (Slough 6A) Best Fit Lines, June/July Field Campaign.

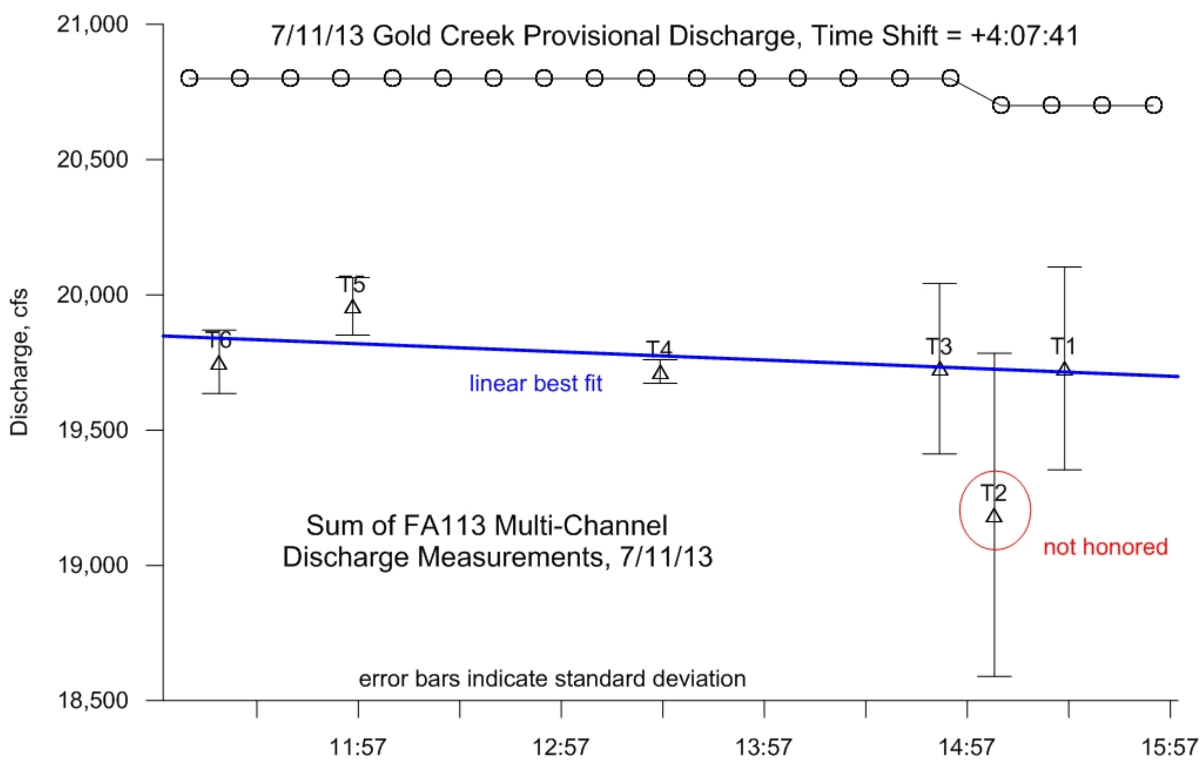


Figure 14. FA-113 (Oxbow 1) Best Fit Lines, June/July Field Campaign.

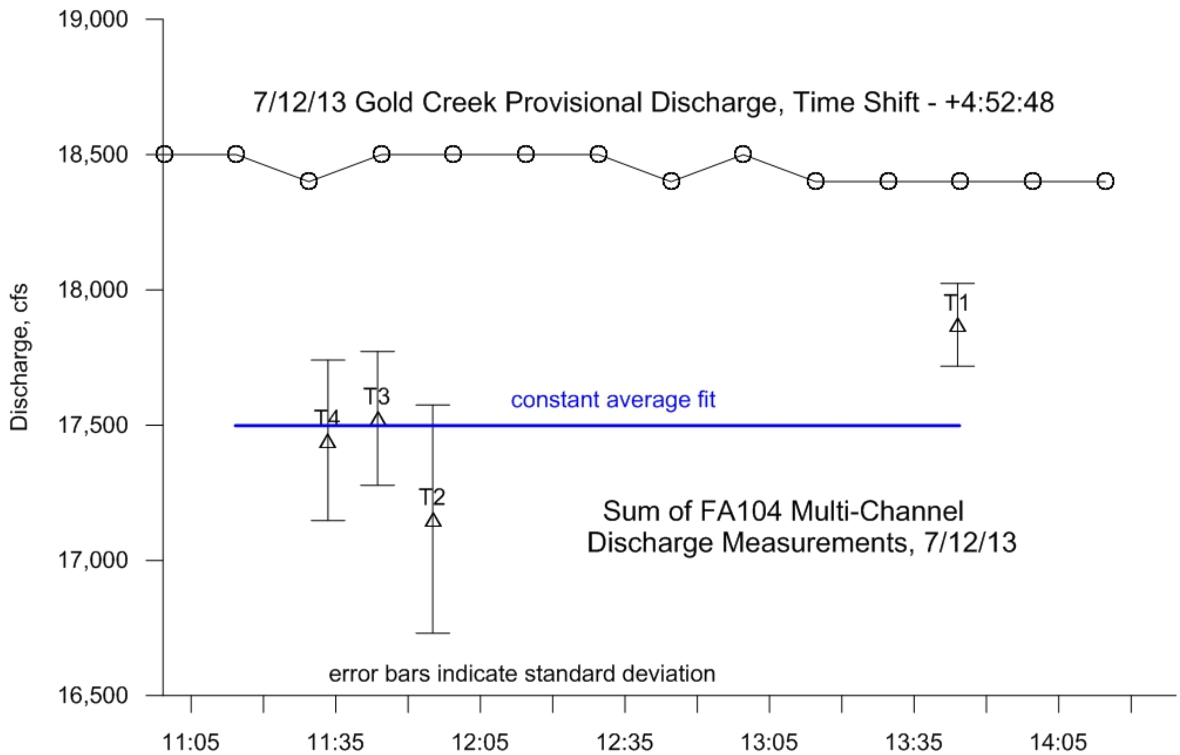


Figure 15. FA-104 (Whiskers Slough) Best Fit Lines, June/July Field Campaign.

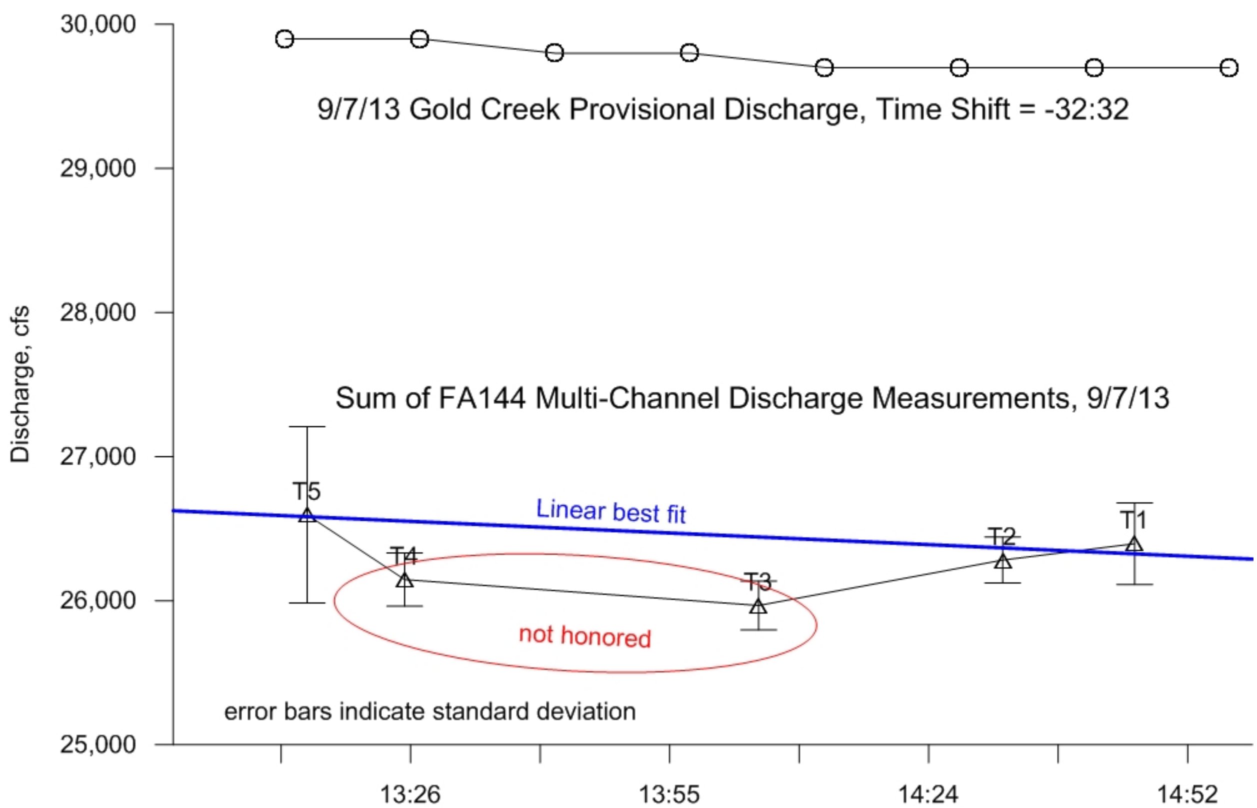


Figure 16. FA-144 (Slough 21) Best Fit Lines, September Field Campaign.

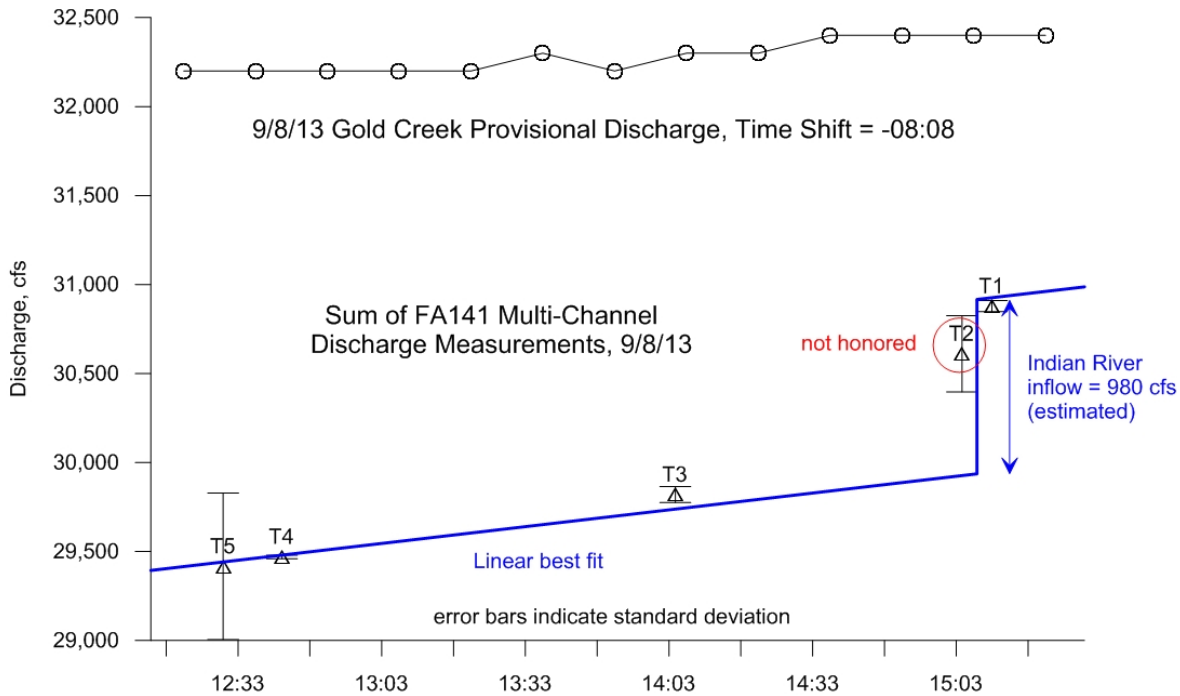


Figure 17. FA-141 (Indian River) Best Fit Lines, September Field Campaign.

