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Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Initial Study Report
Part C - Appendix L[1]
2012-2013 Instream Flow Winter Pilot Studies

Prepared for

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[1] This Appendix was originally prepared as a stand-alone Technical Memorandum in February 2014. For completeness, it has been re-issued and included in the ISR as Appendix L. With the exception of Figure 9 in which a correction was made to the plots of Whisker Creek stage (WC-10), all text, figures, tables, and references are the same as in the original Technical Memorandum. The Instream Flow Winter Studies were initiated in September 2013 (installation of equipment) and completed in 2014 (field surveys conducted in February, March and April 2014). AEA will report on the results of the 2013-2014 winter studies in a Technical Memorandum that will be available to Licensing Participants in 2014.

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Abbreviation	Definition
Cfs	Cubic feet per second
FA	Focus Area
FDA	Fish Distribution and Abundance
HSC	Habitat suitability criteria
his	Habitat suitability indices
IFS	Instream Flow Study
PRM	Project River Mile
TM	Technical Memorandum

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. The Project is located on the Susitna River, an approximately 300-mile long river in the Southcentral Region of Alaska. The Project's dam site will be located at Project River Mile (PRM) 187.1. As currently envisioned, the Project would include a large dam with an approximately 35,000-acre, 41-mile long reservoir. The Project construction and operation would have an effect on the flows downstream of the dam site, the degree of which will ultimately depend on final Project design and operations. Key flow changes will likely occur in the form of load following during the critical winter months of November through April each year. During Project operation, seasonal streamflow conditions will likely be higher in winter and lower during the summer reservoir refill period relative to current hydrologic conditions. The alteration in Susitna River hydrology would influence downstream resources and processes, including resident and anadromous fish species and aquatic habitats. As a result, AEA developed and the FERC approved (on April 1, 2013) a detailed Instream Flow Study (IFS) plan (contained as Section 8.5 in the December 14, 2012 Revised Study Plan; see AEA 2012) designed to evaluate the potential effects of Project operations.

One element of the IFS plan pertains to the completion of winter studies designed to assess patterns of fish habitat use under winter conditions including under ice as well as in open-water leads influenced by groundwater inflow (RSP 8.5.4.5.1.2.1). Companion winter studies were also specified in the RSP as part of the Fish Distribution and Abundance (FDA) study under the Fish Program (RSP 9.6.4.5) (AEA 2012). The RSP specified two separate field efforts for these studies including an initial pilot effort during the winter of 2012-2013 followed by an expanded effort during the winter of 2013-2014. This Technical Memorandum (TM) describes the methods applied and data and information collected as part of the IFS pilot winter studies; results of the pilot winter studies for FDA are presented in a separate TM included in Appendix C of ISR Study 9.6 (R2 et al. 2014). The results of these two studies will provide information useful for developing the 2013-14 expanded winter program.

1.1. Study Background

Winter instream flow conditions are an important component of fish habitat in the Susitna River, particularly with respect to egg incubation and juvenile rearing. Intergravel flow and groundwater upwelling are critical for egg incubation and emergent fry survival, while surface water characteristics (e.g., temperature, depth, and velocity) and groundwater input can be important aspects of winter habitat for juvenile and adult fish.

Winter studies were conducted during the 1980s, when a two dam complex (Watana Dam and Devils Canyon Dam) was proposed for the Susitna River. Those studies indicated that groundwater upwelling was the principal factor affecting salmon egg development and survival in the Middle Susitna River (Vining et al. 1985). Groundwater influence in incubation areas is important for maintaining stable water levels, providing warmer water relative to surface streamflow and creating intergravel water exchange, which is critical for maintenance of adequate water quality conditions for embryo development (Vining et al. 1985, Quinn 2005).

Higher winter Susitna River discharge and stage that may result from Project operations may affect groundwater upwelling in various ways, including: decreased extent and/or degree of groundwater input from floodplain sources, altered rates of intergravel flow and exchange associated with hydraulic gradients between mainstem and off-channel habitats, and increased influence of cold main channel surface water in off-channel habitats supported by relatively warm groundwater. These possible modifications to Susitna River streamflow and groundwater relationships may affect the quality and quantity of habitat in main channel and off-channel areas for egg incubation, and juvenile and adult fish rearing and holding.

Intergravel water temperature is a critical factor during salmon egg incubation, affecting the rate of embryo and alevin development and determining the solubility of oxygen in water (Bjornn and Reiser 1991, Quinn 2005). In general, embryos develop faster at warmer water temperatures, but this relationship varies with species. At 5°C, incubation time (fertilization to hatching) was observed to range dramatically among coho (139 days), chum (161 days), sockeye and pink (173 days, each species) and Chinook (191 days) salmon (Murray and McPhail 1988, Quinn 2005). At 2°C, incubation time increased more than 60% for coho, sockeye and Chinook (Murray and McPhail 1988, Quinn 2005). Although incubation may occur at near freezing temperatures, increased mortality can occur at low temperatures during the early stages of incubation (Burgner 1991, Salo 1991, Bjornn and Reiser 1991). In the Susitna River, intergravel water temperatures were observed to vary among habitat types, such that intergravel water temperatures in tributary and main channel areas were strongly affected by surface water and were near freezing during winter, while temperatures in side sloughs were warmer and more stable as a result of groundwater influence (Hoffman et al. 1983; Seagren and Wilkey 1985; Vining et al. 1985). Side channel intergravel temperatures were highly variable and more dependent on site-specific conditions that controlled the relative influence of groundwater and surface water sources (Vining et al. 1985). Redd dewatering and freezing were observed to be primary sources of chum salmon egg mortality in the Susitna River during winter 1983-1984, and eggs located in side channel habitats were more susceptible to mortality relative to eggs in off-channel habitats influenced by groundwater upwelling (Vining et al. 1985).

Groundwater discharge often contains low levels of dissolved oxygen as organic matter is processed by microbes within the intergravel environment (Allan and Castillo 2007). Uptake of dissolved oxygen by salmon embryos may depend on various factors in addition to dissolved oxygen concentration, including gravel permeability and intergravel flow or exchange rates, such that reduced substrate porosity and flow can inhibit embryo development (Quinn 2005). Research with chum salmon embryos indicated that the amount of oxygen needed by the embryo increases with development time and that embryo sensitivity to hypoxia was greatest early in the incubation period (Alderdice et al. 1958, Bjornn and Reiser 1991, Salo 1991). Although acute mortality in salmon embryos occurs at very low dissolved oxygen concentrations (2.0 – 2.5 mg/L), delayed or deformed development of the embryo and premature hatching can occur at levels above this critical minimum (Alderdice et al. 1958, Bjornn and Reiser 1991, Quinn 2005).

Concentration of dissolved oxygen in spawning habitats of the Susitna River varied considerably among habitats and between surface and intergravel environments during winter studies conducted during the 1980s (Hoffman et al. 1983, Vining et al. 1985). Intergravel dissolved oxygen levels were observed to be higher in main channel, side channel and tributary habitats relative to side slough and upland slough habitats during studies conducted in 1983-1984 (Vining et al. 1985). Low dissolved oxygen levels in side slough and upland slough habitats were attributed to the greater influence of groundwater sources in off-channel areas (Vining et al. 1985). Intergravel dissolved oxygen concentrations of 4 mg/L or lower were recorded in each of the four side slough habitats sampled during spring 1983 (Hoffman et al. 1983). In contrast, surface concentrations of dissolved oxygen were generally higher than 8 mg/L among sampled sites (Hoffman et al. 1983).

Susitna River streamflows are typically lowest during the winter period and, with the exception of open-water leads, the river is largely covered in surface ice. Correspondingly, aquatic habitat conditions can be severe for juvenile and adult fish species during winter and are characterized by reduced levels of water temperature, solar radiation, dissolved oxygen and habitat area and increased water clarity relative to summer ice-free conditions (Reynolds 1997). Nearly all fish species exhibit physiological and/or behavioral responses to the seasonal change in habitat from summer to winter (Reynolds 1997), such as movement to off-channel and low velocity habitats (Peterson 1982, Jakober et al. 1998), shifts in diel activity patterns (Roni and Fayram 2000, Heggenes et al. 1993), and decreased territorial aggression (Reynolds 1997).

Habitat utilization among juvenile and adult fish species in the Susitna River during winter is not well understood. Juvenile coho salmon were observed to typically use off-channel habitats and tributaries for winter habitat, while primary winter habitats for juvenile Chinook consisted of side slough and side channel areas (Delaney et al. 1981, Stratton 1986). Most adult resident fish species tracked during 1980s studies in the Middle Susitna River moved from spawning or feeding areas in late summer to winter holding habitats located in the main channel (Sundet and Wenger 1984, Sundet and Pechek 1985). Adult rainbow trout and Arctic grayling migrated from spawning and feeding tributaries in late summer to main channel areas that were typically downstream and proximal to the spawning tributary, though some individuals exhibited long distance (> 20 miles) movements (Hoffman et al. 1983, Sundet and Pechek 1985, Sundet 1986). Limited radio telemetry during the 1980s indicated that adult resident fish distribution in the Middle Susitna River was patchy in main channel areas, which is consistent with observations of Arctic grayling winter distribution elsewhere in Alaska (Sundet and Pechek 1985, Sundet 1986, West et al. 1992, Reynolds 1997). The specific habitat features of Susitna River holding areas used by adult resident species during 1980s winter telemetry studies were difficult to measure, though groundwater upwelling, overhead cover (depth and/or ice cover), lack of frazil and/or anchor ice, and low water velocity appeared to be common characteristics of known holding habitats (Schmidt et al. 1983, Sundet and Pechek 1985).

Winter conditions in the Susitna River are severe and can be limiting for resident and anadromous fish species. Although groundwater has been observed to be an important aspect of aquatic habitat for many fish species and life stages in the Susitna River, the relationships between other habitat criteria and indices relevant to winter conditions are not well understood. Improved understanding of habitat conditions and utilization by fish species and life stages will be necessary to evaluate overall effects of altered Susitna River streamflow that may result from Project operations on the quality and quantity of aquatic habitats. In terms of the IFS program, observations of winter conditions and fish habitat utilization will support Habit Suitability Curve (HSC) and Habitat Suitability Index (HSI) development for individual fish species and life stages that will be used to develop fish habitat-flow relationships.

2. STUDY OBJECTIVES

The overall objectives of the pilot 2012–2013 IFS winter studies were to: 1) investigate potential relationships between mainstem Susitna River stage and the quality and quantity of winter aquatic habitats that support embryonic, juvenile and adult life stages of fish species; 2) test the feasibility of using different instruments, methods, and approaches for winter data collection (in concert with FDA, see R2 2014); and 3) to begin collecting information on fish behavior and habitat utilization during the winter period. Specific tasks of the pilot study were as follows:

- Compare water level (stage) responses in representative habitat types relative to Susitna River main channel stage through the period of salmon egg incubation.
- Monitor surface and intergravel water temperatures in representative habitat types, at salmon spawning sites and in areas with and without groundwater influence through the period of salmon egg incubation.
- Evaluate potential relationships between Susitna River stage and water temperature recorded in off-channel and main channel habitats.
- Monitor intergravel dissolved oxygen at two salmon spawning sites in off-channel habitats with groundwater influence.
- Describe juvenile and adult fish behavior in representative habitats during day and night conditions to discern potential patterns in behavior and habitat use.
- Record site-specific habitat utilization data for juvenile and adult fish species in support of HSC and HSI development.
- Develop recommendations for future winter studies.

3. STUDY AREA

The pilot 2012-2013 IFS winter studies were conducted in the Middle River Segment of the Susitna River between Three Rivers (PRM 102.4) and PRM 129.5. Data collection primarily occurred within two Focus Areas (FAs): FA-104 (Whisker Slough) and FA-128 (Slough 8A) (Figure 1). These FAs were selected for the 2012-2013 pilot study because they contain a diversity of habitat types with groundwater influence, have documented fish utilization by multiple fish species and life stages, and were accessible during winter. Within each proposed study area, potential sampling locations were identified prior to data collection; however, on-site adjustments to each location were made based upon known fish distribution (e.g., spawning site), logistical considerations (e.g., site access, ice cover) and personal safety. Most of the 2012-2013 winter effort was conducted at FA-104 (Whiskers Slough) due to its proximity to Talkeetna, although each study component was tested at both FAs. Work at FA-104 (Whiskers Slough) was based out of Talkeetna, while a remote camp was used for work at FA-128 (Slough 8A).

4. METHODS

The 2012-2013 winter studies were comprised of two primary components: 1) water level and water quality monitoring and 2) fish behavior and habitat use observations. Data collection occurred during three trips in early 2013: February 1-7, March 19-25 and April 8-13. The 2012-2013 winter studies were coordinated with the study leads for Instream Flow (Study 8.5), Fish Distribution and Abundance in the Middle and Lower River (Study 9.6; R2 2014), Groundwater (Study 7.5), Geomorphology (Study 6.5), and Ice Processes (Study 7.6). The initial work on the 2012–2013 pilot study consisted of a focused review of literature from 1980s studies and of more recent research to identify potential methods for each study component.

4.1. Water Surface Elevation

Water level and water quality were continuously monitored at nine sites in FA-104 (Whiskers Slough) during February – April 2013 (Figure 2). Continuous monitoring sites in FA-104 (Whiskers Slough) were established in early February 2013 in the Susitna River within a variety of macrohabitat types. These included main channel, side channel, side slough, upland slough and tributary habitats. The areas selected were comprised of areas with known or suspected groundwater upwelling, bank seepage and lateral intergravel flow from the main channel, areas of mixing between upwelling and bank seepage, areas with no intergravel discharge, and areas where fish had been observed spawning. In FA-128 (Slough 8A), continuous water level and water quality sites were established during March 2013 in side slough and upland slough habitats (Figure 3). Salmon spawning was observed during fall 2012 at FA-104 (Whiskers Slough) sites WSC-30, WSL-20 and WC-10 and at FA-128 Site SL8A-15 (Figure 2 and Figure 3). Habitat designations (e.g., side channel, slough) used during 2012-2013 winter studies were based on 2012 Middle River Segment remote line habitat mapping (HDR 2013). Most water level and water quality instruments were downloaded and removed prior to completion of the April 2013 trip, however, a subset of water level and temperature instruments were downloaded and redeployed in April 2013 to record hydrologic and temperature conditions through spring ice breakup.