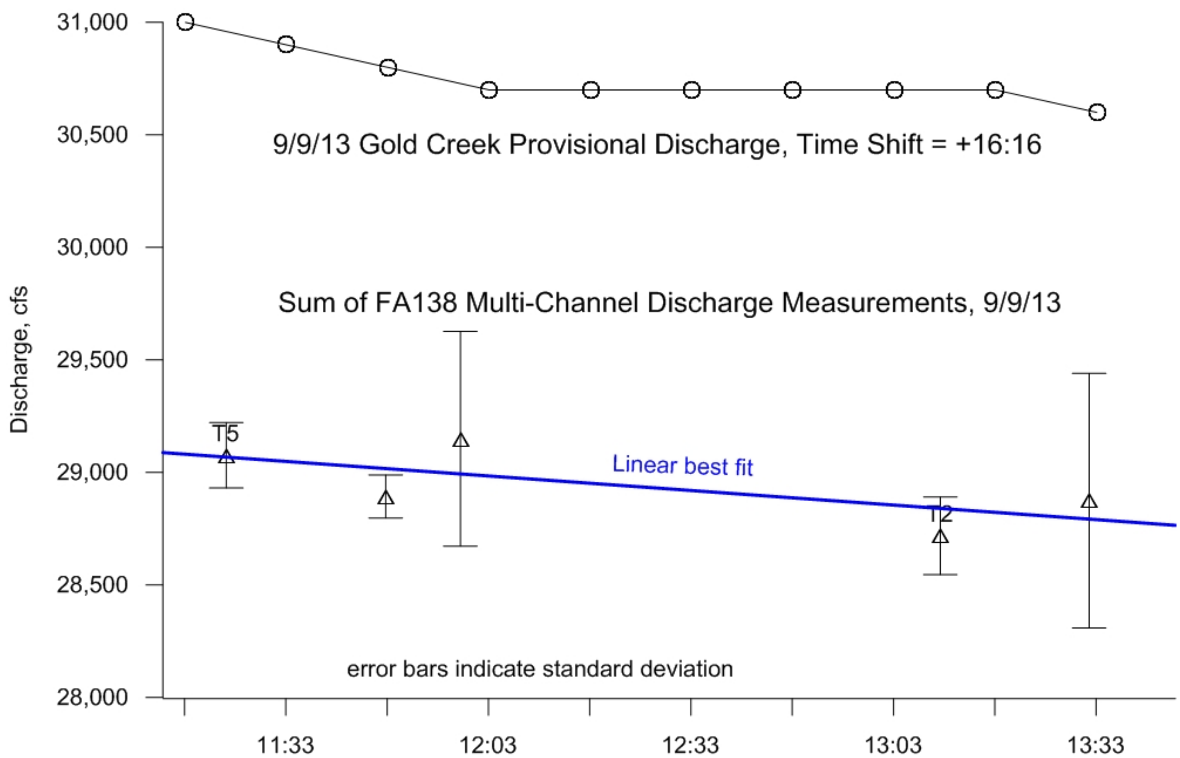


Figure 18. FA-138 (Gold Creek) Best Fit Lines, September Field Campaign.

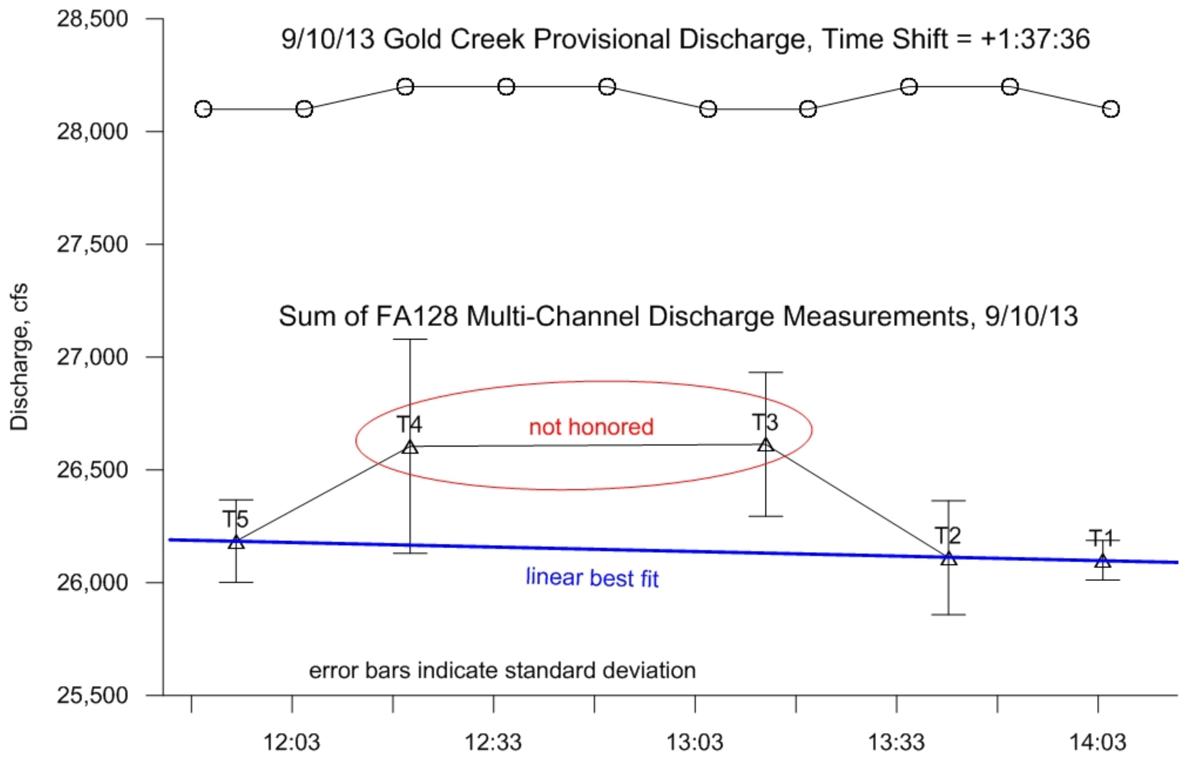


Figure 19. FA-128 (Slough 8A) Best Fit Lines, September Field Campaign.

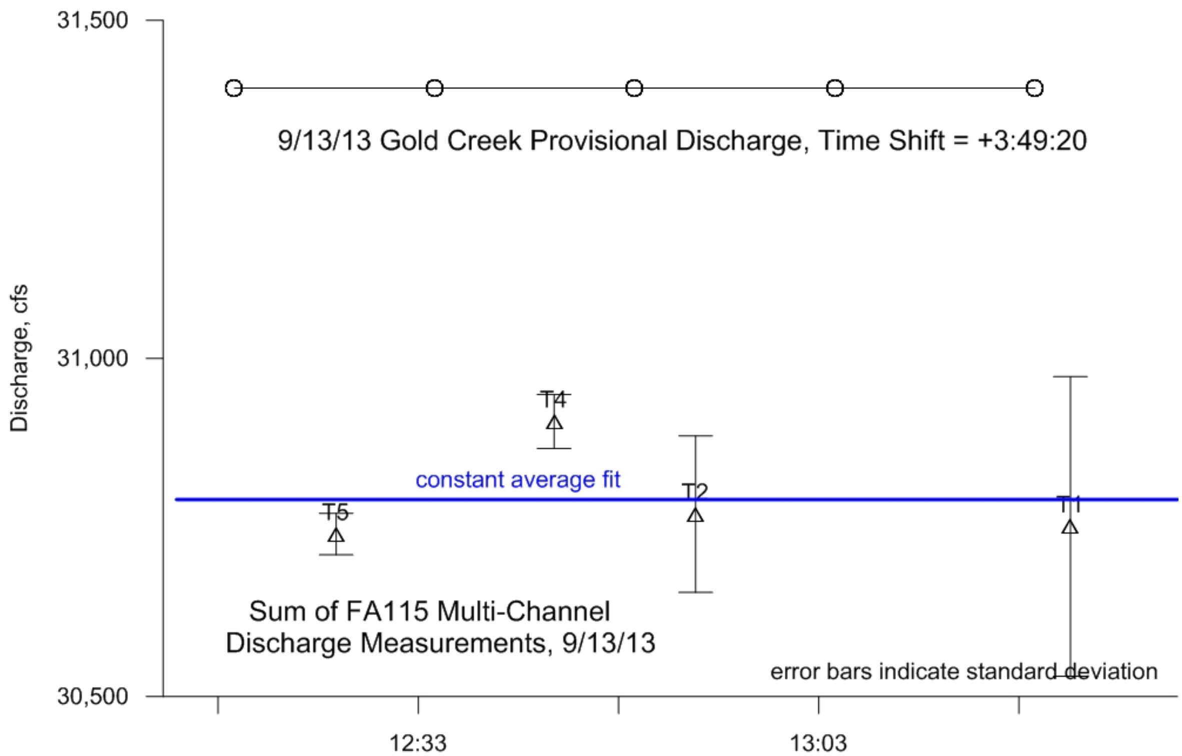


Figure 20. FA-115 (Slough 6A) Best Fit Lines, September Field Campaign.

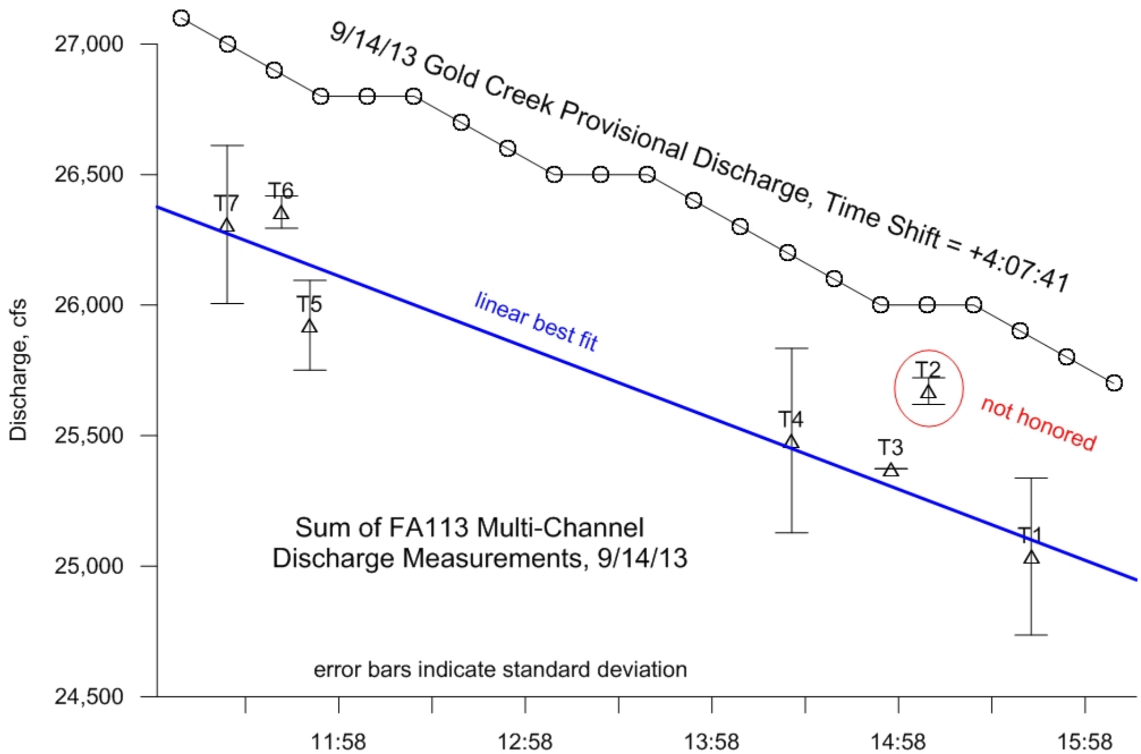


Figure 21. FA-113 (Oxbow 1) Best Fit Lines, September Field Campaign.