Pressure transducers (Solinst leveloggers) were used to record changes in stage at continuous monitoring sites. Transducers were deployed at the substrate surface at each site. To prevent shifting during the deployment period, transducers were anchored with weights and attached to metal stakes driven into the substrate. All transducers were removed during the final data collection period in April 2013, with the exception of instruments in Whiskers Slough (WSL-20) and Slough 3A (SL3A-70) in FA-104 and both sites in FA-128 (Slough 8A) (SL8A-10 and US2-10) (Figure 2 and Figure 3). In FA-104 (Whiskers Slough), comparisons between stage in side channel and off-channel habitats relative to the Susitna River main channel were completed using pressure transducer data normalized to zero at the common start time for all instruments within the FA. At FA-128 (Slough 8A), main channel stage data were not available so stage data recorded at the USGS gage at Gold Creek (#15292000) after ice breakup were used for comparison of main channel and off-channel stage. Pressure data recorded at each continuous monitoring site was compensated with barometric pressure data recorded at FA-104 (Whiskers Slough) and FA-128 (Slough 8A) (Figure 2 and Figure 3).

4.2. Water Quality

Surface and intergravel water temperatures and intergravel dissolved oxygen concentrations were continuously recorded in FA-104 (Whiskers Slough) and FA-128 (Slough 8A) (Figure 2 and Figure 3). Surface water temperature was recorded by pressure transducers at the substrate surface. Intergravel water temperature loggers (Hobo Tidbit v2) were deployed at three separate intergravel depths: 5 centimeters (cm) (2 in), 20 cm (7.9 in), and 35 cm (13.8 in) beneath the substrate surface. These depths reflect observed burial depth ranges of chum and sockeye eggs (Bigler and Levesque 1985; DeVries 1997). Intergravel temperature probes were attached to stainless steel cable and deployed into the gravel using a steel installation device (*sensu* Zimmerman and Finn 2012). Dissolved oxygen loggers (HOBO U26-001), which also recorded water temperature, were bolted within a perforated PVC tube and likewise inserted into the gravel to a depth of approximately 20 cm adjacent to known or historic salmon spawning areas. All intergravel temperature and dissolved oxygen instruments were removed in April 2013 except intergravel temperature loggers at Whiskers Slough (WSL-20) and Whiskers side channel (WSC-30) in FA-104, which were recovered in June 2013 and October 2013, respectively.

The relationship between main channel stage and water temperature was evaluated at three sites in FA-104 (Whiskers Slough) that were observed to support salmon spawning in 2012 (WSC-30, WSL-20, and WC-10). The stage records for each spawning site and the main channel were normalized to zero at the start of data collection and compared to surface and intergravel temperatures.

Instantaneous measurements of surface water quality were recorded at continuous monitoring sites in addition to other main channel and off-channel areas in FA-104 (Whiskers Slough) and FA-128 (Slough 8A) during January, March, and April 2013 using a hand-held water quality meter (YSI Pro 30 or Hanna 98129) (Figure 2 and Figure 3). Measurements of water temperature and specific conductance were recorded on the water surface and at mid-column depth. Instantaneous water quality data were used to characterize surface water quality in each Focus Area and to help discern qualitative differences in groundwater composition among habitats based on water temperature and specific conductance (Rosenberry and LaBaugh 2008).

4.3. Fish Observations

Fish observation and capture efforts occurred in each Focus Area during monthly trips between February-April 2013. Fish observation sites were located in open water and ice-covered areas within off-channel and tributary habitats. Underwater video was used by FDA and IFS staff during each trip at six sites in FA-104 (Whiskers Slough) and at three sites in FA-128 (Slough 8A) to monitor behavior in fish communities and evaluate the effectiveness of different camera types, power supplies, and lighting conditions (AEA 2012, Section 9.6; R2 2014). Dual Frequency Identification Sonar (DIDSON) was utilized by FDA staff at three sites in FA-104 (Whiskers Slough) to gauge its applicability for monitoring fish behavior and habitat utilization during winter (R2 2014). When used in ice-covered areas, the video camera or DIDSON unit was lowered through auger holes drilled through the ice (AEA 2012, Section 9.6). Where possible, video cameras were used to characterize winter habitat attributes such as the presence of anchor ice, hanging dams, and substrate type.

Electrofishing surveys were performed during 2012-2013 IFS winter studies to collect site-specific habitat suitability criteria (HSC) data and augment observations of fish behavior. Surveys were conducted using a backpack electrofisher (Smith Root LR-24) at eight open water sites in FA-104 (Whiskers Slough) and FA-128 (Slough 8A) during day and night surveys in March and April 2013. HSC data (e.g., velocity, water depth, substrate and cover) were measured at the point of fish capture during electrofishing sampling and in association with underwater video monitoring provided fish species and size could be determined during underwater surveys and target fish were observed maintaining a stationary position. Water velocity and depth measurements were made either through holes drilled in the ice or in open-water leads using a wading rod and Price AA water velocity meter. Instantaneous measurements of water temperature, dissolved oxygen and specific conductance were recorded using a hand-held water quality meter (YSI Pro 30) to describe water quality conditions at the location of fish observations.

4.4. Deviations from Study Plan

According to the Study Plan for winter sampling, results of the 2012-2013 winter effort were to be distributed to TWG participants by Q3 2013. Although condensed results from winter data collection were communicated to TWG participants during IFS presentations at quarterly TWG meetings in June, September and December 2013, a more comprehensive report was not distributed. This deviation from the Study Plan is not expected to affect overall study objectives, although it will be important to obtain feedback from TWG participants regarding 2012-2013 winter study results in order to plan for 2013-2014 efforts. This Technical Memorandum is intended to facilitate communication regarding winter data collection so that comments from TWG participants may be incorporated into the 2013-2014 study.

5. RESULTS

5.1. Water Surface Elevation

Water surface levels of the Susitna River main channel in FA-104 (Whiskers Slough) exhibited an overall downward trend during February to April 2013, although some short-term oscillations from 0.05 – 0.30 feet in magnitude occurred throughout the measurement period (Figure 4). Water levels recorded at side channel Site WSC-30 were generally similar to levels in the main channel (MC-50) in terms of the long-term trend and short-term fluctuations based on comparison of normalized water levels (Figure 4). At monitoring sites in side slough and upland slough habitats, the long- and short-term stage patterns were generally much more stable compared to the main channel (Figure 4). At most off-channel sites, water elevation changes through the period of measurement were small (0.02 – 0.05 feet) and the short-term stage fluctuations evident at off-channel monitoring sites in late March 2013 differed from the main channel in terms of magnitude and duration (Figure 4). The magnitude of short-term stage fluctuations at side slough Site WSC-20 (0.02 – 0.07), upland slough Site SL3A-70 (0.02 – 0.06 feet) and side channel Site SL3B-10 (0.02 – 0.04 feet) in late March were typically not as large in magnitude or duration as main channel Site MC-50 (0.05 – 0.30 feet) (Figure 4). The stage record in Whiskers Creek was similar to that of Site SL3B-10 in terms of overall trend and magnitude of short-term fluctuations (0.02 – 0.04 feet) (Figure 4). The inlets to side channel and off-channel habitats in FA-104 (e.g., Whiskers Slough, Slough 3A) were not visible due to snow and ice cover during the February – April 2013 effort, so it was not possible at the time to determine whether channels had been breached by Susitna River main channel streamflow.

Water surface elevations in FA-128 (Slough 8A) exhibited similar stage responses between upland slough (US2-10) and side slough (SL8A-15) habitats in terms of the magnitude and timing of seasonal and daily trends (Figure 5). Diurnal fluctuations before ice break-up in April 2013 were approximately 0.15 feet at each site, while the magnitude of stage change after ice break-up in June 2013 ranged from approximately 0.8 – 1.5 feet (Figure 5). In addition, stage fluctuations at FA-128 (Slough 8A) off-channel sites were generally similar to the main channel Susitna River stage response during and after ice breakup (late May – early August 2013) based on comparison of normalized water levels between FA-128 sites and the recorded stage at the USGS gage at Gold Creek (#15292000) (Figure 5). A large-scale stage fluctuation in mid-June 2013 measured approximately 1.4 feet in magnitude at each of the main channel and off-channel monitoring sites (Figure 5). During March and April 2013 data collection trips, the inlet of Slough 8A did not appear to be breached by Susitna River main channel flow and it is not known whether or how long the Slough 8A inlet may have been breached during spring flood events in May and June 2013.

5.2. Water Quality

Surface and intergravel water temperatures differed among habitat types at FA-104 during the 2012-2013 winter pilot study based on data collected at nine continuous monitoring sites. In the Susitna River main channel (Site MC-50) and side channel Site WSC-30, surface water temperatures were near 0°C throughout the February – April 2013 measurement period and ranged from 0.0 – 0.1°C (Figure 6). Elsewhere, surface water temperatures ranged from 1.1 – 3.8°C at upland slough Site SL3A-70, 0.8 – 3.0°C at side channel Site SL3B-10, 0.1 – 2.8°C at tributary Site WC-10, 0.4 – 2.4°C at side slough Site WSL-20, and 2.7 – 4.8°C at side slough Site WSL-40 (Figure 7 and Figure 8). Intergravel water temperatures were warmer than surface water at all sites, although the difference at the main channel site (MC-50) was negligible. Intergravel water temperature ranged from 0.0 – 0.1°C at main channel Site MC-50, 3.1 – 3.9°C at side channel Site WSC-10, 2.9 – 3.5°C at side slough Site CFSL-10, 1.8 – 3.2°C at upland slough Site SL3A-70, 1.1 – 4.1°C at side channel Site SL3B-10, 0.0 – 2.5°C at side channel Site WSC-10, 0.3 – 2.2°C at tributary Site WC-10, 0.5 – 2.3°C at side slough Site WSL-20, and 2.7 – 5.0°C at side slough Site WSL-40 (Figure 6, Figure 7, and Figure 8).

Diurnal fluctuation of continuous water temperature data was common among FA-104 monitoring sites, but was generally more prevalent among off-channel and tributary monitoring sites relative to mainstem locations (Figure 6, Figure 7, and Figure 8). Diurnal temperature changes were apparent throughout the vertical gradient at nearly all off-channel and tributary sites. The magnitude of daily fluctuation exceeded 1°C in Whiskers Creek, Whiskers Slough, and at sites SL3B-10 and SL3A-70 (Figure 6, Figure 7, and Figure 8). At side channel Site WSC-30 and side slough Site CFSL-10, a fluctuating daily temperature pattern was evident near the substrate surface (-5 cm), but was negligible at intergravel depths of 20 cm and 35 cm (Figure 6). Diurnal temperature variation was not apparent at main channel Site MC-50 (Figure 6).

There was no clear effect of Susitna River main channel water level fluctuations on intergravel temperatures at the three FA-104 sites that were known to support salmon spawning in fall 2012 (WSC-30, WSL-20, WC-10). Although water level at the side channel Site WSC-30 was variable throughout the measurement period and reflected the main channel (Site MC-50) stage response, intergravel water temperatures at Site WSC-30 remained relatively stable; Site WSC-30 intergravel water temperature at -20 cm gravel depth ranged from 3.7 – 3.9°C during the measurement period (Figure 9). At side slough Site WSL-20, stage was stable relative to the main channel and surface and intergravel water temperatures at WSL-20 did not change in relation to main channel stage fluctuations (Figure 9). Responses of stage and water temperatures at Whiskers Creek Site WC-10, suggested they were not influenced by main channel stage fluctuation (Figure 9).

Instantaneous measurements of surface water temperature recorded in April 2013 at FA-104 (Whiskers Slough) indicated generally warmer surface water in side slough and upland slough habitats relative to Susitna River main channel and side channel sites, which was consistent with data recorded at continuous temperature monitoring sites (Figure 10). Specific conductance at mainstem instantaneous measurement sites was conversely higher than off-channel and tributary areas (Figure 10). Exceptions to this general trend were at side channel Site SL3B-10, which exhibited specific conductance and water temperature unlike other side channel sites, and side slough Site CFSL-10 at which the recorded specific conductance was more similar to mainstem habitat than other side slough habitats (Figure 10). Specific conductance measurements at FA-104 ranged from 123.0 – 155.6 µS/cm among main channel (MC-50) and Whiskers Side Channel (WSC) sites, 120.3 µS/cm at side slough Site CFSL-10, 52.0 – 55.9 µS/cm at side channel Site SL3B-10, 19.0 – 49.9 µS/cm at Whiskers Slough (WSL) sites, 19.0 – 20.1 µS/cm at Whiskers Creek Site WC-20, and 53.0 – 61.6 µS/cm at Slough 3A (SL3A) sites (Table 1).

At FA-128, instantaneous water quality measurements measured during April 2014 suggested that side slough and upland slough habitats were generally warmer relative to main channel and side channel areas, but that specific conductance was not substantially different among habitats (Figure 11). Instantaneous surface water temperature measurements ranged from 0.1°C at main channel Site MC-50, 0.2 – 1.9°C at Skull Side Channel (SSC) sites, 0.6 – 4.2°C at Side Channel 8A (SC8A) sites, 0.9 – 4.3°C among Slough 8A (SL8A) sites, 1.9 – 2.9°C at Upland Slough 2 (US2) sites, and 0.8 – 3.0°C at Half Moon Slough (HMSL) sites (Table 1). Specific conductance was lower within Slough 8A (side slough sites) relative to main channel, side channel and upland slough habitats (Figure 11). Bank seepage flow at side channel sites SSC-20 and SC8A-15 was characterized by warmer temperature than adjacent surface water, whereas in upper Slough 8A (SL8A-50) bank seepage was very similar to the main water body in terms of temperature and specific conductance (Figure 11). Specific conductance measurements at FA-128 ranged from 168.2 µS/cm at main channel Site MC-50, 137.0 – 162.3 µS/cm at Skull Side Channel (SSC) sites, 109.0 – 150.6 µS/cm at Side Channel 8A (SC8A) sites, 90.0 – 123.3 µS/cm among Slough 8A (SL8A) sites, 125.0 – 149.0 µS/cm at Upland Slough 2 (US2) sites, and 144.5 – 168.2 µS/cm at Half Moon Slough (HMSL) sites (Table 1).

Intergravel dissolved oxygen recorded at approximately 20 cm below the substrate surface at Site SL8A-15 in FA-128 was generally stable at approximately 5.2 mg/L through late March and April 2013 (Figure 12). Water temperature recorded by the dissolved oxygen logger was 2.7°C during the measurement period and was similarly stable with minimal daily fluctuation (Figure 12). Intergravel dissolved oxygen recorded at FA-104 Site SL3B-10 was measured to be near 0 mg/L for much of the measurement period but fluctuated frequently and substantially (range: 0.0 – 6.0 mg/L) near the end of the deployment period. The highly erratic nature of the intergravel dissolved oxygen data at Site SL3B-10 suggested the logger may have been fouled and because values were not validated with instantaneous measurements, the intergravel dissolved oxygen data are not reported. The intergravel water temperature data recorded by the dissolved oxygen logger at FA-104 Site SL3B-10 closely reflected temperature values measured at a similar depth by an intergravel temperature logger at the site.