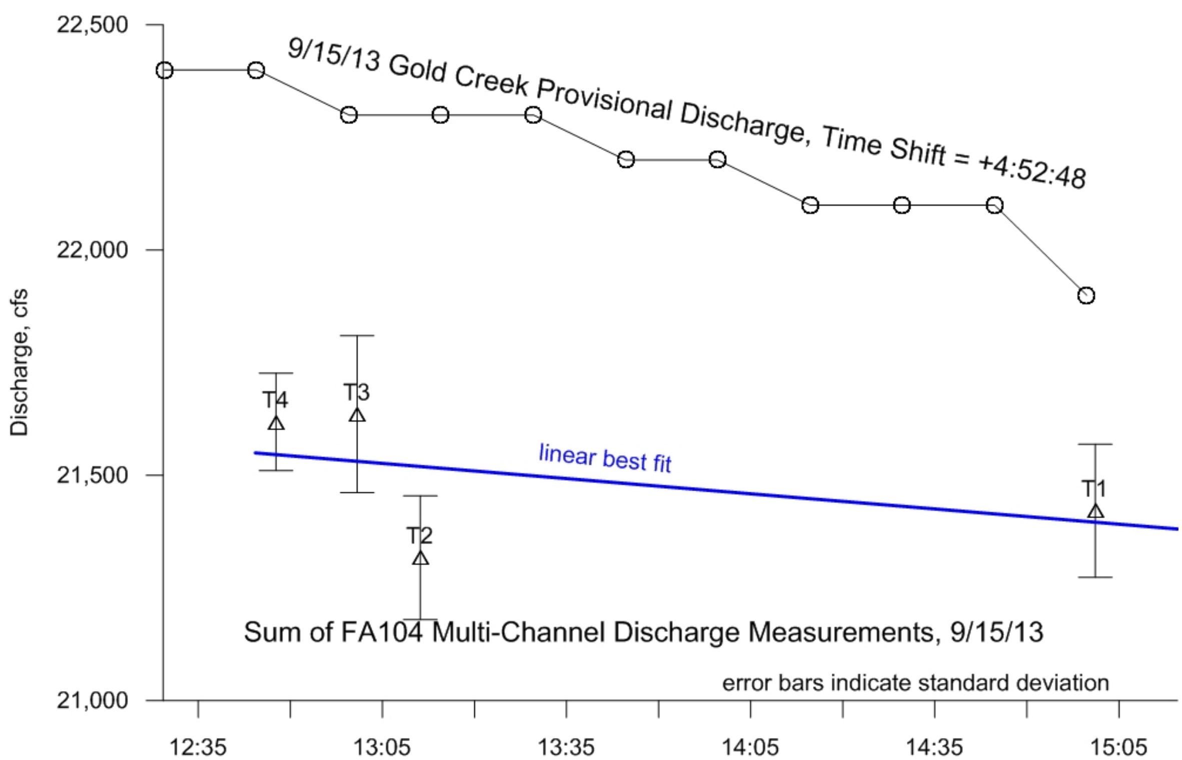


Figure 22. FA-104 (Whiskers Slough) Best Fit Lines, September Field Campaign.

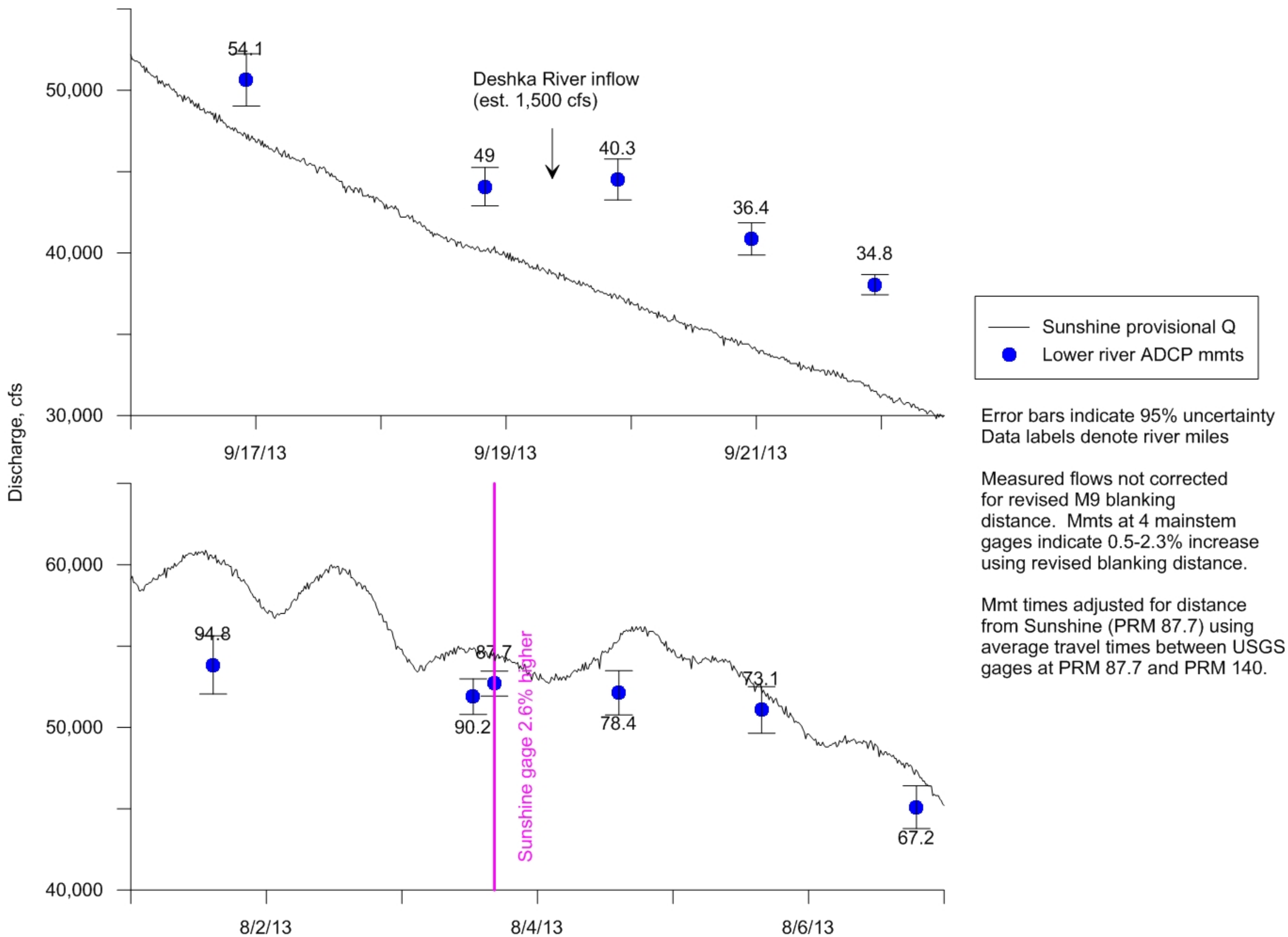


Figure 23. Sunshine vs. Lower River Discharge Measurements.

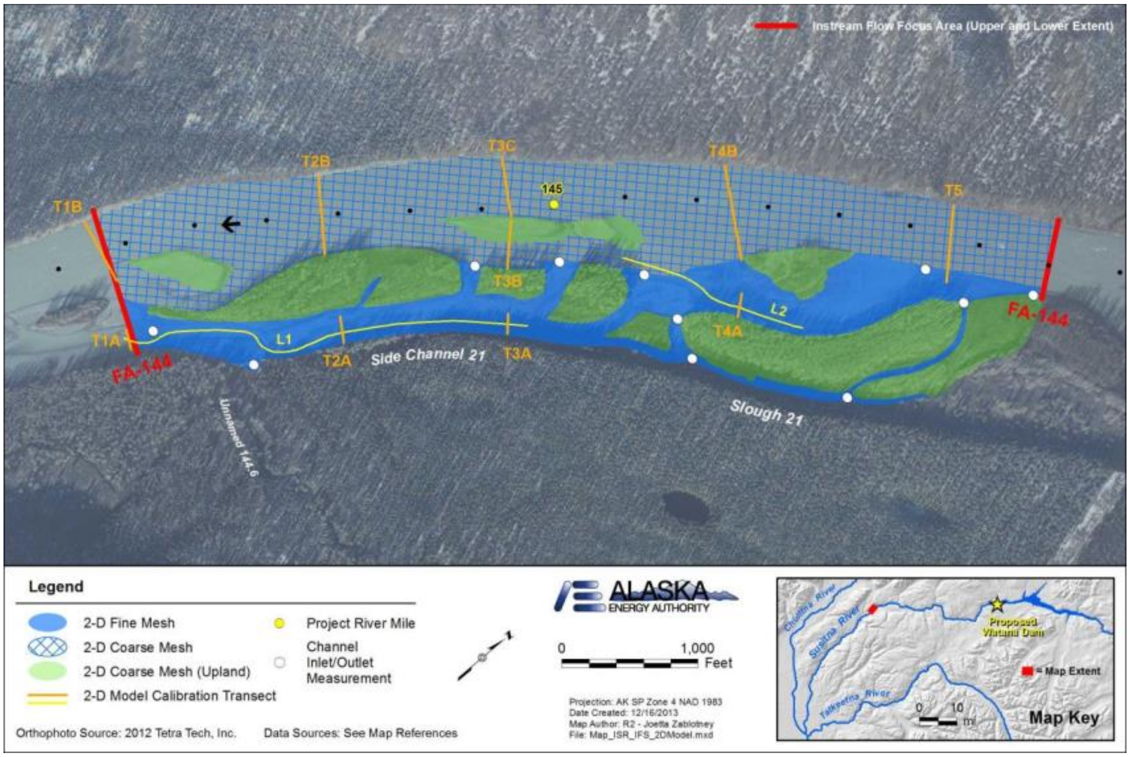


Figure 24. 2-D Model Flow Measurement Locations – FA-144 (Slough 21).

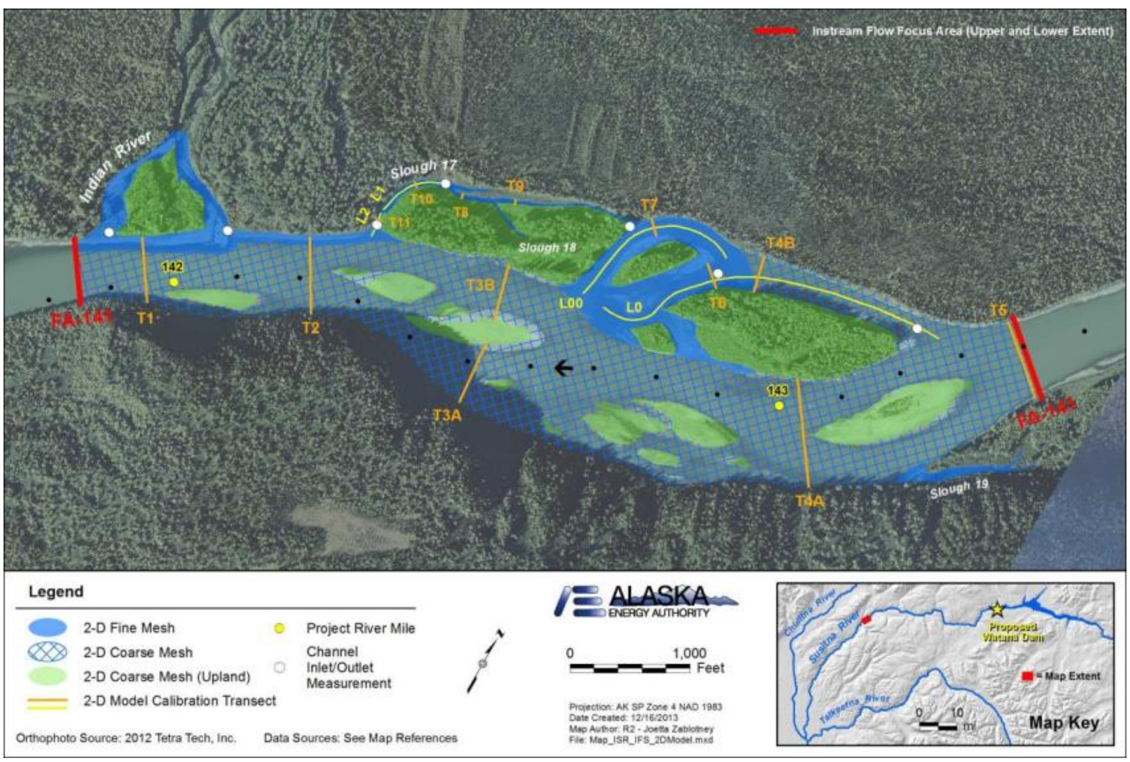


Figure 25. 2-D Model Flow Measurement Locations – FA-141 (Indian River).

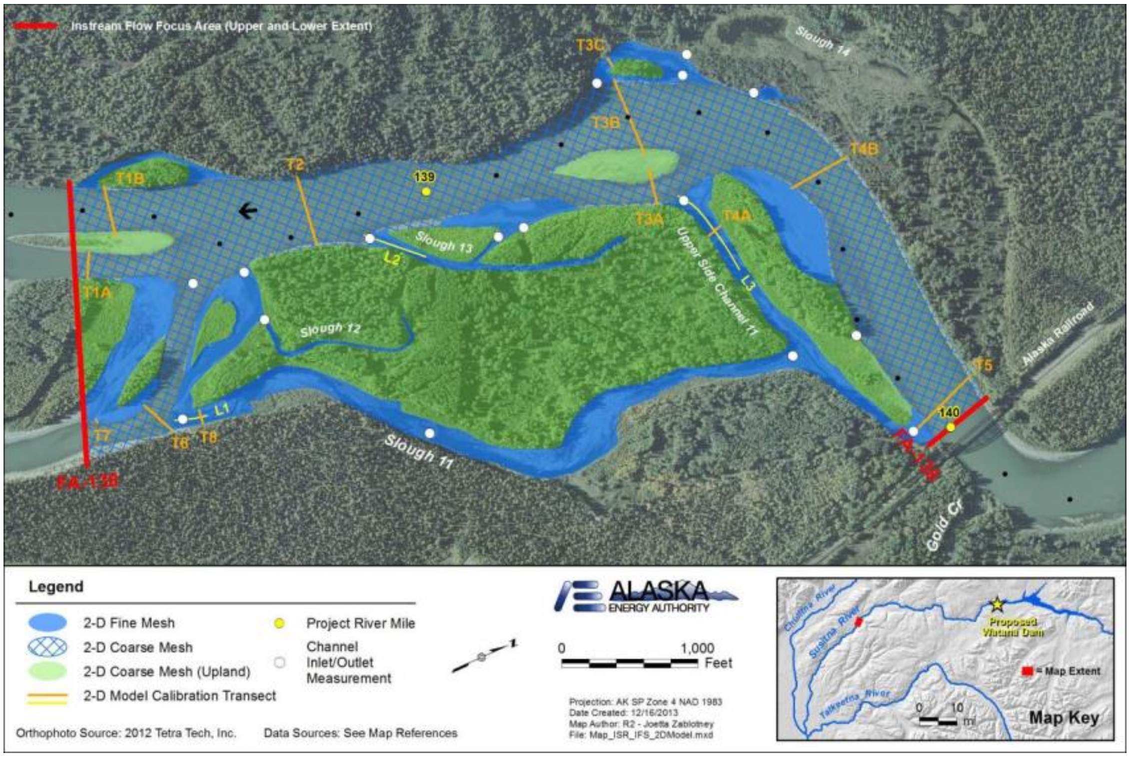


Figure 26. 2-D Model Flow Measurement Locations – FA-138 (Gold Creek).

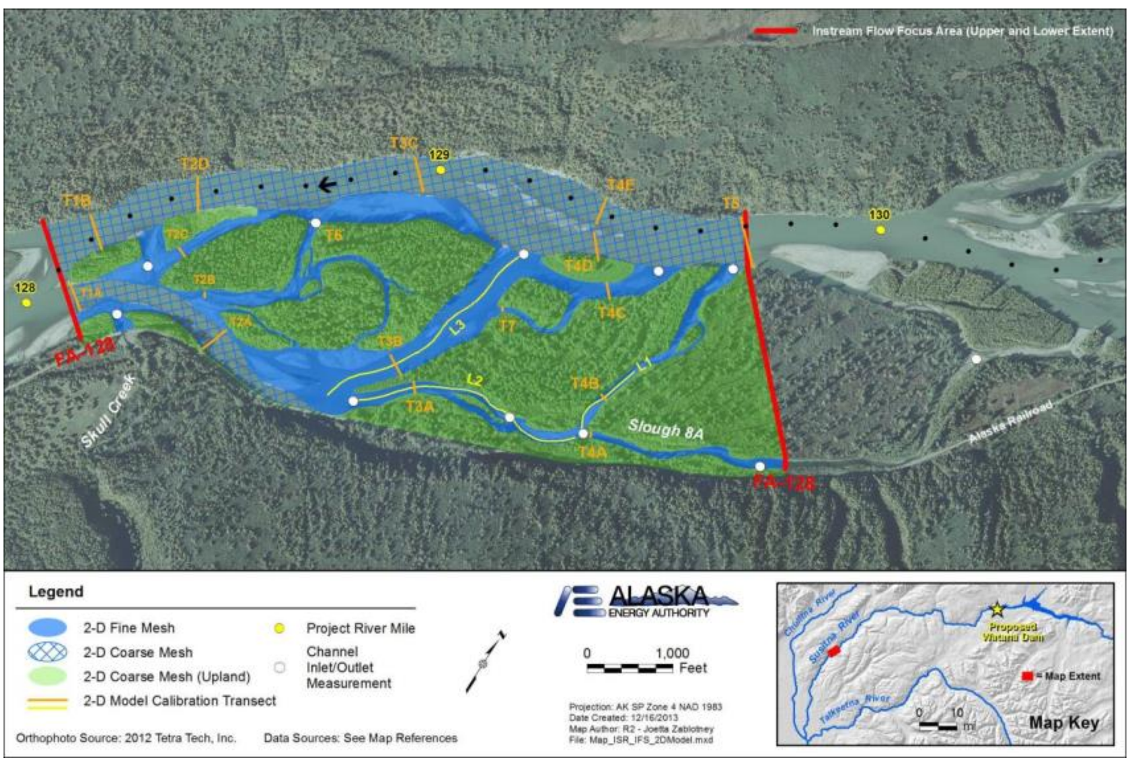


Figure 27. 2-D Model Flow Measurement Locations – FA-128 (Slough 8A).

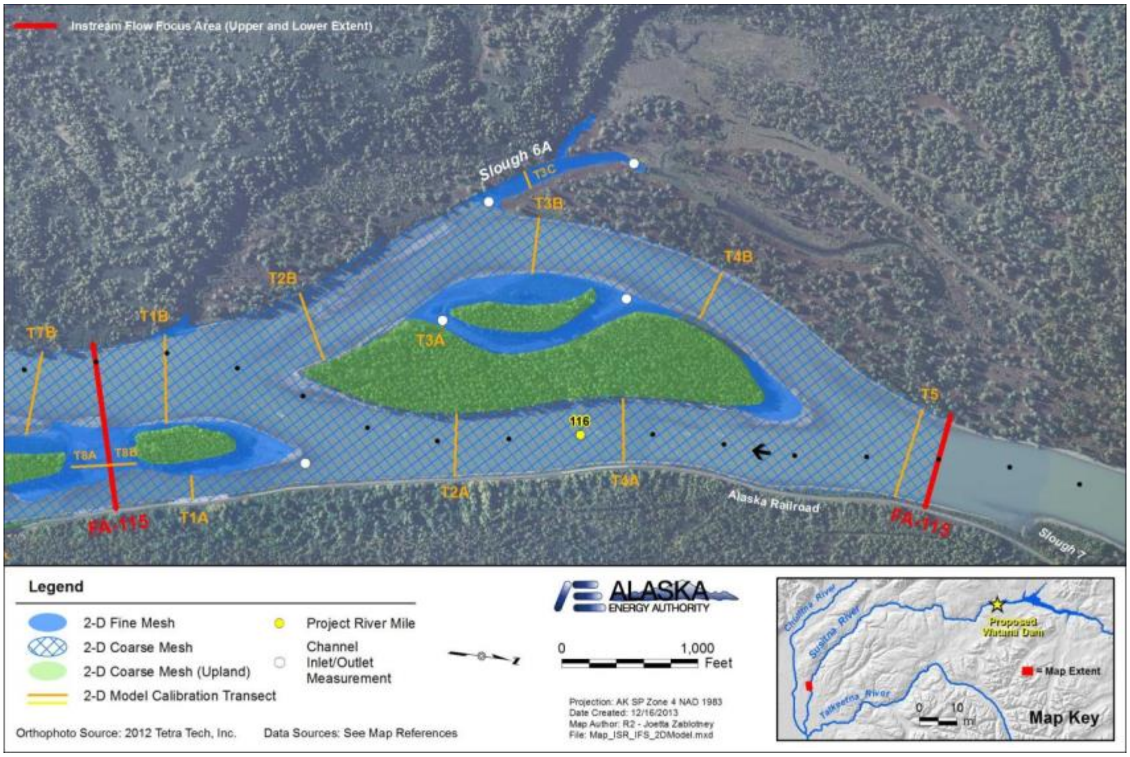


Figure 28. 2-D Model Flow Measurement Locations – FA-115 (Slough 6A).

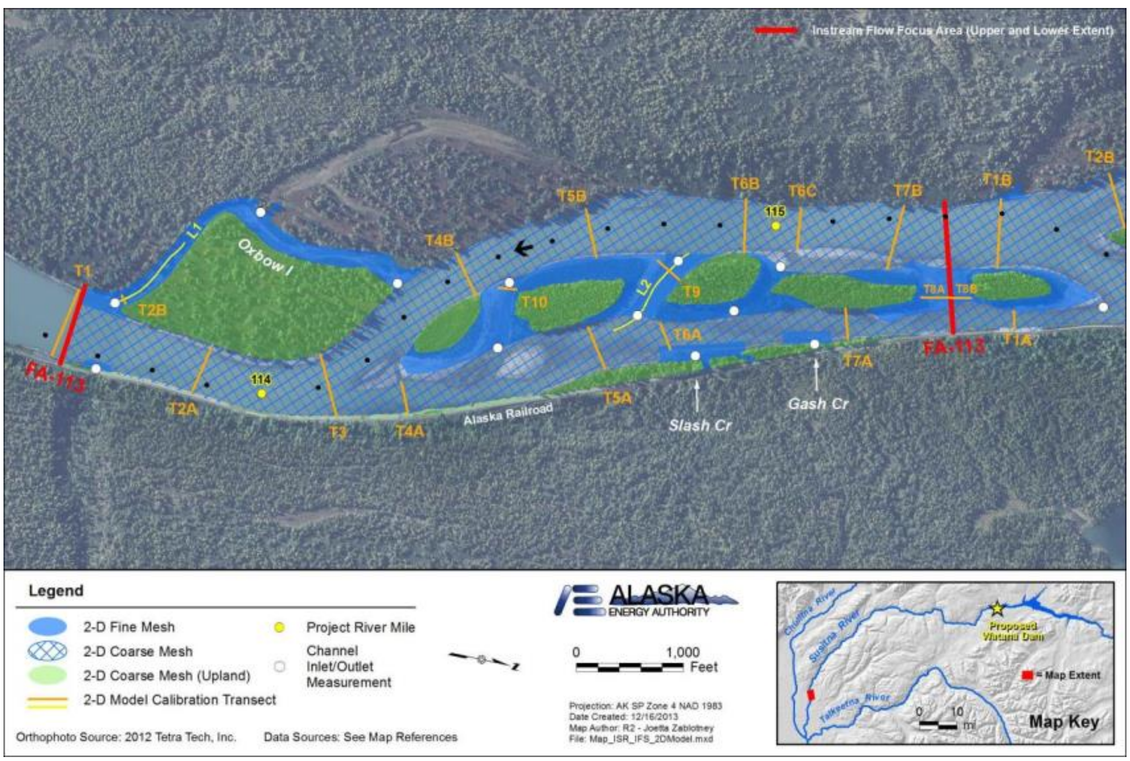


Figure 29. 2-D Model Flow Measurement Locations – FA-113 (Oxbow 1).