5.3. Fish Observations

Underwater observations of fish and fish capture efforts during the February – April 2013 study period indicated that juvenile fish were active during both day and night periods in both FA-104 and FA-128. Fish activity was observed during day and nighttime opportunistic underwater surveys of ice-covered side channel, side slough, and upland slough habitats in FA-104 (Whiskers Slough) and FA-128 (Slough 8A) (9 total sites) in which optical video cameras were used to actively scan the channel from one or more fixed positions under the ice (see AEA 2012, Section 9.6). Juvenile Chinook and coho salmon (< 150 mm fork length), adult rainbow trout (> 150 mm fork length), adult round whitefish (> 150 mm fork length), and sculpin species were observed during underwater video surveys. No distinct difference in fish activity was apparent during day and night surveys during optical video camera surveys, however, DIDSON sonar surveys in FA-104 near Site WS-70 identified directional movements of juvenile fish (approximately 100 – 200 mm total length) at dusk and at dawn that were not apparent at other times. The crepuscular fish movements detected during the DIDSON survey were in an upstream direction at dusk and downstream at dawn; the species of fish detected by the DIDSON could not be discerned (R2 2014). Day and nighttime electrofishing surveys of eight open water sites also indicated potential differences in diurnal fish behavior, with more fish captured during the night. Overall, total fish capture at night was higher than daytime at all sites sampled during both diurnal periods in FA-104 (SL3A-71) and FA-128 (SSC-20, SC8A-28, SL8A-10, US2-10), except Site 128-SSC-20 at which no fish were caught (Table 2). A total of four juvenile Chinook salmon (size range: 65 – 72 mm fork length) were caught during daytime electrofishing surveys, while 23 Chinook salmon (size range: 55 – 110 mm fork length) and three coho salmon (size range: 46 – 65 mm fork length) were captured during nighttime (Table 2). Composition of fish captured during IFS electrofishing surveys consisted of Chinook and coho salmon and sculpin species.

A total of 29 HSC observations of juvenile Chinook and coho habitat utilization were recorded during 14 electrofish sampling surveys of four open water sites in each of FA-104 and FA-128 in March and April 2013 (Table 3). Of this total, 26 observations were recorded for juvenile Chinook and three for juvenile coho salmon (Table 3). No HSC data were recorded in ice covered areas in association with underwater optical video surveys.

6. DISCUSSION AND CONCLUSION

Winter is a critical period for various life stages of Susitna River fish species and aquatic habitat conditions can be severe. Susitna River areas that support spawning and egg incubation, juvenile fish rearing and adult holding are critical winter habitats and may be altered by proposed Project operations. The 2012-2013 winter study was a pilot effort to test methods, instruments and approaches to evaluate potential relationships between mainstem Susitna River stage and the quality and quantity of winter aquatic habitats that support embryonic, juvenile and adult life stages of fish species.

The 2012-2013 winter pilot study was conducted at two Focus Areas, FA-104 (Whiskers Slough) and FA-128 (Slough 8A), that supported salmon spawning in 2012 and contained a diversity of main channel and off-channel habitats. The close proximity of FA-104 to Talkeetna allowed greater focus on field data collection relative to logistic support demands (e.g., remote camp construction and travel). Future winter data collection will incorporate additional study sites to help evaluate potential Project effects on winter habitat conditions within the Middle River Segment of the Susitna River (see Section 7).

6.1. Water Surface Elevation

The stage data collected from this initial study provided for some insight into how different macrohabitat types may respond to main channel flows during winter periods. Comparison of stage records at FA-104 during February – April 2013 indicated a direct relationship between Susitna main channel Site MC-50 and the proximal side channel Site WSC-30 suggesting that either the side channel had been breached enabling a surface flow connection throughout the period or that shallow groundwater flow from the main channel was still being provided and was subject to main channel stage changes. However, these relationships were less apparent between main channel stage and off-channel monitoring sites suggesting that either these areas had not been breached or groundwater sources may have an influence on water levels for these areas. More insight into this will be made as part of the groundwater studies (AEA 2012, Section 7.5). The importance of local groundwater sources for maintaining flow and habitat conditions in off-channel habitats was documented during 1980s Susitna River studies, although the relationship between main channel and off-channel stage and groundwater upwelling was not completely understood (Quane et al. 1984, Aaserude et al. 1985, Keklak and Withrow 1985, Vining et al. 1985). Studies conducted during the 1980s indicated that Susitna River main channel discharge volumes and corresponding stage levels affected discharge in off-channel habitats via intergravel flow through islands and gravel bars even if the inlet was not breached by main channel streamflow (Harza-Ebasco and R&M 1984, Trihey & Associates and Entrix 1985). It was estimated that one-foot reductions in main channel stage resulted in changes of 0.3 – 0.6 cfs in side slough flow, depending on the slough (Harza-Ebasco and R&M 1984, Trihey & Associates and Entrix 1985). This relationship was believed to be similar between winter and summer based on similar Susitna River main channel stage levels between seasons (Harza-Ebasco and R&M 1984, Trihey & Associates and Entrix 1985). A better understanding of breaching flows (i.e., flows at which surface flows from the main channel Susitna River begin to enter side channel and off-channel habitats) and relationships between under-ice stage and main channel flows within each of the Focus Areas will be possible once the open water and under ice 2-D hydraulic models are fully developed (AEA 2012, Sections 6.6 and 7.6).

6.2. Water Quality

Continuous surface and intergravel water temperature monitoring during the pilot 2012-2013 effort indicated that surface and intergravel temperatures were generally warmer in off-channel areas relative to the main channel and diurnal temperature fluctuations were more evident at some sites (e.g., WS-40) relative to others (WSC-30). Researchers during 1980s Susitna River studies similarly identified off-channel areas with warmer water temperatures relative to the main channel that were of particular importance for winter fish use (Keklak and Withrow 1985, Vining et al. 1985, Stratton 1986). Temperature data collected during 1984-1985 indicated that intergravel water temperature in the Susitna River main channel and tributaries were closely associated with surface water temperature, while surface and intergravel temperatures in side sloughs was generally warmer than the main channel due to groundwater input (Vining et al. 1985). Continuous monitoring sites with pronounced diurnal patterns in surface and intergravel temperatures in 2013 may represent areas of downwelling (negative hydraulic gradient) in which surface flows that are susceptible to diurnal changes in temperature are moving into the groundwater, while sites with warm intergravel temperature (3-4°C) and minimal diurnal temperature oscillation (e.g., WSC-30 and CFSL-10) likely represent areas of groundwater upwelling (positive hydraulic gradient) (Constantz et al. 2008).

The surface and intergravel water temperature data, when analyzed in conjunction with the stage data also provide some insight into the thermal influence of main channel flows on off-channel habitats. For example, the effect of Susitna River main channel water level fluctuations during February – April 2013 on intergravel temperatures at FA-104 sites that were known to support salmon spawning in 2012 was negligible (Figure 9). At side channel site WSC-30, intergravel temperature was stable throughout the measurement period, despite variations of 0.2 – 0.3 feet in water level (Figure 9). Warm intergravel temperatures (3-4°C) at WSC-30 likely reflect a strong groundwater influence and contrast with near-zero surface temperature (Figure 9). However, as noted above, it was not known whether breaching had occurred during any of the monitoring period. Stage changes induced by hydrostatic pressure under ice may result in breaching flows that bring in cold surface water from the main channel into these off-channel habitats which can result in intergravel temperature changes. Results of 2013-2014 winter studies coupled with the groundwater and ice processes studies should provide more information concerning this. During 1980s studies, intergravel water temperatures in areas of off-channel upwelling were observed to be insensitive to surface water temperature when the inlet to the slough was not breached by main channel streamflow (Trihey & Associates and Entrix 1985). However, when the slough inlet was breached, intergravel water temperature was affected by surface water and such effects were most evident during the freeze-up period in early winter (Trihey & Associates and Entrix 1985). Monitoring of water level and surface and intergravel temperature in habitats that support critical fish life stages, including adult spawning, egg incubation and juvenile rearing will help evaluate the relationship between Susitna River stage and winter habitat conditions.

Instantaneous measurements of surface water temperature and specific conductance during February – April 2013 supported the general trend indicated by continuous temperature data of warmer surface water in off-channel areas relative to the main channel. Instantaneous measurements recorded in April 2013 in FA-104 indicated that side slough and upland slough habitats typically exhibited higher temperature and lower conductance than main channel and side channel areas. A similar pattern was apparent in FA-128, though the degree of difference in water temperature and conductance between mainstem and off-channel sites was not as distinct as that observed at FA-104. Instantaneous water quality, in conjunction with continuous temperature and water level data, will be helpful to discern the relative influence of varied groundwater and surface water sources in critical aquatic habitats.

Intergravel dissolved oxygen concentrations recorded at FA-128 (Slough 8A) were stable throughout the March – April 2013 measurement period. Recorded values of dissolved oxygen (5.2 mg/L) and temperature (2.7°C) correspond to approximately 35% saturation, which could be below the ideal level for anadromous salmon egg incubation, but may represent adequate conditions for egg development depending on intergravel flow, substrate permeability and other factors (Bjornn and Reiser 1991, Quinn 2005, USGS 2011). Similarly low levels of dissolved oxygen were recorded during 1980s studies, particularly in off-channel habitats (Vining et al. 1985). Mean intergravel dissolved oxygen at FA-128 (Slough 8A) in April 1983 was 4.6 mg/L, which was the lowest mean value among the four off-channel sites sampled during that period (Slough 8A, Slough 9, Slough 11 and Slough 21) (Hoffman et al. 1983). At FA-104 (Whiskers Slough), continuous dissolved oxygen measurements recorded during February-April 2013 appeared erroneous and were not reported, though the cause of the unusually low and highly erratic measurements was not clear. It is possible that measurements by the probe were affected by fouling and/or sedimentation. For future studies, field calibration of the dissolved oxygen loggers will be performed to minimize these concerns.

6.3. Fish Observations

Fish presence was recorded in day and night periods in ice covered areas during underwater video monitoring, while underwater sonar observations and fish capture totals indicated that some species may exhibit diel shifts in activity. Upstream and downstream crepuscular movements of juvenile fish recorded during underwater sonar monitoring suggest shifts in habitat utilization between day and night periods, while greater fish capture totals during night electrofish surveys may indicate increased overall activity during nighttime. Diel differences in fish behavior are common among fish species, particularly during winter, but information specific to the Susitna River is sparse. In general, when day length is short and water temperatures are low, fish activity often shifts from diurnal to nocturnal periods, such that individuals become inactive and/or hide during the day to minimize energy expenditure and reduce predation risk (Roni and Fayram 2000, Quinn 2005, Reeves et al. 2009). The presence of ice cover, however, may mitigate such behavioral shifts. During a winter study of the effect of ice cover on fish behavior, greater fish activity and foraging was observed in the presence of ice cover relative to its absence (Watz 2013). Monitoring of fish activity and behavior during future day and nighttime winter surveys using underwater video, sonar and fish capture techniques will help elucidate potential winter behavioral patterns exhibited by fish species in the Susitna River.

7. PLANS FOR 2014

The 2013-2014 IFS Winter Studies will expand on the pilot studies conducted during winter 2012-2013 and will be performed in conjunction with winter work by FDA and groundwater resource disciplines. Data collection by IFS, FDA and groundwater groups will be coordinated with IFS-riparian, river productivity, geomorphology, water quality and ice processes resource disciplines.

The goals of the 2013-2014 IFS winter studies remain the same as stated above and are to evaluate potential relationships between mainstem Susitna River stage and the quality and quantity of winter aquatic habitats that support embryonic, juvenile and adult life stages of fish species and to record fish behavior and habitat utilization in support of HSC and HSI development. Objectives for the 2013-2014 work are identified in Section 2. The general approach of the 2013-2014 IFS winter study will be similar to the 2012-2013 pilot effort (see Section 4), except that the level of effort will be increased and the study areas will be expanded to three Focus Areas: FA-104 (Whiskers Slough), FA-128 (Slough 8A), and FA-138 (Gold Creek) (Figure 13). Specific tasks include:

- Continuous stage and water quality (temperature and dissolved oxygen) monitoring will occur at FA-104, FA-128 and FA-138 through the period of salmon egg incubation (September 2013 – April 2014) (Figure 13).
- Stage and water temperature data (surface and intergravel) will be continuously monitored at main channel and off-channel sites in each of FA-104, FA-128 and FA-138. Monitoring sites within each FA will be distributed among habitat types, at locations of known salmon spawning, and at sites with and without groundwater influence (Figure 14, Figure 15, and Figure 16).
- Intergravel dissolved oxygen will be continuously recorded at known salmon spawning locations in FA-128 and FA-138.
- Fish observation and capture efforts will be performed at available habitat types in each of FA-104, FA-128 and FA-138; additional sites outside of these FAs will be sampled based on observed fish distribution, site access, weather conditions and personnel safety.
- Fish activity and behavior will be monitored using underwater video equipment to discern potential patterns in activity related to diurnal and seasonal periodicity and/or habitat (e.g., side channel, side slough).
- Site-specific habitat suitability criteria (HSC) for juvenile and adult fish will be recorded using electrofish capture methods in open water areas and underwater video in ice covered habitats.
- Instantaneous surface water quality measurements (temperature, dissolved oxygen, specific conductance) will be recorded in association with maintenance of continuous stage and water quality monitoring sites and fish observation and capture efforts.

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9. TABLES

Table 1. Instantaneous surface water temperature and specific conductance recorded at mid-column depth at sites within FA-104 (Whiskers Creek) and FA-128 (Slough 8A).

Focus Area	Site	Water Body	Habitat Type[1]	Date	Temperature (°C)	Specific Conductance (µS/cm)
104	CFSL-40	Chicken Foot slough	Side Slough	4/12/13	2.2	120.3
	MC-50	Susitna River	Main channel	4/12/13	0.1	149.8
	SL3A-70	Slough 3A	Upland Slough	3/25/13	1.0	57.9
	SL3A-70	Slough 3A	Upland Slough	4/12/13	2.5	61.6
	SL3A-75*	Seepage; Slough 3A	Upland Slough	3/25/13	2.5	56.5
	SL3B-10	Slough 3B	Side Channel	3/25/13	1.1	55.9
	WC-10	Whiskers Creek	Tributary	4/13/13	0.8	20.0
	WSC-10	Whiskers Side Channel	Side Channel	3/25/13	0.2	149.2
	WSL-15	Whiskers Slough	Side Slough	2/6/13	0.5	23.0
	WSL-18	Whiskers Slough	Side Slough	3/25/13	0.8	25.2
	WSL-20	Whiskers Slough	Side Slough	2/6/13	0.4	23.0
	WSL-35	Whiskers Slough	Side Slough	2/6/13	1.8	43.0
	WSL-40	Whiskers Slough	Side Slough	2/6/13	2.7	45.0
	WSL-40	Whiskers Slough	Side Slough	4/13/13	3.3	49.9
128	HMSL-20	Half Moon Slough	Upland Slough	4/10/13	1.4	144.5
	HMSL-25	Half Moon Slough	Upland Slough	4/10/13	2.8	168.2
	MC-50	Susitna River	Main Channel	4/10/13	0.1	168.2
	SC8A-15	Side Channel 8A	Side Channel	4/10/13	2.3	124.6
	SC8A-15*	Seepage; Side Channel 8A	Side Channel	4/10/13	4.2	147.4
	SC8A-20	Side Channel 8A	Side Channel	3/22/13	0.6	109.0
	SC8A-28	Side Channel 8A	Side Channel	4/9/13	3.1	124.5
	SC8A-30	Side Channel 8A	Side Channel	3/22/13	1.7	149.0
	SC8A-30	Side Channel 8A	Side Channel	4/9/13	1.5	149.9
	SL8A-10	Slough 8A	Side Slough	3/22/13	1.0	114.0
	SL8A-10	Slough 8A	Side Slough	4/9/13	4.3	113.4
	SL8A-15	Slough 8A	Side Slough	4/10/13	1.5	99.0
	SL8A-44	Slough 8A	Side Slough	4/9/13	1.9	95.9
	SL8A-50	Slough 8A	Side Slough	3/22/13	3.0	104.0
	SL8A-50	Slough 8A	Side Slough	4/9/13	3.3	105.8
	SL8A-50*	Seepage; Slough 8A	Side Slough	4/9/13	3.3	105.2
	SL8A-52	Slough 8A	Side Slough	4/9/13	1.7	123.3
	SSC-20	Skull Side Channel	Side Channel	4/10/13	0.2	162.3
	SSC-20	Seepage; Skull Side Channel	Side Channel	4/10/13	1.9	137.0
	SSC-30	Skull Side Channel	Side Channel	4/10/13	0.3	161.4
	US2-10	Upland Slough 2	Upland Slough	3/22/13	2.7	149.0
	US2-10	Upland Slough 2	Upland Slough	4/10/13	2.9	148.0
	US2-11	Upland Slough 2	Upland Slough	4/10/13	2.0	140.4

Notes:

1 Habitat designations are based on 2012 Middle Susitna River remote line habitat mapping (HDR 2013).

Table 2. Total number of fish captured by species and lifestage during daytime and nighttime electrofishing surveys conducted in FA-104 and FA-128 in March and April 2013.

Site	Survey Date	Habitat Type[1]	Area Surveyed (sq. ft.)	Capture totals, by species: Chinook, Juvenile	Capture totals, by species: Coho, Juvenile	Capture totals, by species: Sculpin sp., Juvenile, adult	Total Count
104-WSL-20	24-Mar	SS	12502	0	0	8	*8*
104-WSC-10	24-Mar	SC	4256	0	0	0	*0*
104-SL3B-10	24-Mar	SC	3432	1	0	4	*5*
104-SL3A-71	24-Mar	US	4455	1	0	35	*36*
	25-Mar[2]		4455	12	3	35	*50*
128-SL8A-10	22-Mar	SS	14850	0	0	1	*1*
	22-Mar[2]		14850	3	0	0	*3*
	9-Apr		18150	2	0	8	*10*
128-SC8A-28	9-Apr	SC	4356	0	0	0	*0*
	9-Apr[2]		4356	7	0	6	*13*
128-SSC-20	10-Apr	SC	5610	0	0	0	*0*
	10-Apr[2]		5610	0	0	0	*0*
128-US2-10	22-Mar	US	240	0	0	0	*0*
	22-Mar[2]		240	1	0	0	*1*

Notes:

1 SS = Side slough, SC = Side Channel, US = Upland Slough; habitat designations are based on 2012 Middle Susitna River remote line habitat mapping (HDR 2013).

2 Survey was conducted at night.

Table 3. Total number of HSC observations recorded during electrofish sampling in March and April 2013 by species and lifestage.

Species	Lifestage	Whiskers Slough, FA-104	Slough 8A, FA-128	Total
Chinook salmon	Juvenile	14	12	26
Coho salmon	Juvenile	3	0	3

10. FIGURES

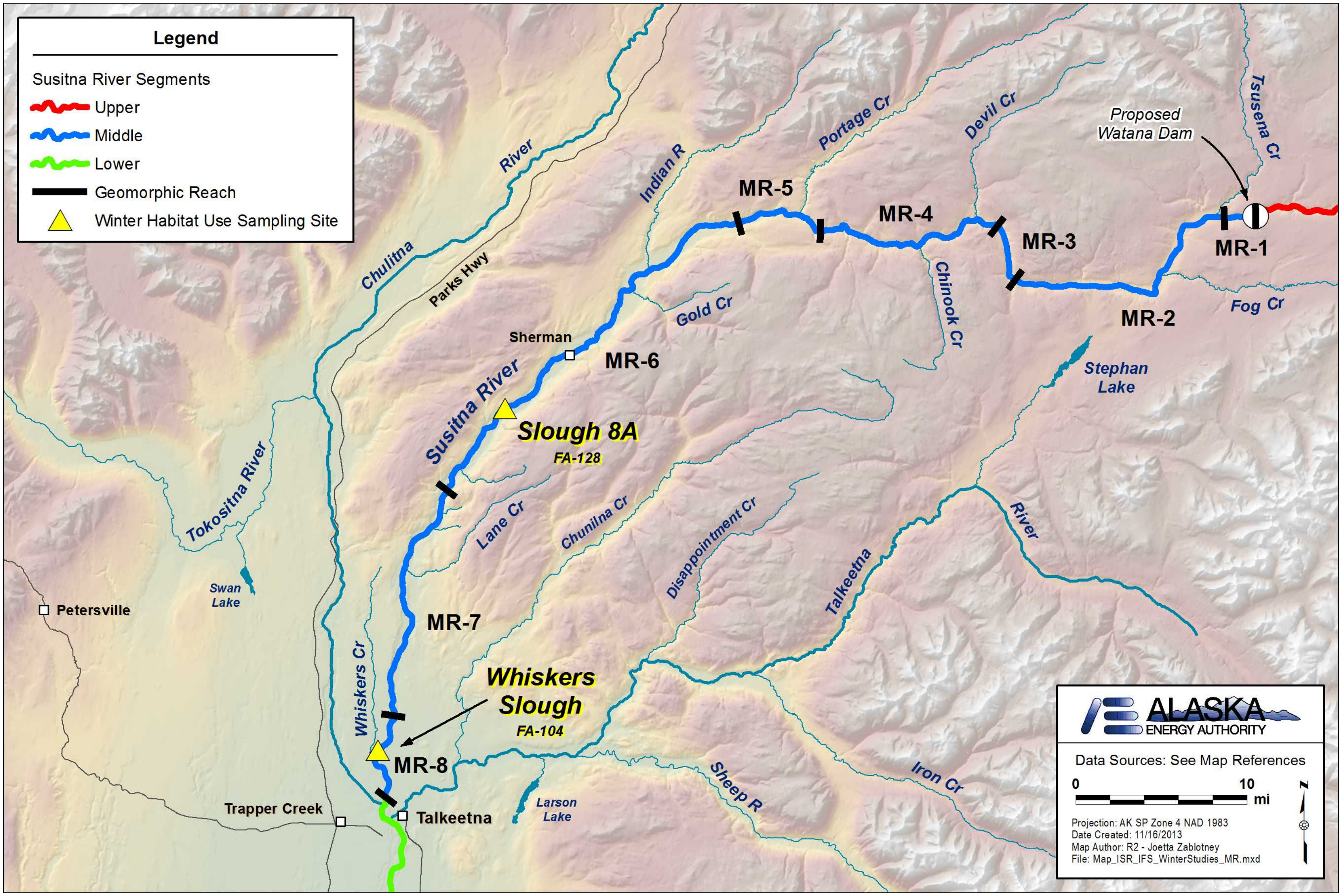


Figure 1. Location of Focus Areas used for 2012-2013 winter data collection.

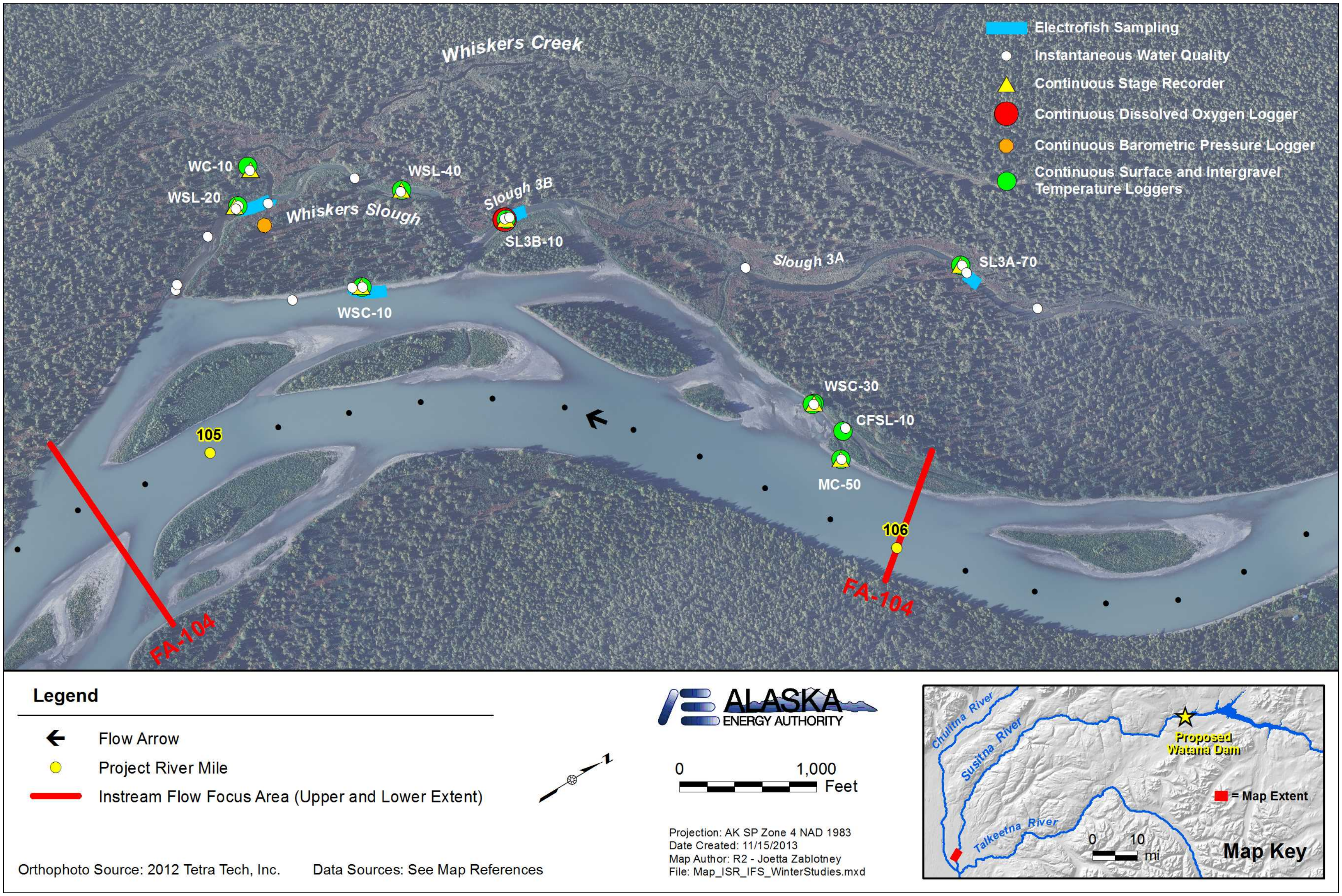


Figure 2. Locations of 2012-2013 winter sites for continuous and instantaneous water quality monitoring, water level monitoring, and fish sampling in FA-104.

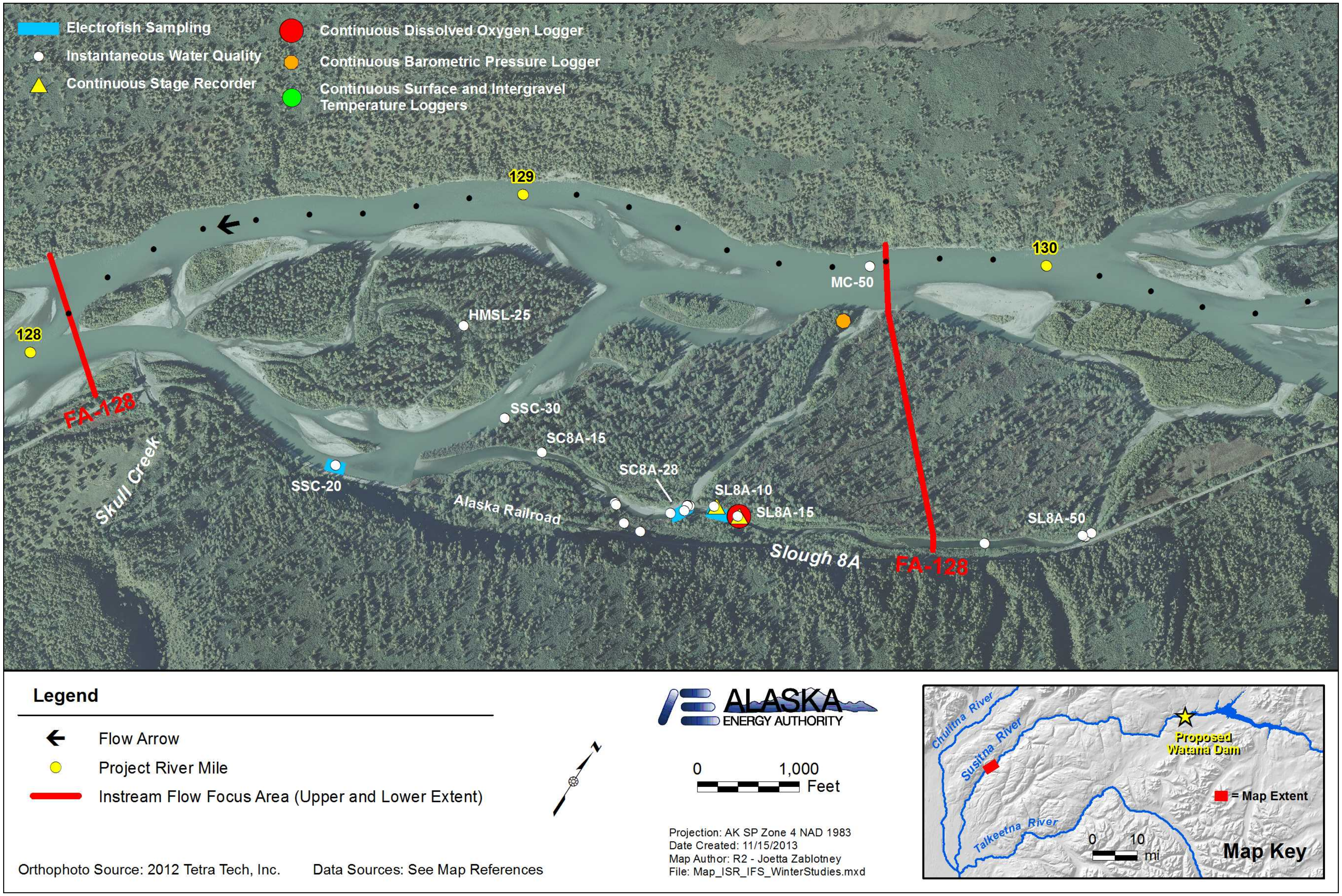


Figure 3. Locations of 2012-2013 winter sites for continuous and instantaneous water quality monitoring, water level monitoring, and fish sampling in FA-128.