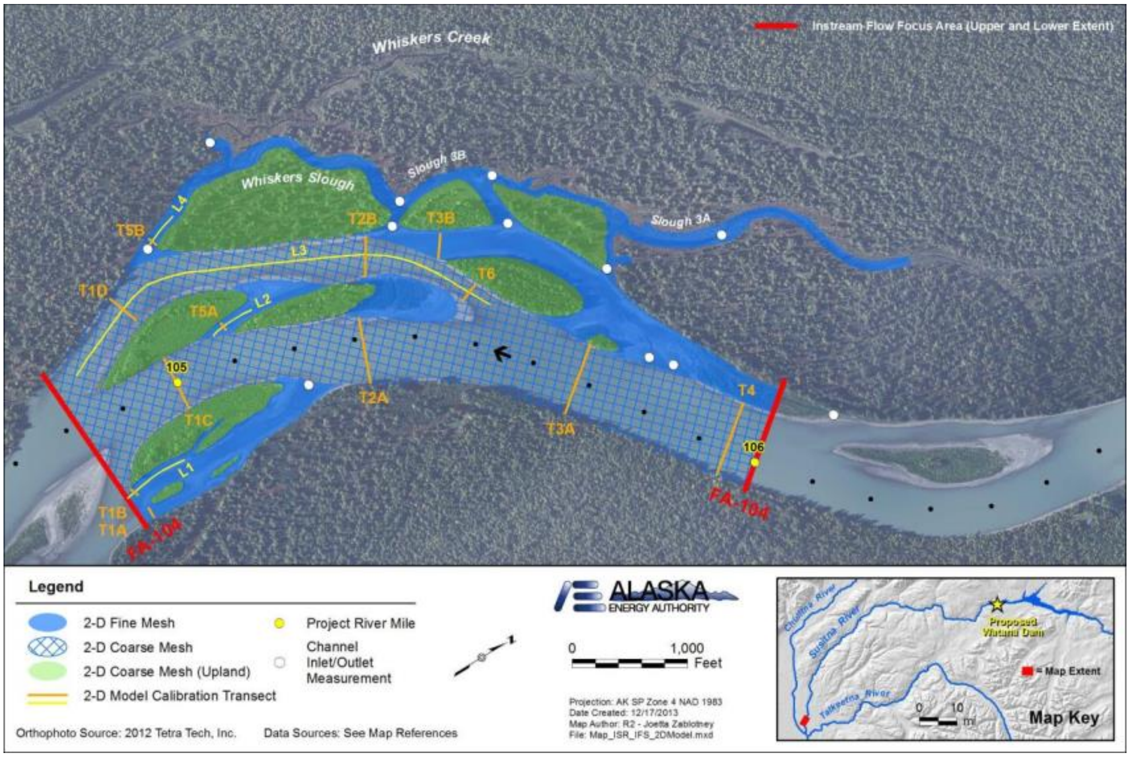


Figure 30. 2-D Model Flow Measurement Locations – FA-104 (Whiskers Slough).

PART A - EXHIBIT 1. LONGITUDINAL VELOCITY PROFILES

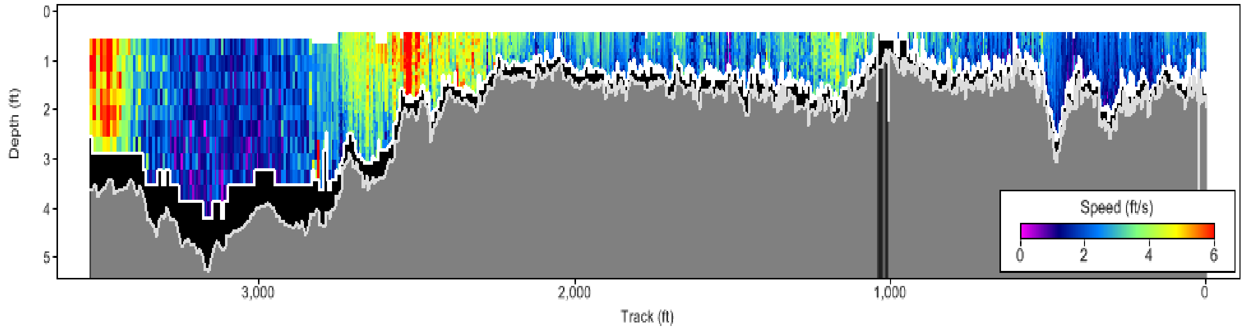


Figure A.1-1. Longitudinal velocity profile L1, FA-144 (Slough 21), June 29, 2013.

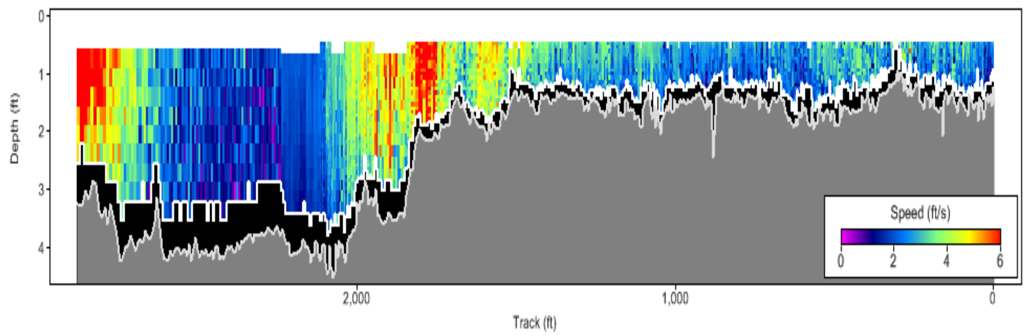


Figure A.1-2. Longitudinal velocity profile L1, FA-144 (Slough 21), September 7, 2013.

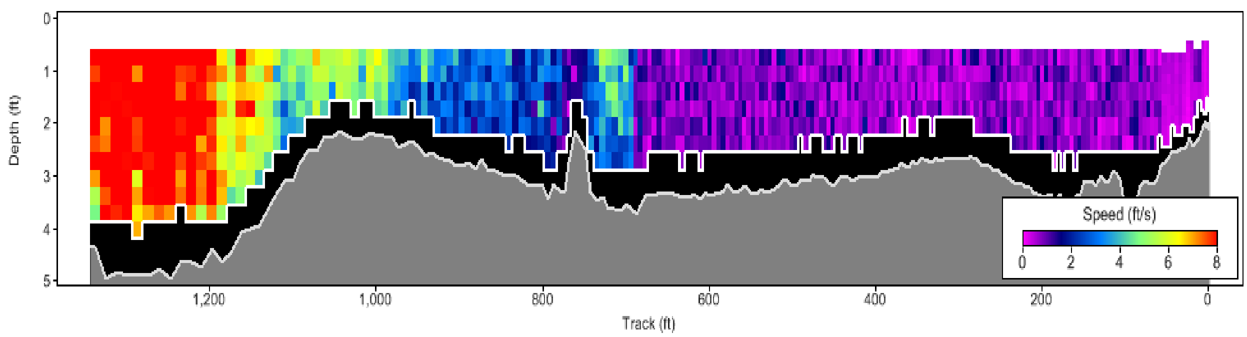


Figure A.1-3. Longitudinal velocity profile L2, FA-144 (Slough 21), June 29, 2013.

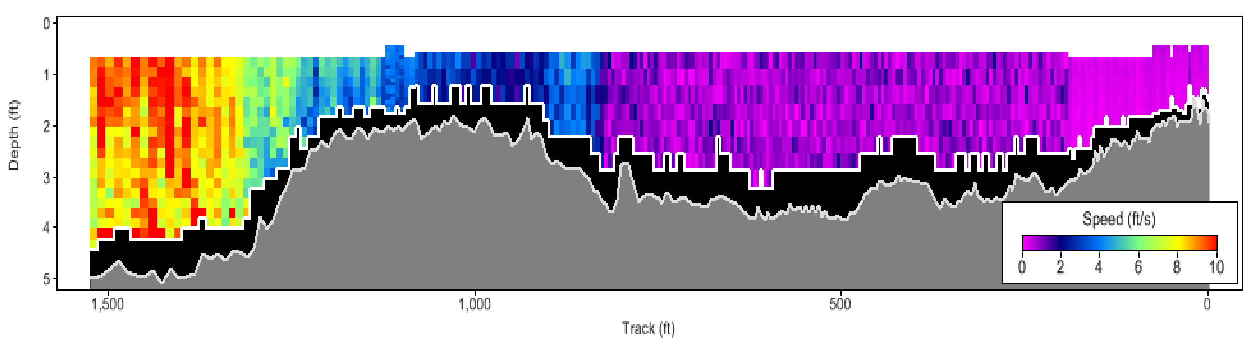


Figure A.1-4. Longitudinal velocity profile L2, FA-144 (Slough 21), September 7, 2013.

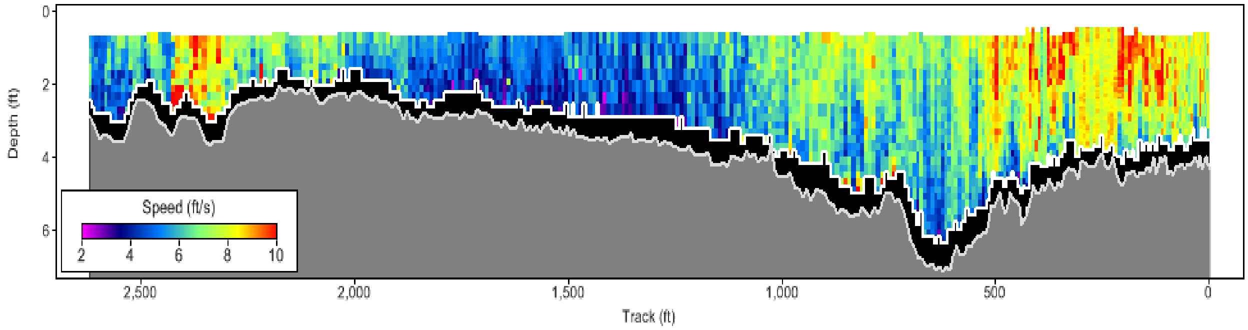


Figure A.2-1. Longitudinal velocity profile L0, FA-141 (Indian River), June 30, 2013.