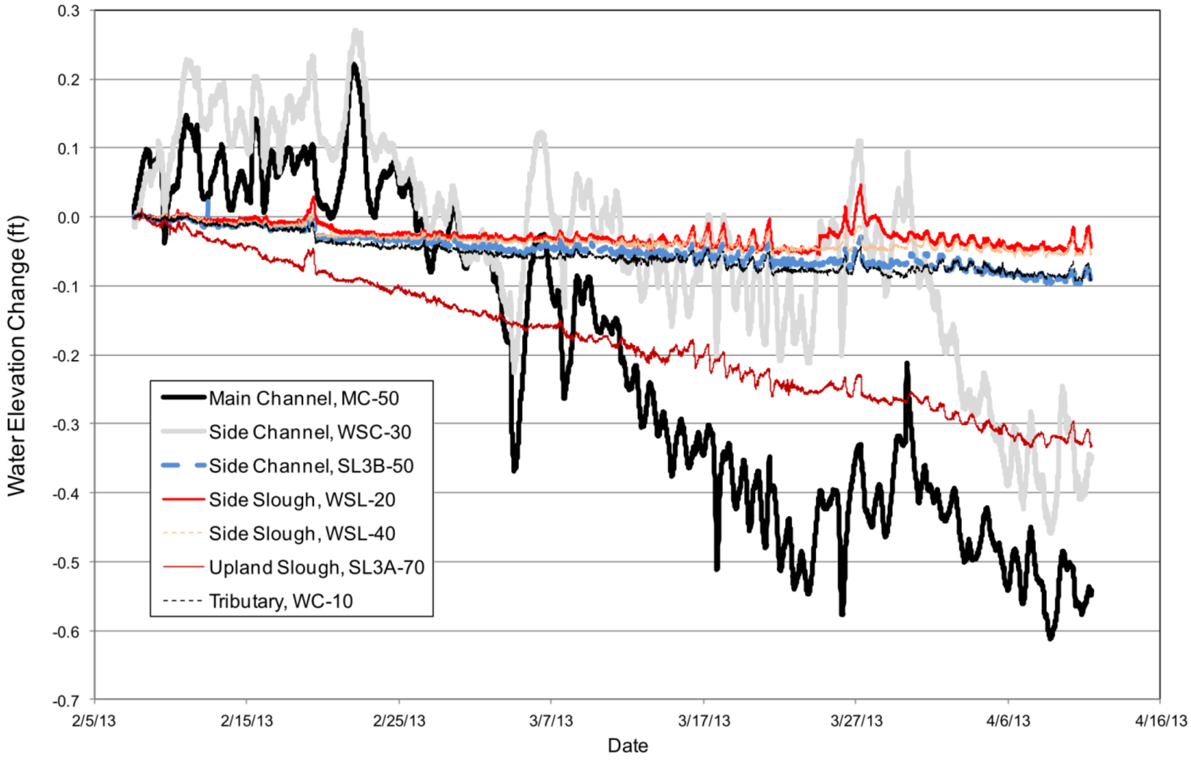


Figure 4. Comparison of change in normalized water surface elevation among continuous monitoring sites in FA-104 during February through April 2013. Elevations were normalized to zero at the start of main channel stage data collection on February 7.

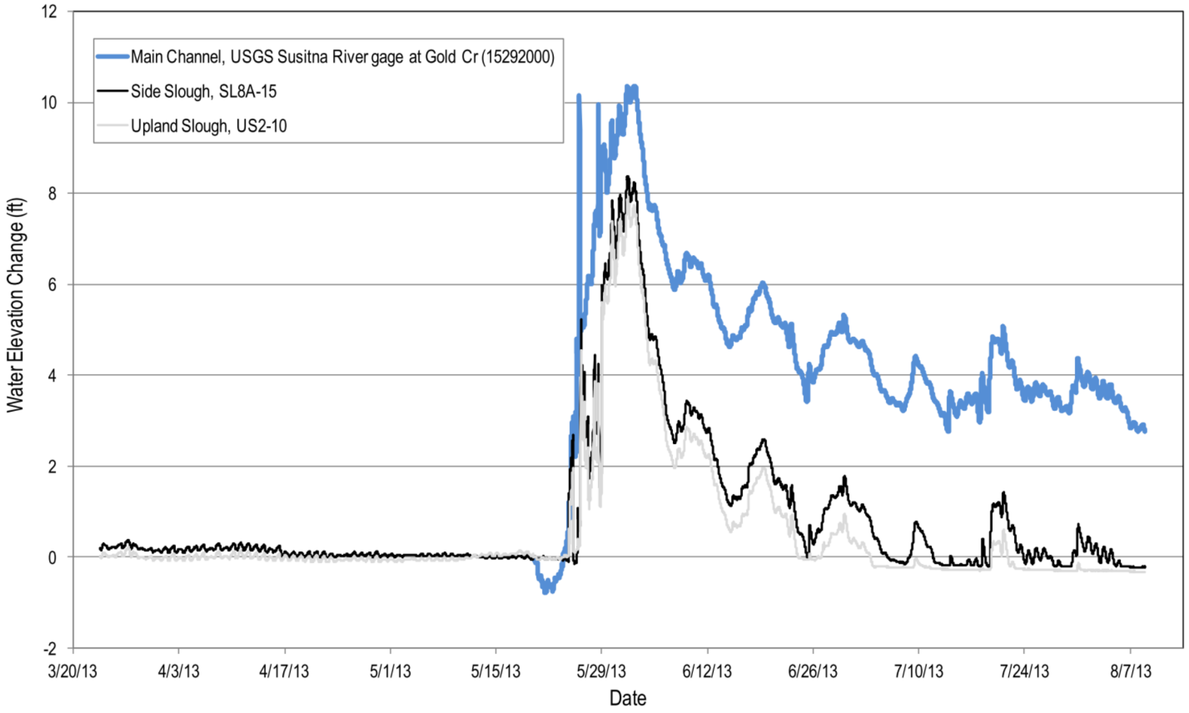


Figure 5. Comparison of change in normalized water surface elevation among continuous monitoring sites in FA-128 and the USGS Susitna River gage at Gold Creek (#15292000) during March through early August 2013. Elevations were normalized to zero at time of ice-free main channel stage data collection at the USGS gage on May 20.

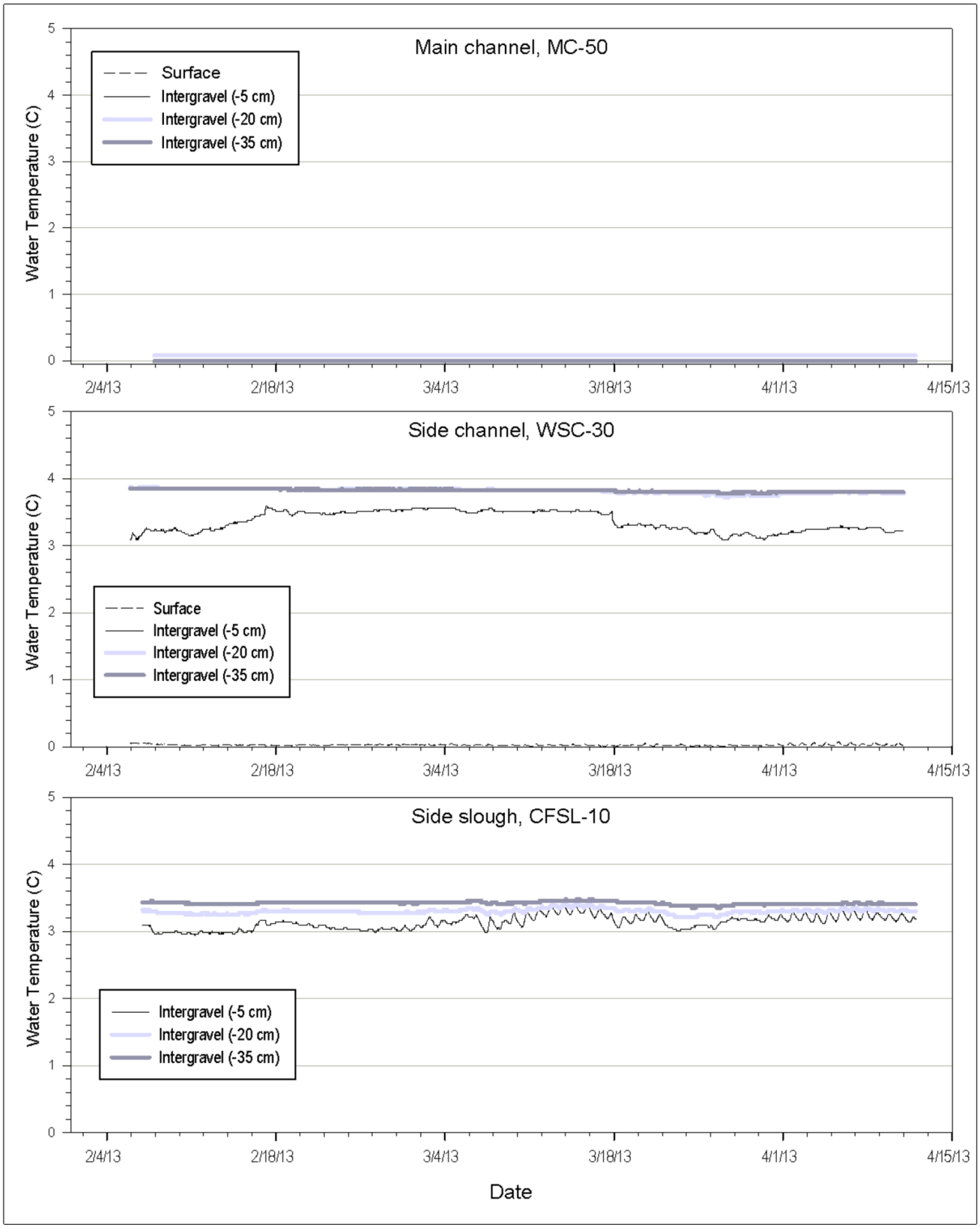


Figure 6. Water temperature recorded above the substrate surface and at intergravel depths of 5 cm (2 in), 20 cm (7.9 in), and 35 cm (13.8 in) at main channel (MC-50), side channel (WSC-30) and side slough (CFSL-10) continuous monitoring sites in FA-104 during February - April 2013.

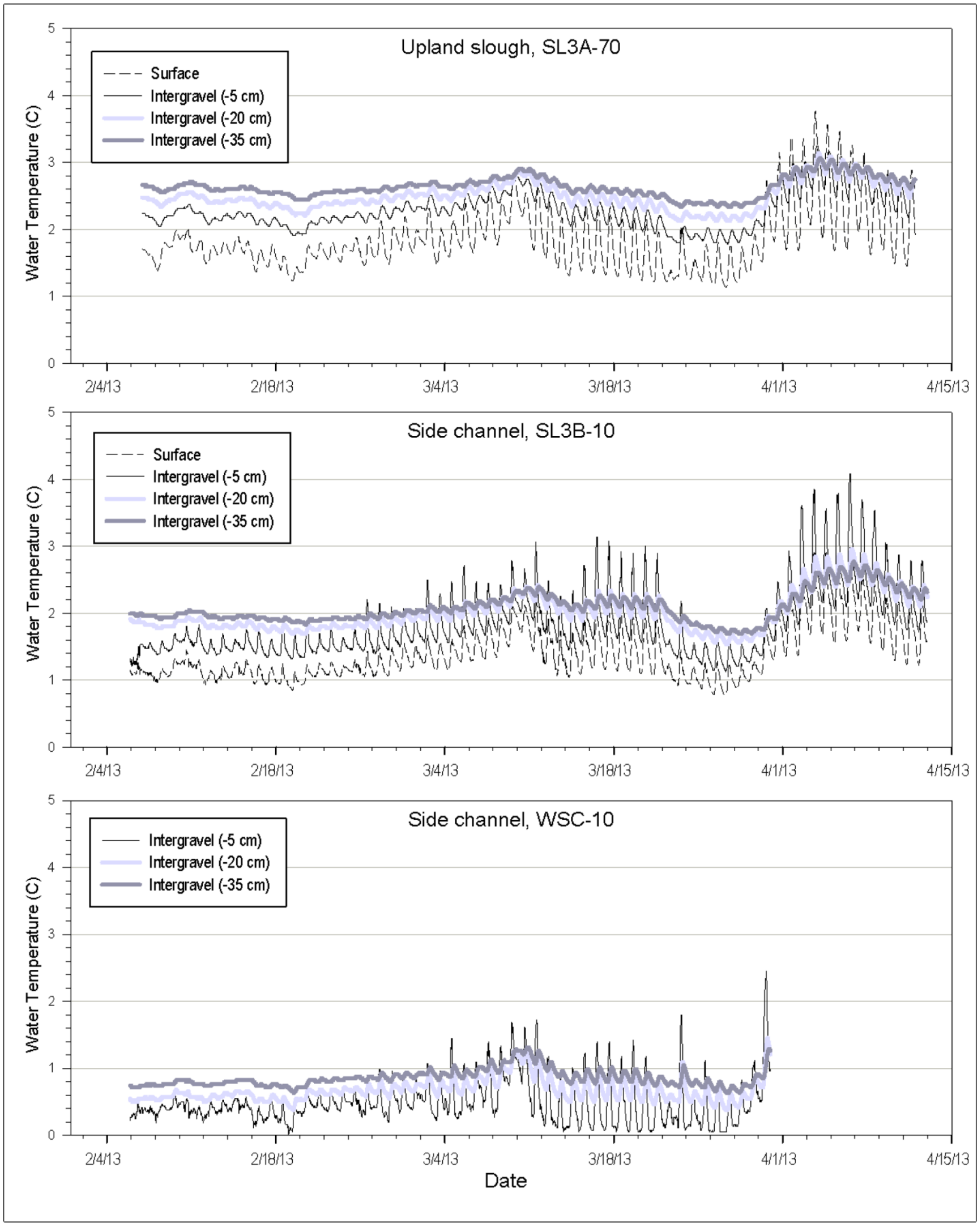


Figure 7. Water temperature recorded above the substrate surface and at intergravel depths of 5 cm (2 in), 20 cm (7.9 in), and 35 cm (13.8 in) at upland slough (SL3A-70) and side channel (SL3B-10, WSC-10) continuous monitoring sites in FA-104 during February - April 2013.

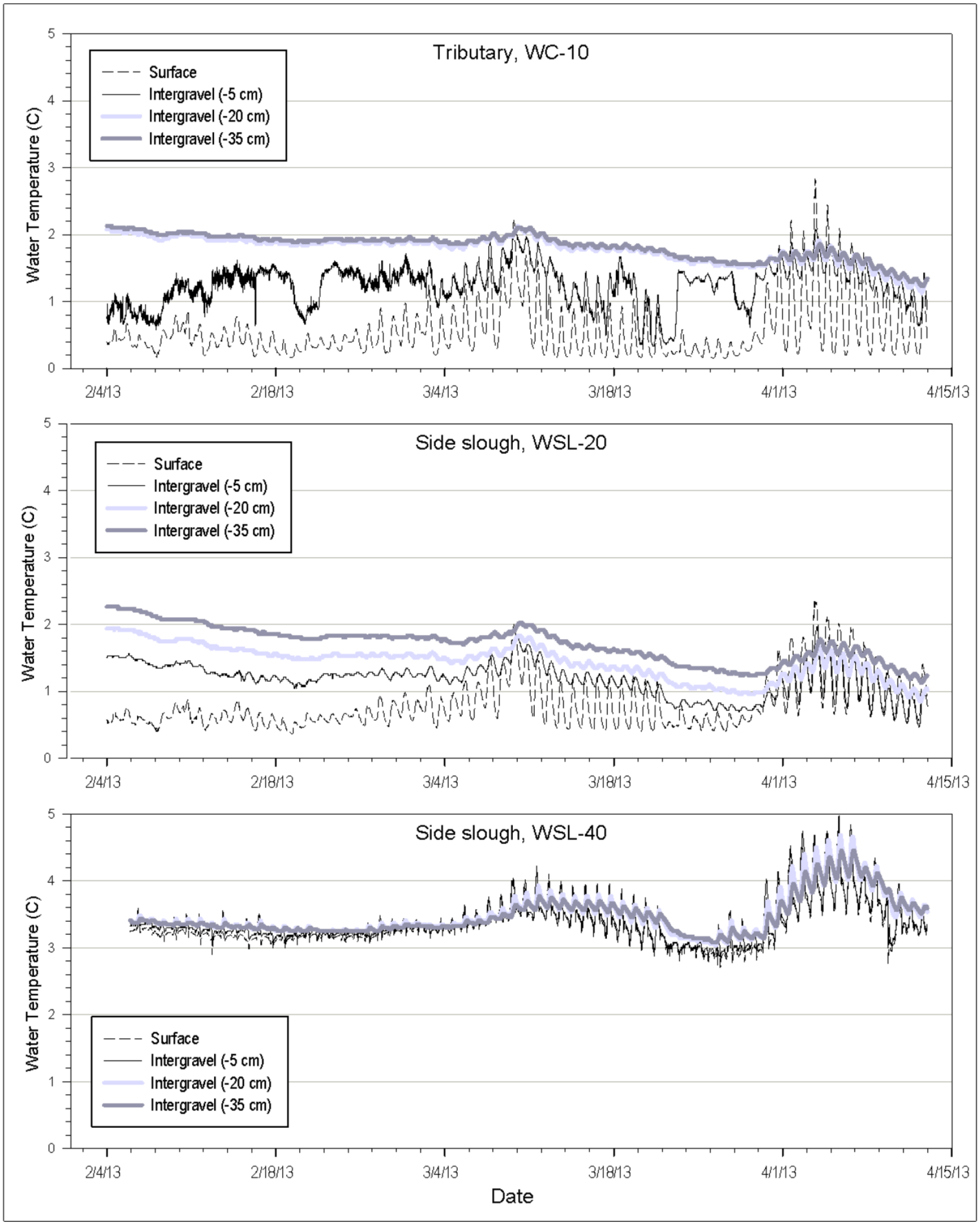


Figure 8. Water temperature recorded above the substrate surface and at intergravel depths of 5 cm (2 in), 20 cm (7.9 in), and 35 cm (13.8 in) at tributary (WC-10) and side slough (WS-20, WS-40) continuous monitoring sites in FA-104 during February - April 2013.

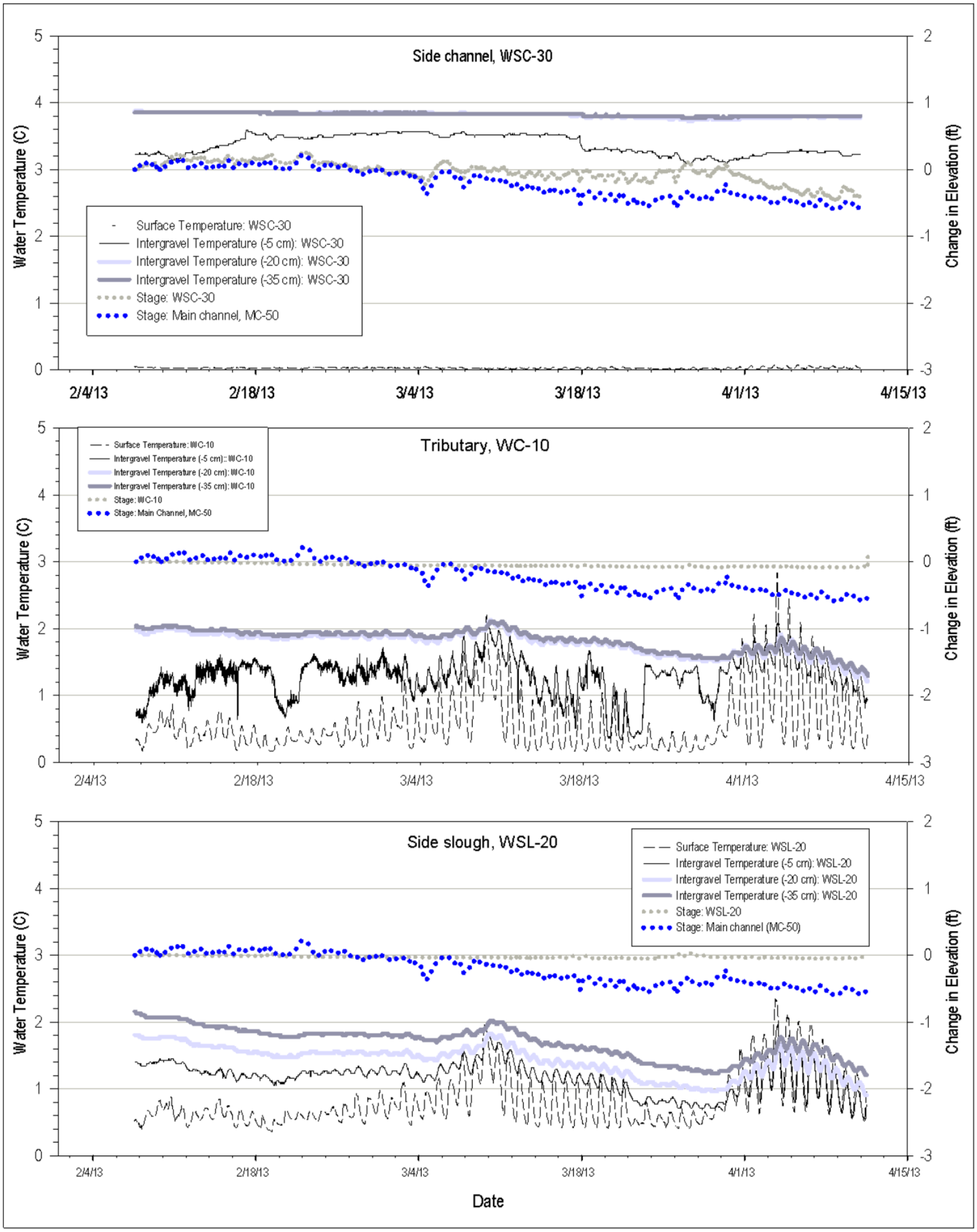


Figure 9. Comparison of continuous surface and intergravel water temperatures recorded above the substrate surface and at intergravel depths of 5 cm (2 in), 20 cm (7.9 in), and 35 cm (13.8 in) at side channel (WSC-30), tributary (WC-10) and side slough (WSL-20) sites relative to change in normalized water surface elevation at each site and at main channel site MC-50. Water elevations were normalized to zero at the start of main channel stage data collection on February 7.

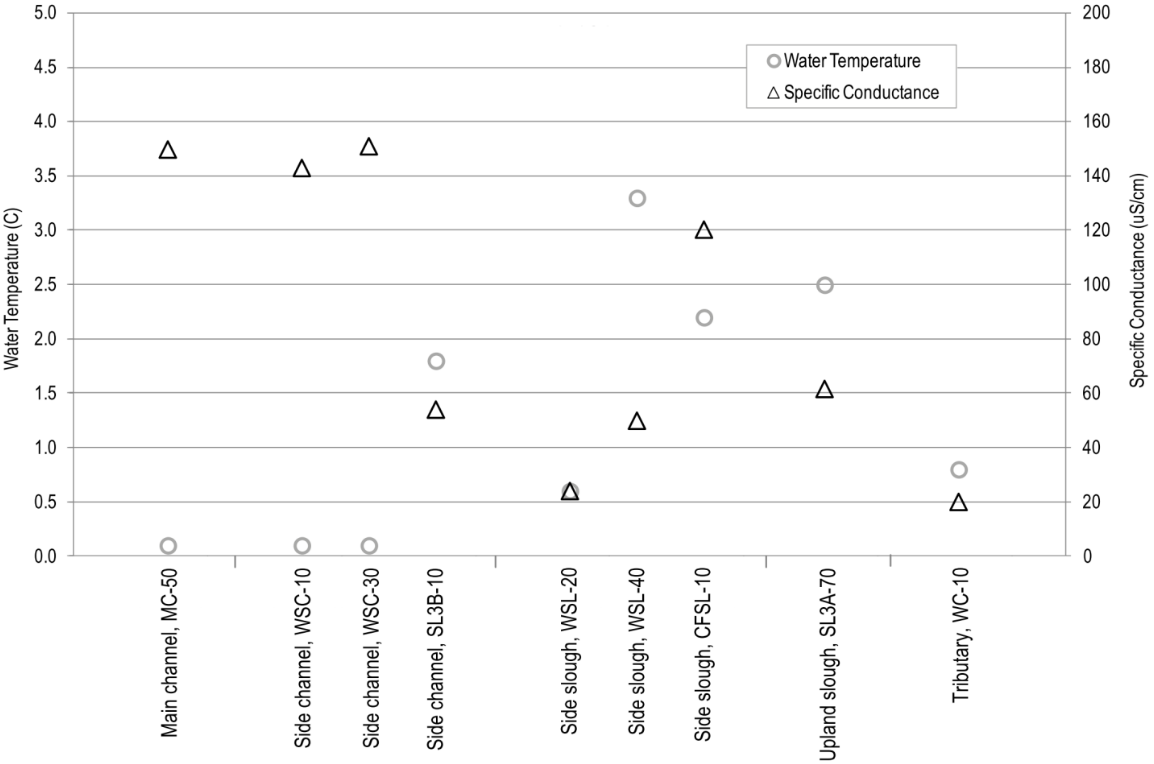


Figure 10. Instantaneous measurements of surface water temperature and specific conductance recorded at sites in FA-104 during April 2013, by habitat type.

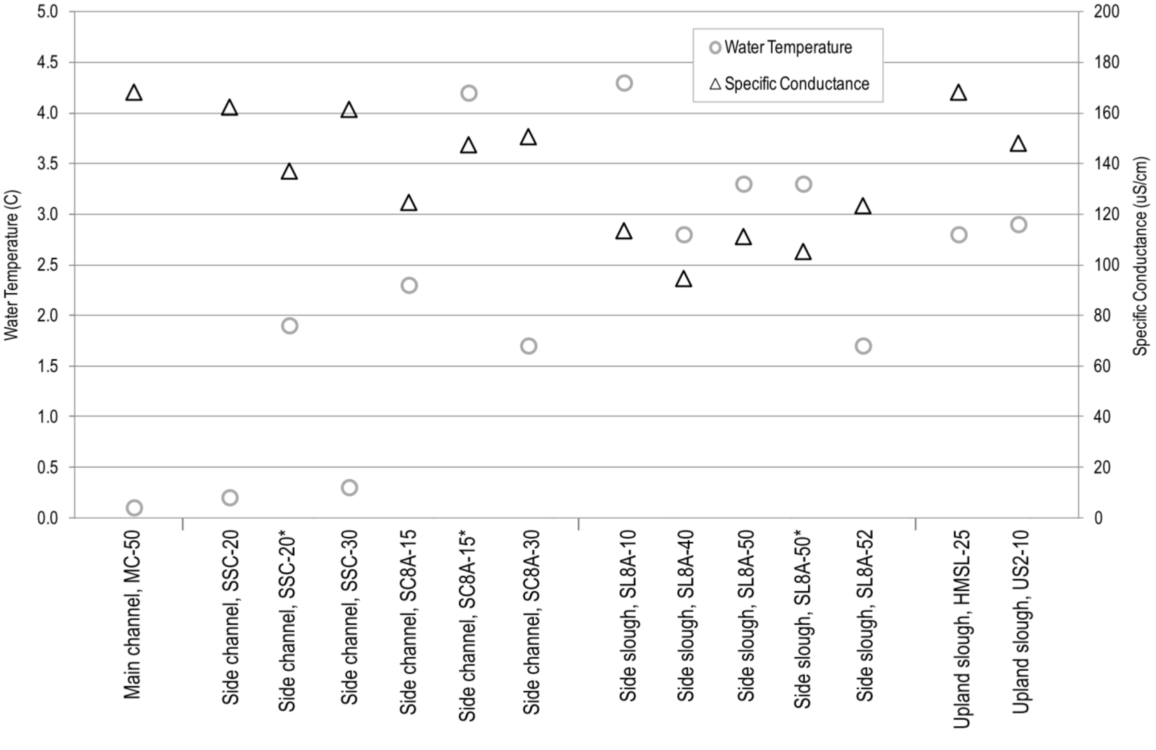


Figure 11. Instantaneous measurements of surface water temperature and specific conductance recorded at sites in FA-128 during April 2013, by habitat type. Asterisks represent measurements of bank seepage.