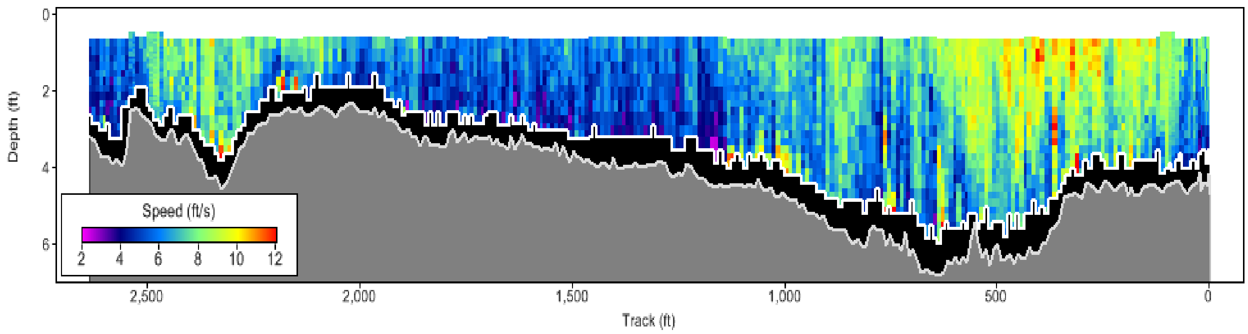


Figure A.2-2. Longitudinal velocity profile L0, FA-141 (Indian River), September 8, 2013.

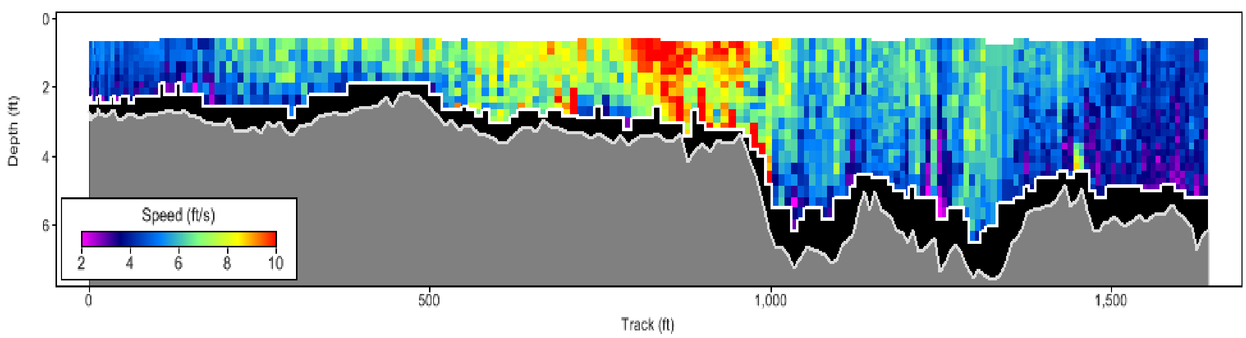


Figure A.2-3. Longitudinal velocity profile L00, FA-141 (Indian River), June 30, 2013.

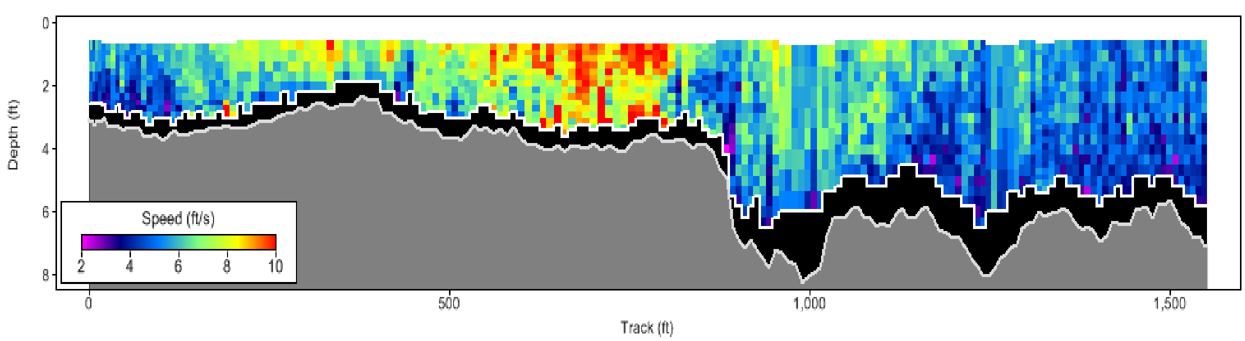


Figure A.2-4. Longitudinal velocity profile L00, FA-141 (Indian River), September 8, 2013.

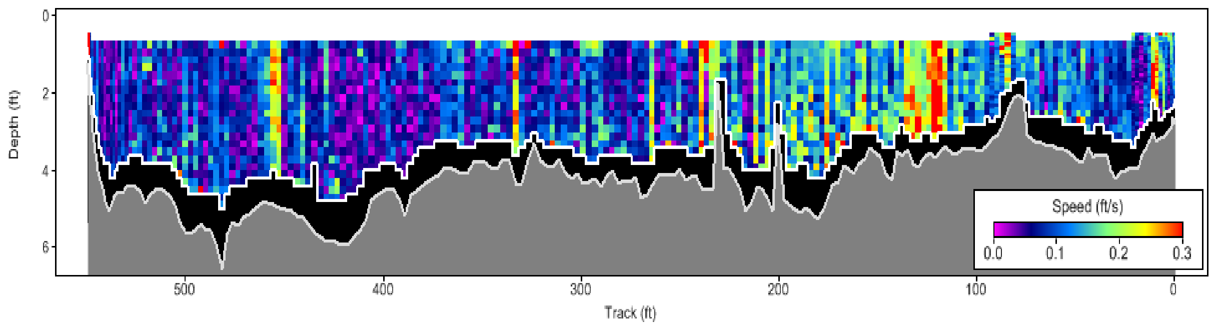


Figure A.2-5. Longitudinal velocity profile L1, FA-141 (Indian River), June 30, 2013.

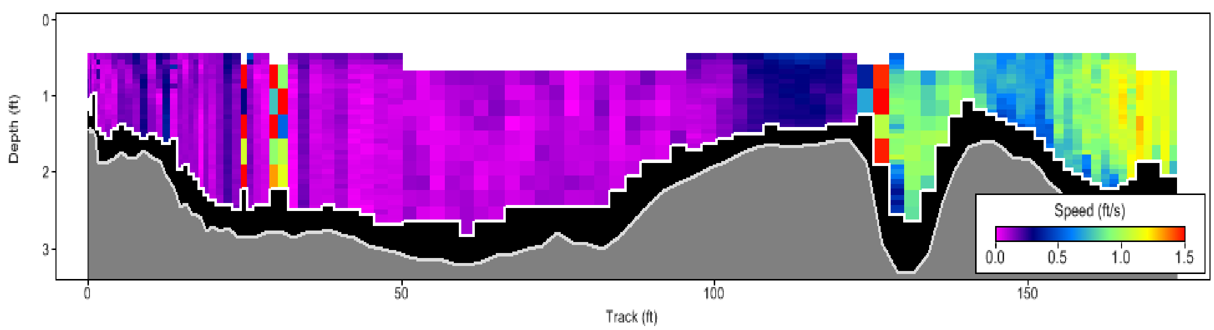


Figure A.2-6. Longitudinal velocity profile L2, FA-141 (Indian River), June 30, 2013.

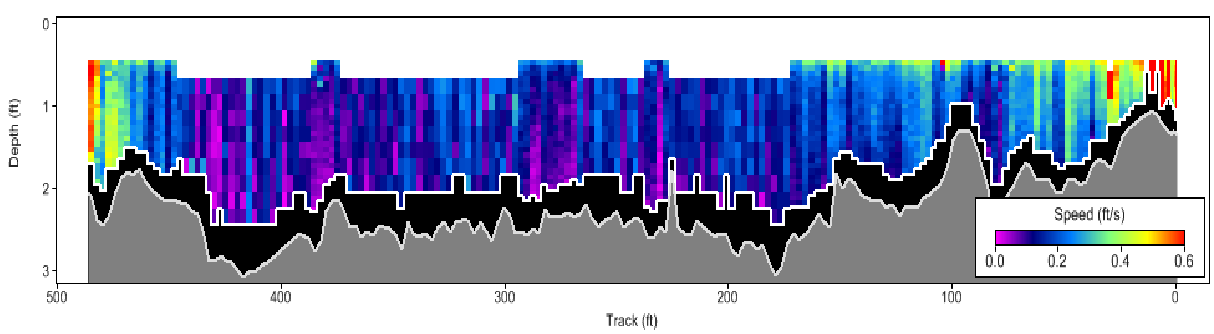


Figure A.3-1. Longitudinal velocity profile L1, FA-138 (Gold Creek), July 1, 2013.

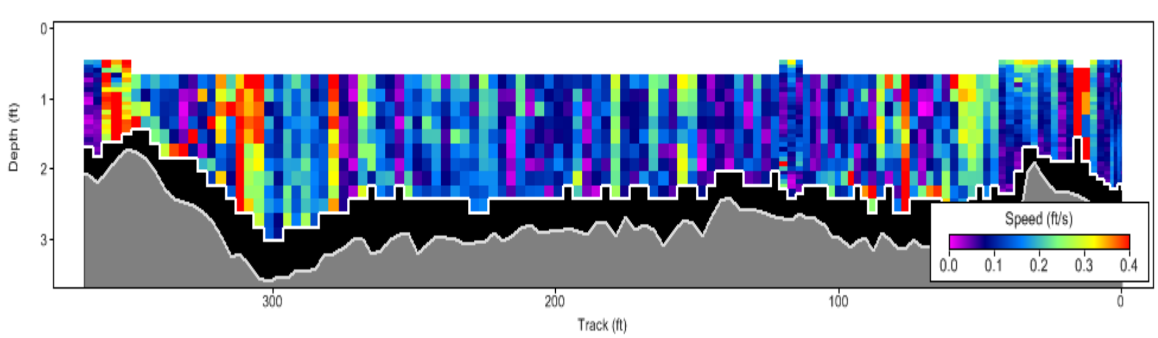


Figure A.3-2. Longitudinal velocity profile L1, FA-138 (Gold Creek), September 9, 2013.

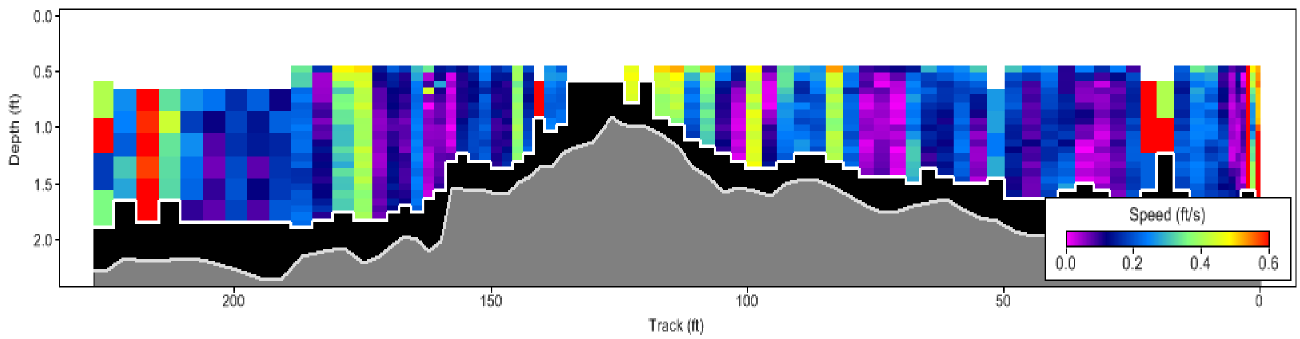


Figure A.3-3. Longitudinal velocity profile L2, FA-138 (Gold Creek), July 1, 2013.