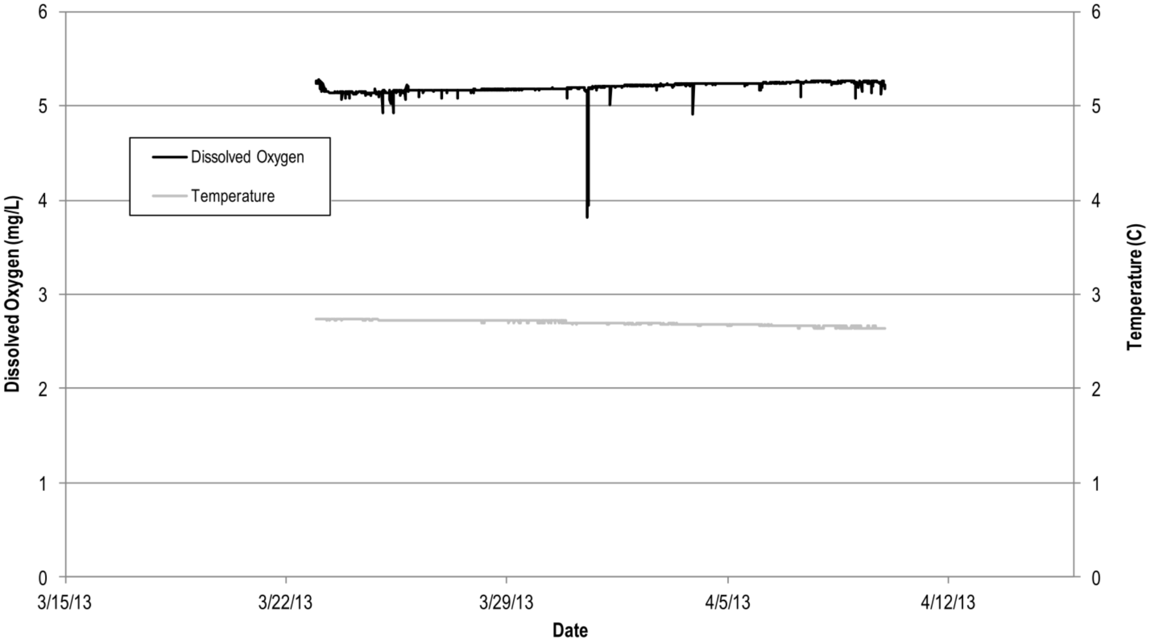


Figure 12. Dissolved oxygen concentration and water temperature recorded approximately 20 cm (7.9 in) below the substrate surface at Site SL8A-15 in FA-128 during March and April 2013.

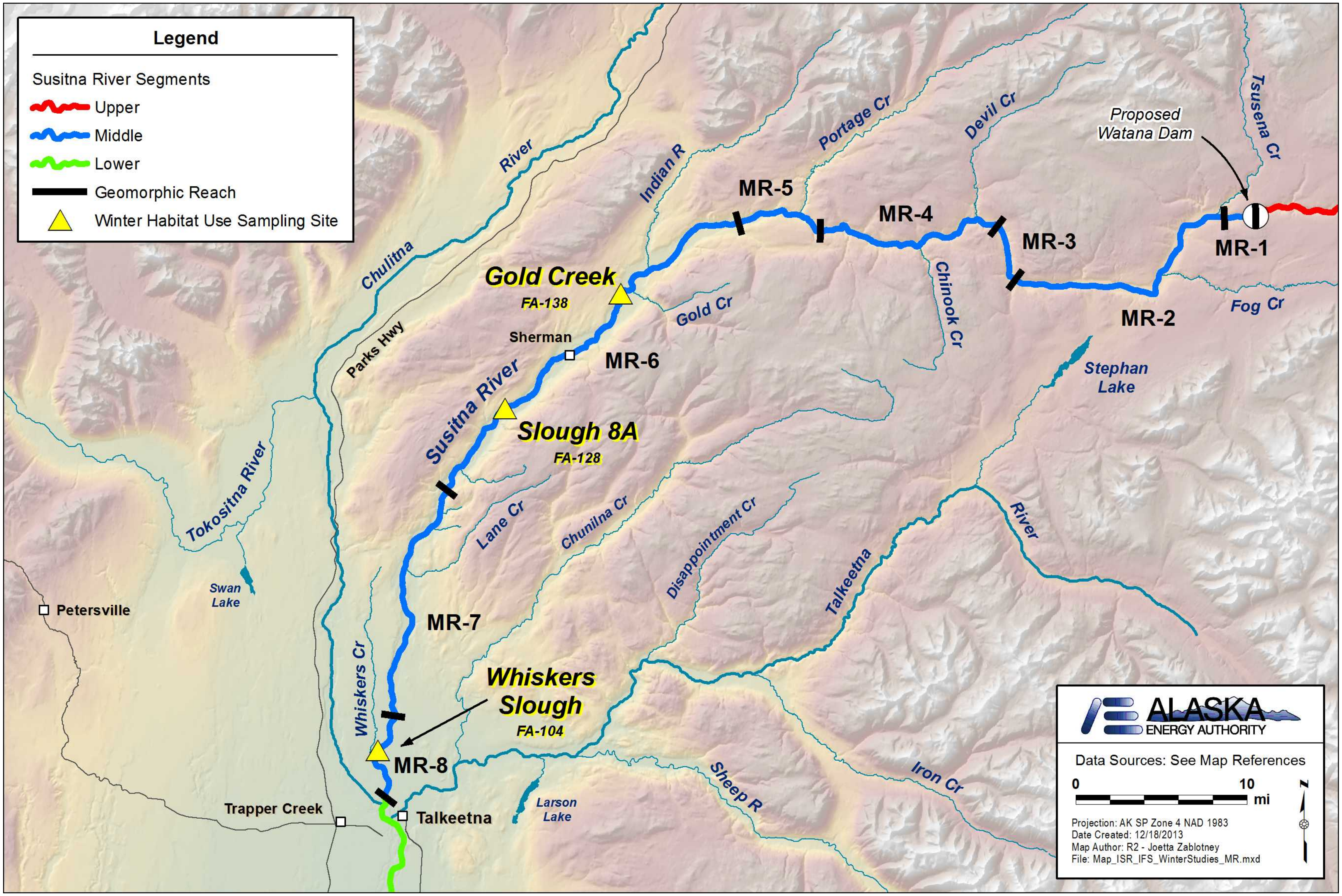


Figure 13. Location of Focus Areas to be used for 2013-2014 winter data collection.

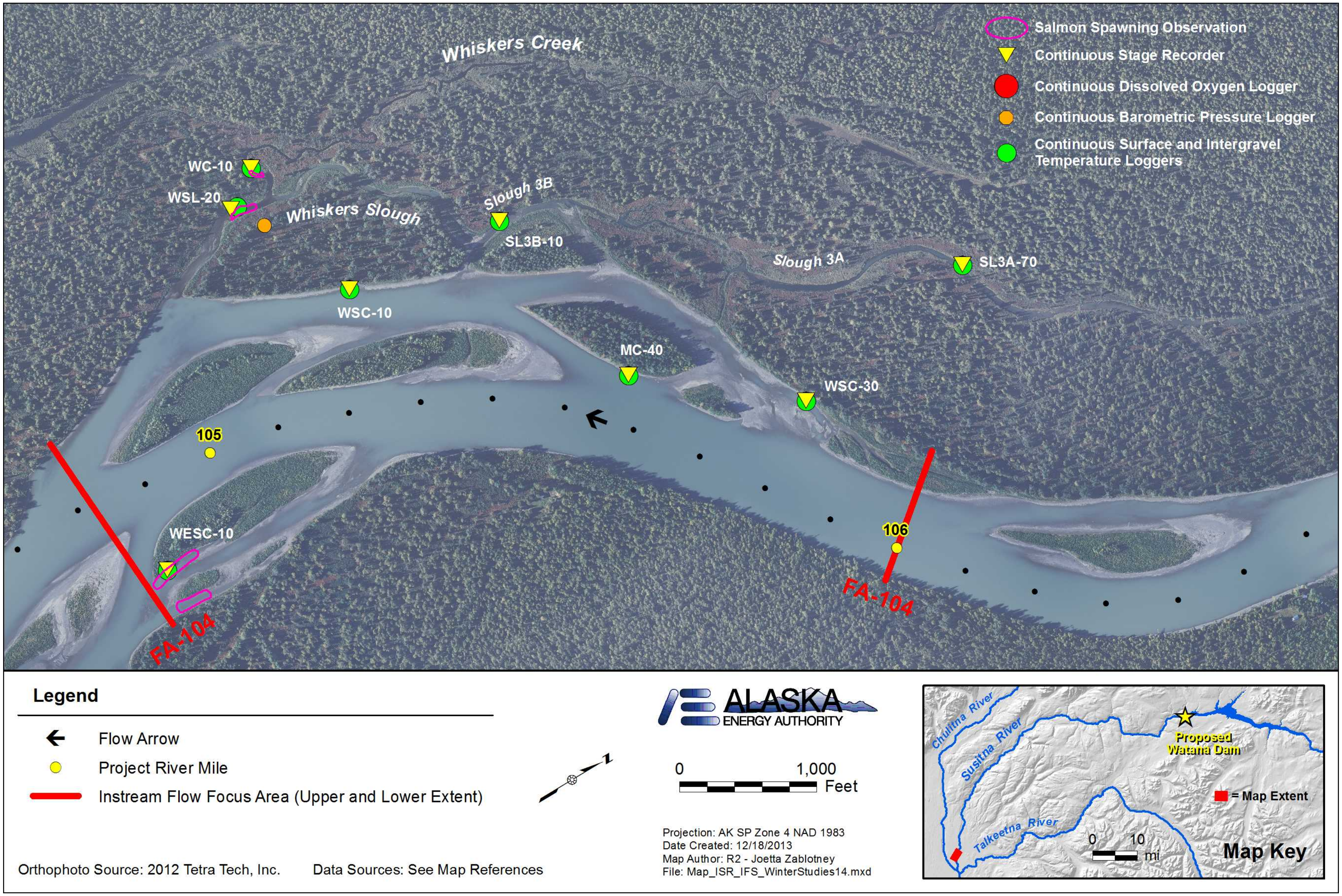
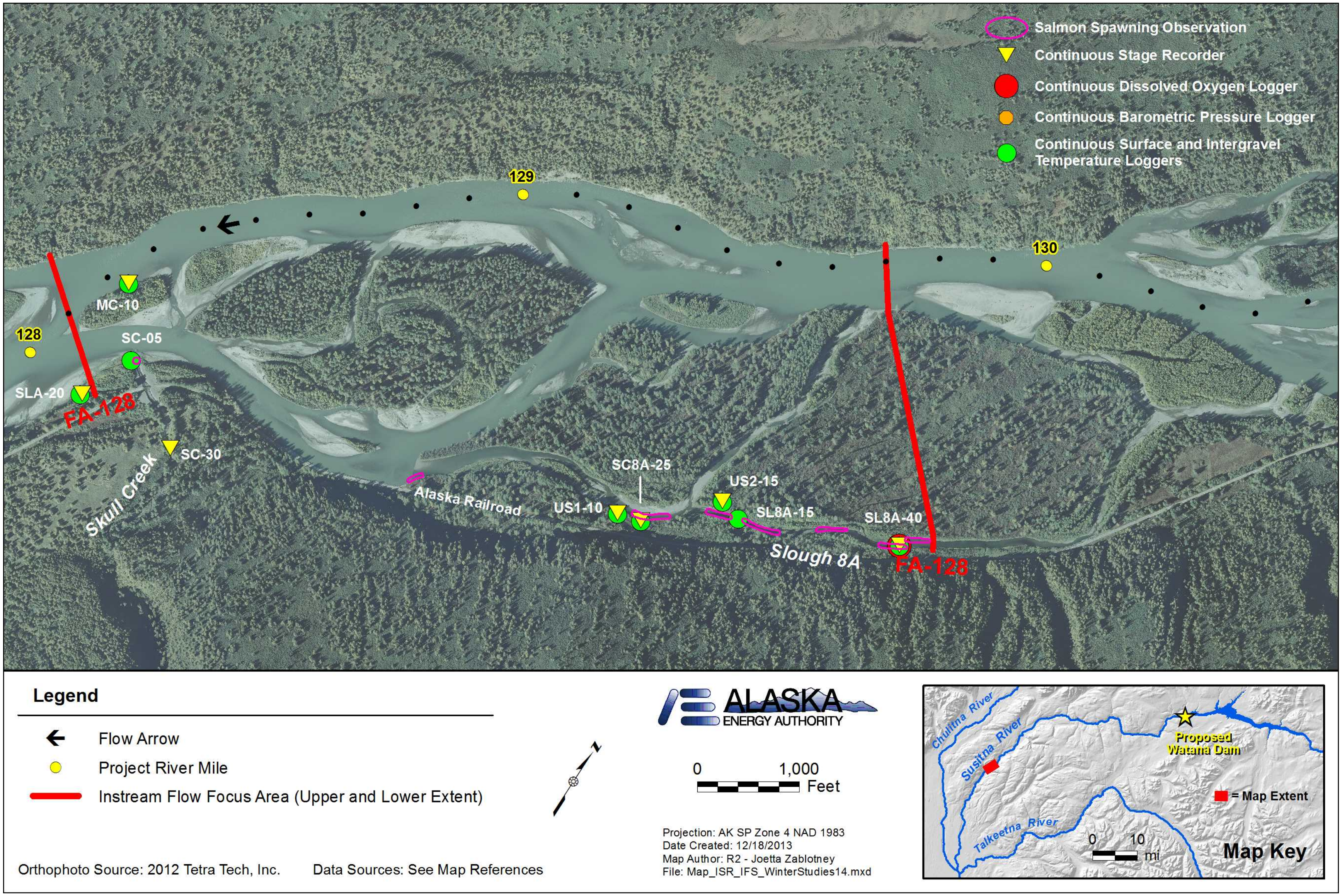


Figure 14. Locations of 2013-2014 winter sites for continuous water level and water quality monitoring relative to observed 2013 salmon spawning areas in FA-104.



Orthophoto Source: 2012 Tetra Tech, Inc.
Data Sources: See Map References

Projection: AK SP Zone 4 NAD 1983
Date Created: 12/18/2013
Map Author: R2 - Joetta Zablotney
File: Map_ISR_IFS_WinterStudies14.mxd

Figure 15. Locations of 2013-2014 winter sites for continuous water level and water quality monitoring relative to observed 2013 salmon spawning areas in FA-128.