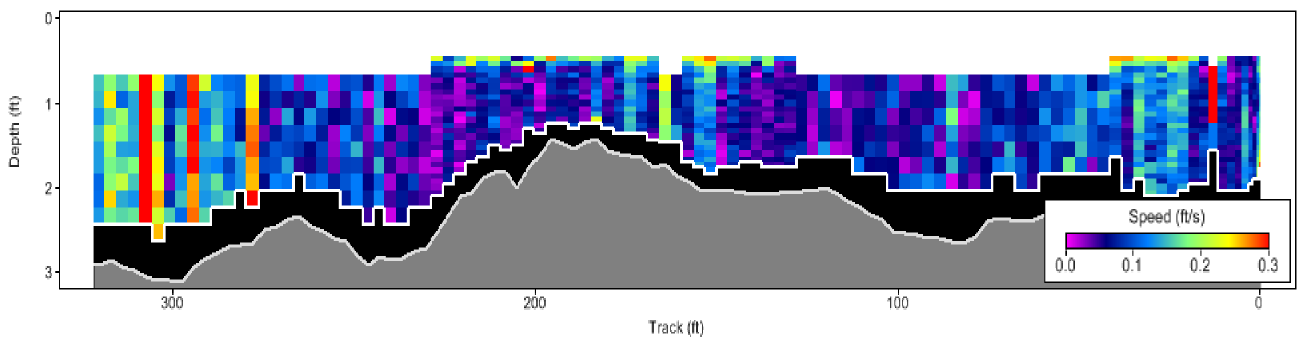


Figure A.3-4. Longitudinal velocity profile L2, FA-138 (Gold Creek), September 9, 2013.

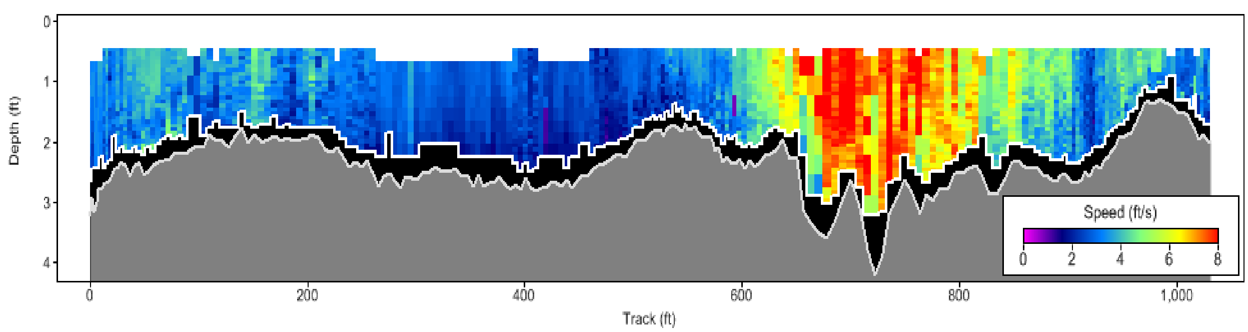


Figure A.4-1. Longitudinal velocity profile L1, FA-128 (Slough 8A), July 2, 2013.

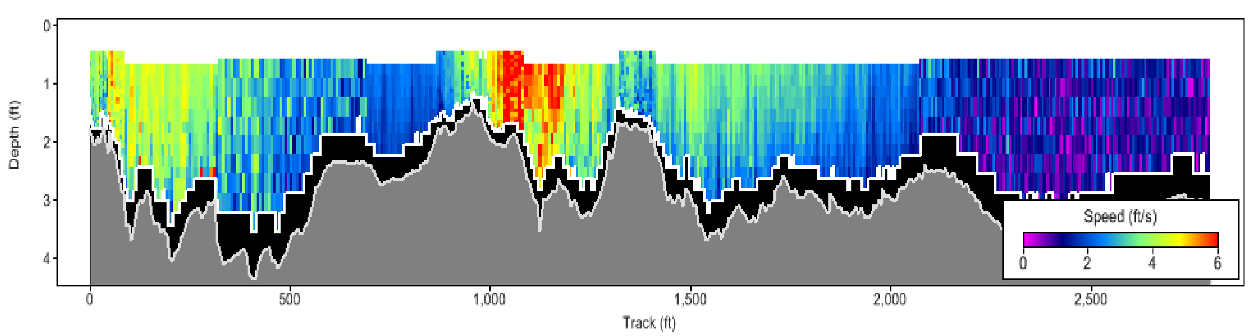


Figure A.4-2. Longitudinal velocity profile L2, FA-128 (Slough 8A), July 2, 2013.

(upper half of Slough 8A blocked by fallen log on 9/10/13)

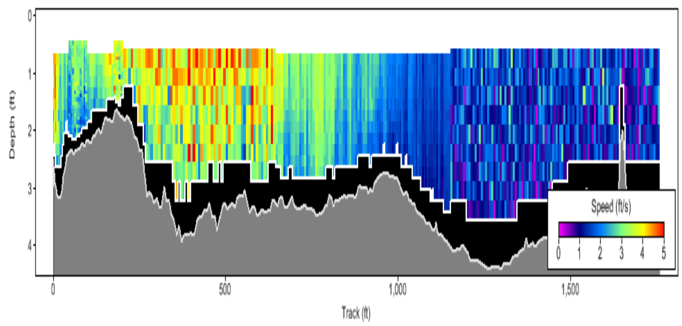


Figure A.4-3. Longitudinal velocity profile L2, FA-128 (Slough 8A), September 10, 2013.

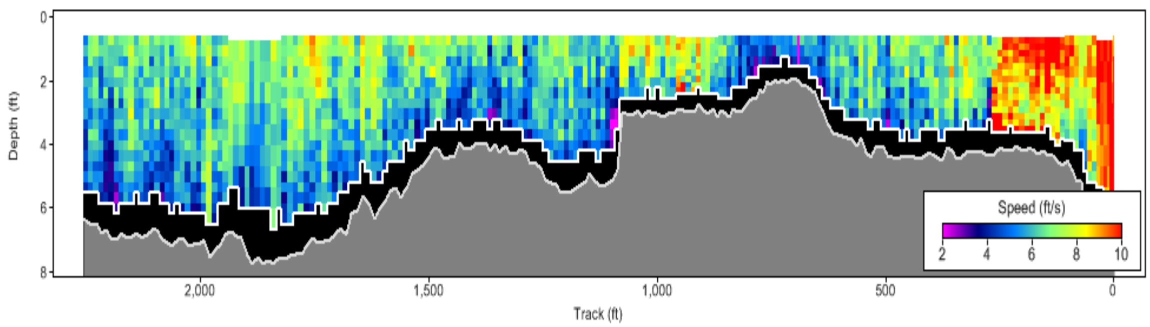


Figure A.4-4. Longitudinal velocity profile L3, FA-128 (Slough 8A), July 2, 2013.

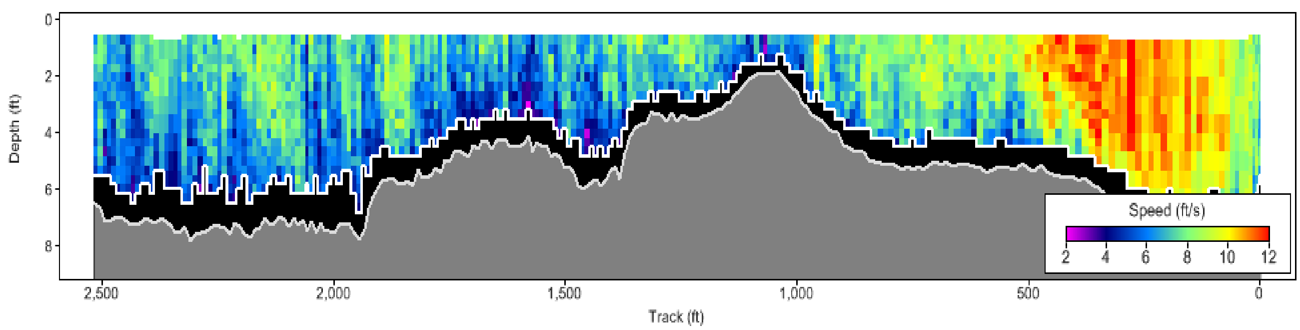


Figure A.4-5. Longitudinal velocity profile L3, FA-128 (Slough 8A), September 10, 2013.

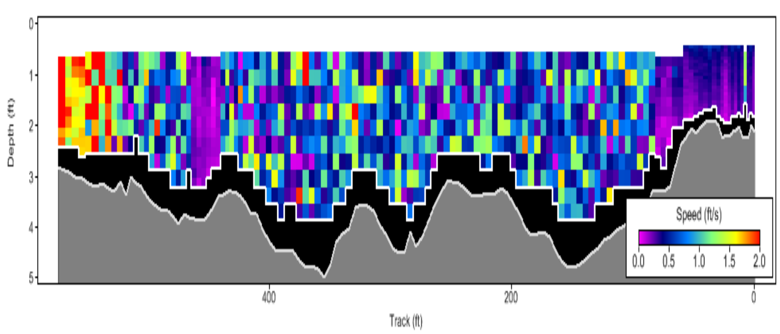


Figure A.5-1. Longitudinal velocity profile L1, FA-113 (Oxbow 1), July 11, 2013.

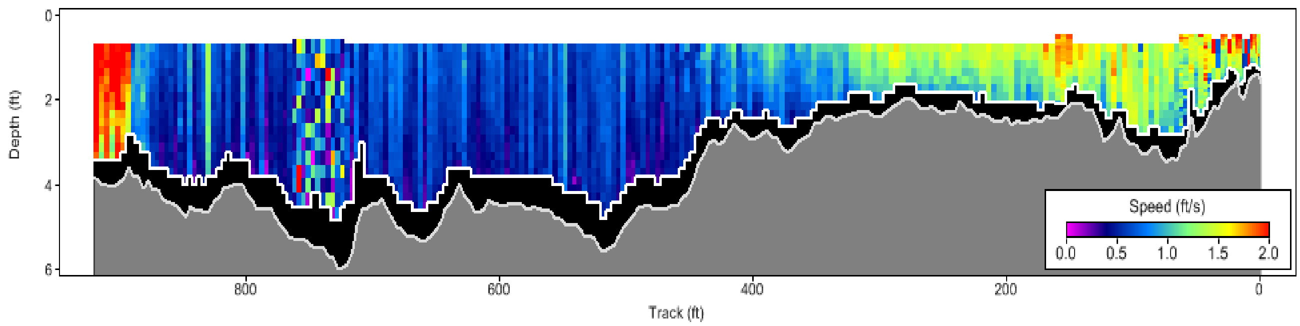


Figure A.5-2. Longitudinal velocity profile L1, FA-113 (Oxbow 1), September 14, 2013.

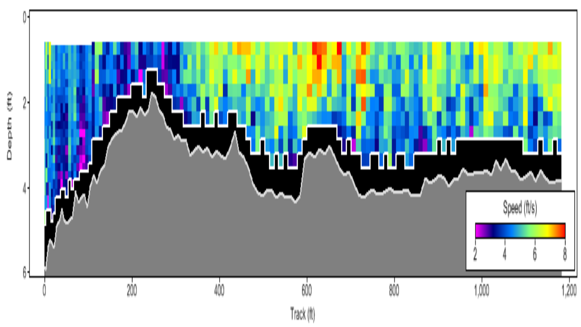


Figure A.5-3. Longitudinal velocity profile L2, FA-113 (Oxbow 1), July 11, 2013.

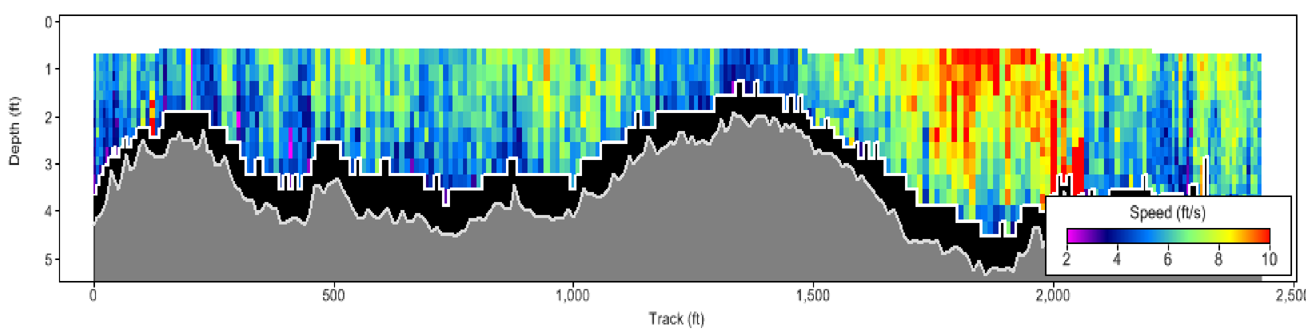


Figure A.5-4. Longitudinal velocity profile L2, FA-113 (Oxbow 1), September 14, 2013.

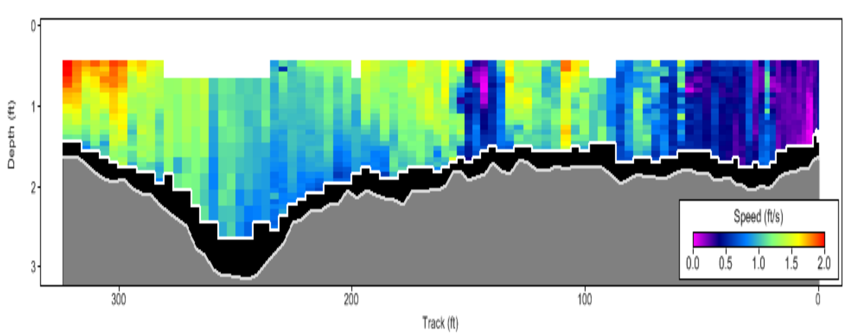


Figure A.6-1. Longitudinal velocity profile L1, FA-104 (Whiskers Slough), July 12, 2013.

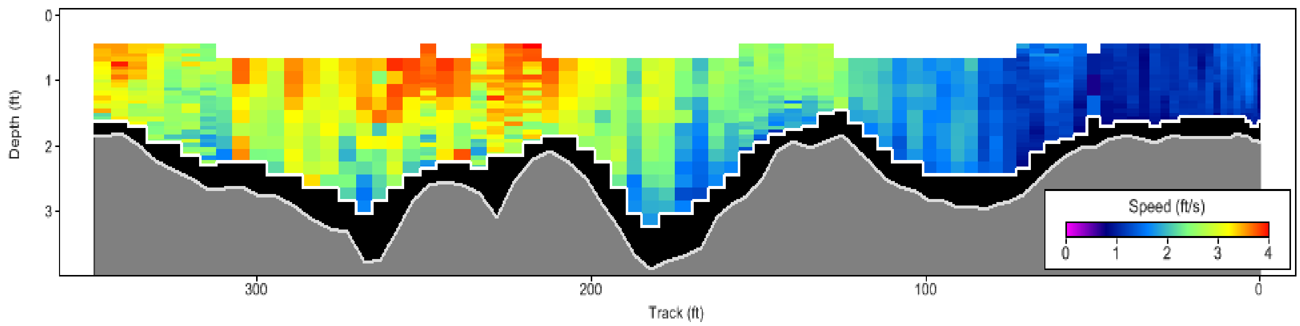


Figure A.6-2. Longitudinal velocity profile L1, FA-104 (Whiskers Slough), September 15, 2013.

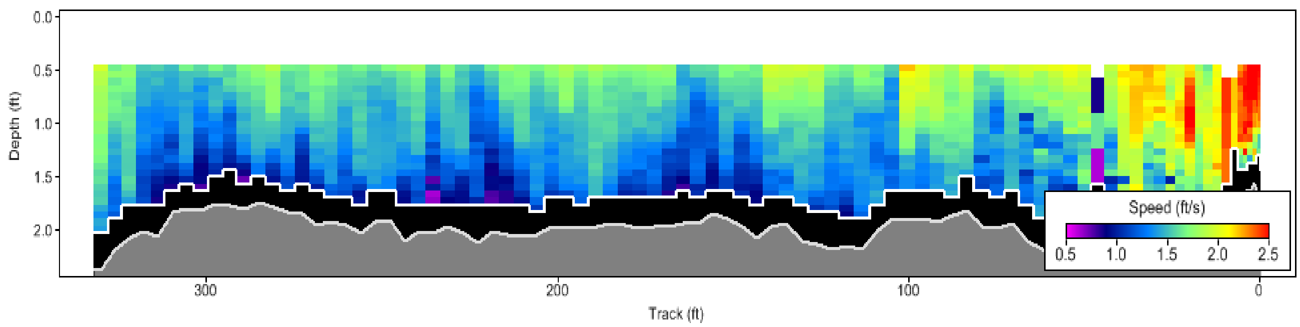


Figure A.6-3. Longitudinal velocity profile L2, FA-104 (Whiskers Slough), July 12, 2013.

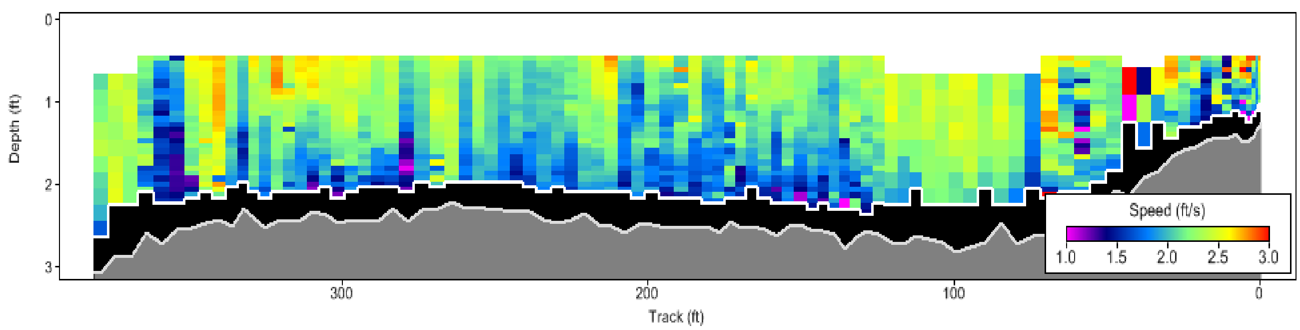


Figure A.6-4. Longitudinal velocity profile L2, FA-104 (Whiskers Slough), September 15, 2013.

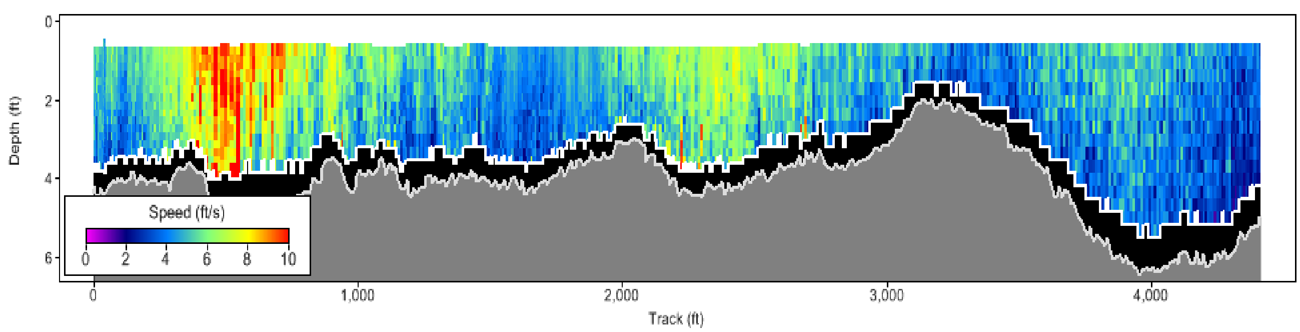


Figure A.6-5. Longitudinal velocity profile L3, FA-104 (Whiskers Slough), July 12, 2013.

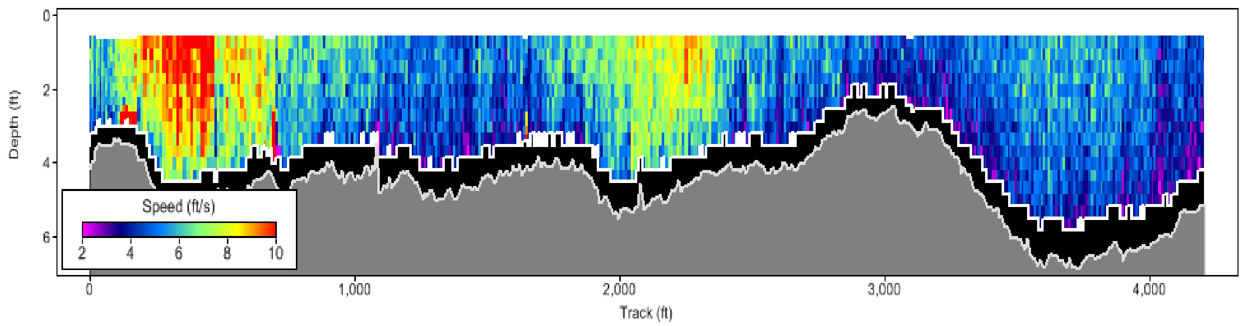


Figure A.6-6. Longitudinal velocity profile L3, FA-104 (Whiskers Slough), September 15, 2013.

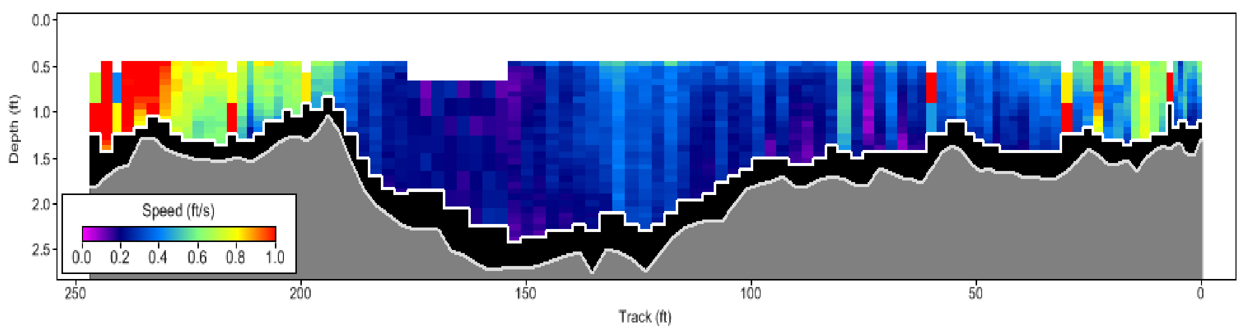


Figure A.6-7. Longitudinal velocity profile L4, FA-104 (Whiskers Slough), July 12, 2013.

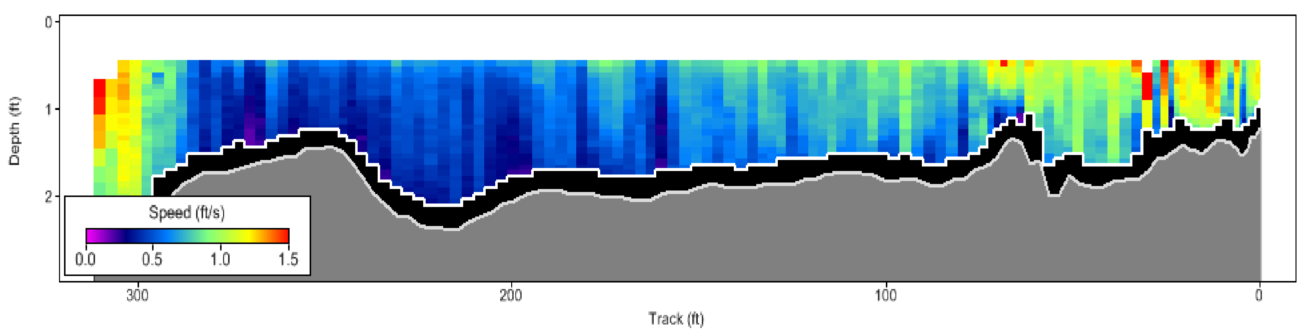


Figure A.6-8. Longitudinal velocity profile L4, FA-104 (Whiskers Slough), September 15, 2013.