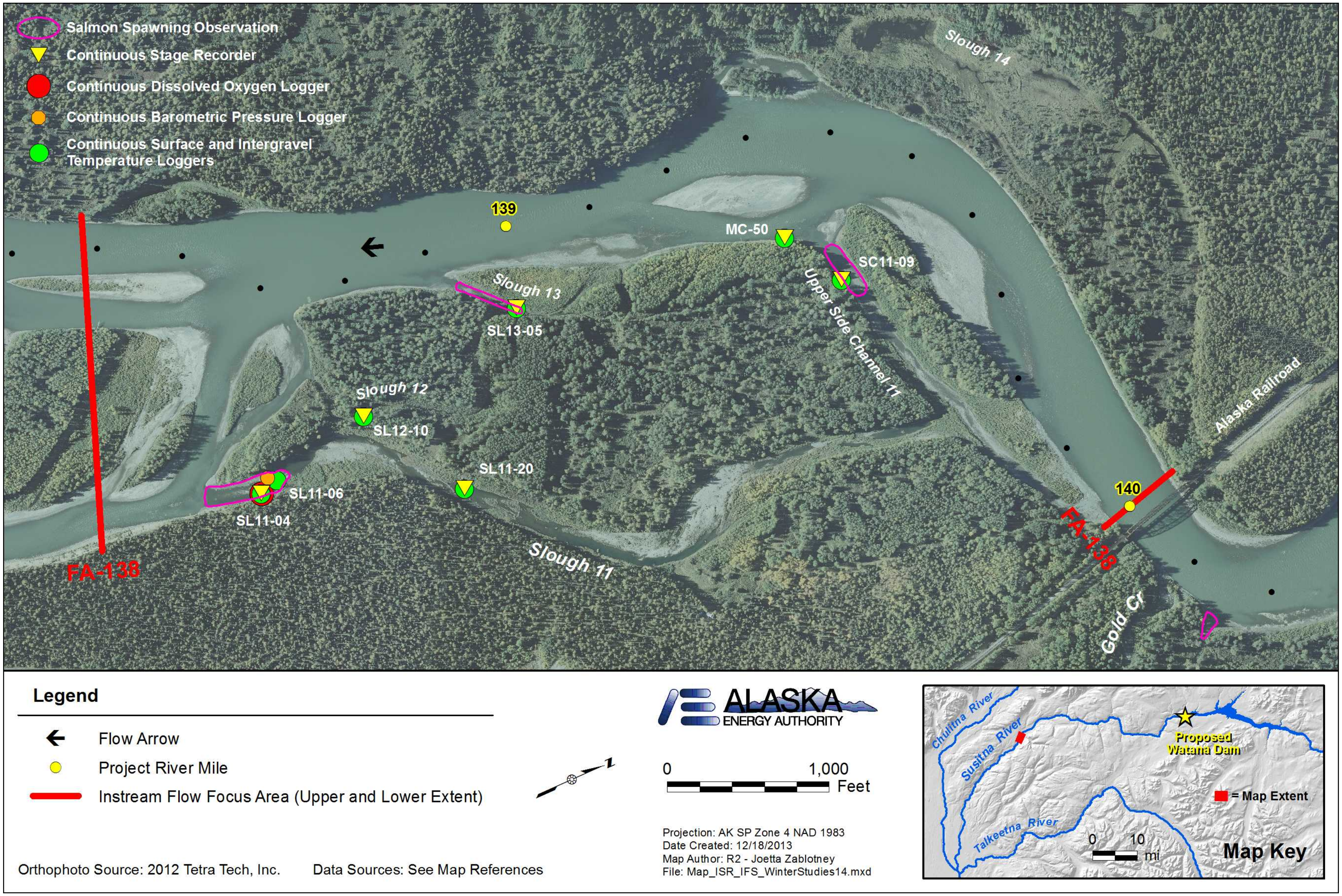


Figure 16. Locations of 2013-2014 winter sites for continuous water level and water quality monitoring relative to observed 2013 salmon spawning areas in FA-138.

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fish and Aquatics Instream Flow Study (8.5)

Initial Study Report
Part C - Appendix M
Habitat Suitability Curve Development

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO
Clean, reliable energy for the next 100 years.

Prepared by

R2 Resource Consultants, Inc.

June 2014

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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
DeltaAIC	Difference in Akaike's Information Criteria between two models
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

Habitat Suitability Criteria (HSC) curves and Habitat Suitability Indices (HSI), collectively HSC/HSI, have been utilized by natural resources scientists for over two decades to assess the effects of habitat changes on biota. HSC/HSI curves/models provide a quantitative relationship between numerous environmental variables and habitat suitability. They represent an assumed functional relationship between an independent variable, such as depth, velocity, substrate, groundwater upwelling, turbidity, etc., and the response of a species life stage to a gradient of the independent variable (suitability). In traditional instream flow studies, HSC/HSI curves for depth, velocity, substrate and/or cover are combined in a multiplicative fashion to rate the suitability of discrete areas of a stream for use by a species and life stage of interest. HSC/HSI curves translate hydraulic and channel characteristics into measures of overall habitat suitability. Depending on the extent of data available, HSC curves can be developed from the literature, or from physical and hydraulic measurements made in the field in areas used by the species and life stages of interest (Bovee 1986).

This appendix presents AEA's planned statistical approach for developing habitat suitability criteria/models for the Susitna River using site-specific habitat utilization and availability data. Ultimately, the habitat suitability modeling will provide information on which habitat variables (of those collected synoptic with HSC/HSI) are most predictive of fish presence, as well as final predictive multivariate HSC/HSI models to be used to assess Project effects. The results presented in this appendix are intended to provide detail on the HSC/HSI development process, including examples of preliminary findings for chum salmon spawning and coho salmon fry. These models will be refined and updated as more data are collected and the process is finalized. The same general process will be followed for all species and life stages for which sufficient observations can be attained.

For some species and life stages, the 2013 site-specific HSC/HSI curves discussed above may be used as final curves. However, additional HSC sampling is planned for the next year of study and it is anticipated that most HSC/HSI relationships will be updated. For species and life stages that are rarely observed, final HSC/HSI curves may be based on additional data, including utilization data from 2012 and the 1980s studies on the Susitna River. However, there may still be some species where few or no empirical HSC/HSI data were attainable. In those cases, AEA will consider methods based on literature, enveloping (see, for example, Jowett et al. 1991, and GSA BBEST 2011), guilding (e.g., creating a combined HSC/HSI curve representing multiple species and/or life stages; see, for example, Vadas, Jr. and Orth 2001, GSA BBEST 2011), expert opinion/round table discussions), and Bayesian statistical methods for combining different sources of data (see, for example, Hightower et al. 2012).

Draft site-specific HSC/HSI curves developed based on the 2013 data were presented at an Instream Flow Study (IFS) Technical Team (TT) meeting March 21, 2014 (AEA 2014), and have been updated based on corrections to data and improved analyses. Data collected during the next year of study will include availability data and will be combined with the 2013 data to refit the logistic regressions, with potential consideration of different time periods.

2. METHODS

2.1 General Approach

Habitat suitability will be determined based on the likelihood of habitat use by each fish species/lifestage. Habitat observations have been taken where fish have been observed (utilization data) and at additional stratified random locations at each selected sampling site (availability data). The probability of fish presence as a function of habitat variables will be modeled with univariate and multivariate logistic regression, using availability measurements as a "0" response and utilization measurements as a "1" response (Manly et al. 1993). Logistic regression is a generalized linear model used for non-normally distributed (e.g., binomial) dependent variables. The models will include polynomial effects when the hypothesized relationships with individual variables may be non-linear.

For practical sampling reasons, observations locations were comprised of sampling sites which can be viewed as clusters of fish utilization and availability measurements. Generally, the clusters (sites) are included as random effects in statistical models, to prevent bias based on unequal sampling probabilities. Mixed effects models (with a random effect for site) provide a way to account for differences among blocks without fitting separate means for each block.

Because of the ephemeral nature of spawning and the vast spatial scale of the Susitna River, it seemed unlikely that random sites alone would provide enough spawning information for HSC/HSI curves. In order to attain more spawning observations, non-random historic spawning locations were also sampled as time allowed (heretofore labeled "select" spawning sites). These non-random sites are likely to have higher overall percentages of observed spawning; it is possible that they also have different relationships with habitat variables. Because of this potential difference, a fixed two-level factor for this grouping is included in the set of potential "univariate" models as a main effect or as an interaction effect. If the interaction effect appears in the best fit model, this would indicate differences among the two types of sites other than mean spawning level, which should be investigated. The final model cannot include this factor because it would not be possible to segregate all locations on the river into these categories.

2.2 Univariate Models

Models including only one habitat variables are referred to as univariate models, although fixed and random blocking variables are included. Univariate models were attempted for:

- Depth
- Velocity
- Substrate (Redds) or Cover (Other species/lifestages)
- Upwelling (Categorical: positive vertical hydraulic gradient (VHG) => Upwelling)
- Surface water temperature
- Dissolved oxygen
- Conductivity

Polynomial models up to order 4 were included, using the *glm* function in *R* (version 3.02; R Core Team 2013) for fixed effects models, and the *glmer* function in R package *lme4* (Bates et al. 2013) for models including random effects. Best fitting models were selected based on minimizing Akaike's Information Criteria (AIC). Models with absolute AIC within 2.0 of the best model are considered potential models (Burnham and Anderson, 2002), while models outside of this range have weak to no evidence. Following Zuur et al. (2009), the inclusion of the random effect was evaluated first, comparing the model allowing random means for each site with the full model (the habitat variable polynomial, the random/select site grouping factor, and interaction between them). In the second step, the interaction between site group and the habitat variable was evaluated. If this term was included in the best fit model, the form of interaction was evaluated. Clear differences in the impact of the habitat variable at random versus select sites may indicate cause for concern.

In the third step, the null model with the best random structure (random effect or no random effect) was compared to polynomial models with the habitat variable in question, without the site grouping factor. If no models containing the habitat variable were superior to the null model using the 2.0 AIC criteria, then there is no or weak evidence that the habitat variable has predictive value for this fish species/lifestage. If there was strong evidence that any model containing the habitat variable provides a superior fit, it may be predictive, and it is retained for HSC analysis.

2.3 Multivariate Models

For instream flow models, suitability indices from univariate HSC/HSI curves based on depth, velocity, and substrate are typically multiplied together to form a composite suitability index. Other methods include using the arithmetic or geometric average, the minimum, or a weighted product equation with the exponents determined by multiple linear regression (Ahmadi-Nedushan et al. 2006). However, all of these methods of combining variables are based on an assumption of independence among the predictors, as well as an assumption of the relative importance of each predictor.

Instead, AEA will use a multiple regression approach to combine all significant predictors into an overall estimate of suitability. Interactions among variables (e.g., the impact of velocity depends on substrate type) may be important, and can be examined using multiple regression. Multiple regression candidate models included all combinations of main effects for which univariate models were found to be predictive. The multivariate models were compared using the AIC criterion, and models within AIC of 2.0 of the optimal model (Burnham and Anderson 2002) were considered potential final models.

2.3.1 Multicollinearity

Correlation among predictors in a multiple regression is labeled multicollinearity, and it impacts the precision of individual regression coefficients and their interpretation. It does not impact the strength or predictive capabilities of the model if the prediction space is in the range of data used to fit the model, and if the correlations among variables also remain the same (Neter et al. 1990). However, the relative importance of each predictor cannot be interpreted based on the magnitude of the regression coefficients, which are subject to change depending on which variables are included in the model. For example, when two variables X1 and X2 are strongly collinear, the data contain little information about the impact of X1 when holding X2 constant, because in reality there is little variation in X1 when X2 is fixed.

Because HSC/HSI models are mainly concerned with prediction (e.g., which habitats are most suitable to spawning) as opposed to interpretation of most important habitat covariates, collinearity is not a serious issue for the HSC/HSI analysis. However, measures to reduce collinearity are taken when possible, and collinearity is measured and reported. Although some authors recommend centering continuous variables (i.e., subtracted from the mean value) to reduce collinearity (Neter et al. 1990), this will not produce an HSC/HSI curve that is useful for absolute habitat values. Instead, collinearity in categorical variables (e.g., upwelling) is reduced by fitting them without an overall mean (i.e., intercept) and including multiple categorical variables as combined categories (e.g., sites with upwelling and gravel substrates is one category) rather than as two separate variables.

Variance inflation factors (VIFs) are used as a formal check of collinearity. The square-root of the VIF is an estimate of the multiplicative inflation of the confidence interval around the coefficient estimates. Because the predictors are categorical (substrate and upwelling), the generalized variance inflation factors due to Fox and Monette (1992) are used, with a similar interpretation. If there are p degrees of freedom in a term, then $\mathrm{GVIF}^{1/2p}$ is a one-dimensional expression of the decrease in the precision of estimation due to collinearity. Polynomials of the same variable are obviously correlated, but do not need to be interpreted separately. The generalized VIF is estimated for the model without random effects because it is unclear how to estimate the VIF for mixed effects models. Some authors recommend that VIF>10 indicates a problem with collinearity (Ahmadi-Nedushan et al. 2006, Neter et al. 1990). If the generalized VIF adjusted for degrees of freedom is equivalent to a VIF of 10 or greater for one of the included variables, alternative models will be considered.

2.3.2 Interaction

It is possible that some environmental habitat variables interact in their relationship to fish habitat selection. However, interactions are seldom considered in multivariate habitat suitability modeling. One reason for this may be generally low numbers of fish observations. Even when there are large numbers of observations (as for chum salmon spawning), there may be insufficient replication of environmental conditions to properly infer interaction relationships in most cases. For example, high velocity sites with fine sediments have not been observed, so there cannot be inference on whether suitability at high velocity sites would differ among substrate types. Thus, only carefully selected interactions are included in the HSC/HSI multivariate analysis presented here.

In addition to the main effects multivariate model, all possible models with a single two-way interaction in the original candidate set were also considered. If there was strong evidence that one of these interactions improved model predictions, the interaction term was carefully considered using graphical methods, and retained if the interaction relationship is well-defined. In this case, well defined means there is sufficient replication at the combinations of variables that are driving the interaction effect, and also that the observed interaction effect is biologically reasonable.

3. RESULTS – CHUM SALMON SPAWNING

3.1 Data Considerations

For spawning, only data collected by the HSC/HSI program (i.e., not aerial surveys) were used for this analysis, because availability measurements were necessary. Also, data collected from turbid sampling locations (NTU > 30) were not used, because redds are generally not observable in turbid water.

The intention for the availability data was to quantify the habitat available to spawning chum salmon near the locations and during the time when they were observed. The first chum salmon spawning observation in 2013 was made on August 12, so only availability data collected on or after that date were used. Also, availability data collected during a time when there was no observed spawning within the Focus Area (or within the general vicinity for non-Focus Area sites) were removed from the analysis. Note that this deletion of availability data does not impact the analysis when random effects are used, because in that model, only availability data within sites where spawning is observed impact the analysis.

Observations of VHG, turbidity, water temperature, conductivity, and dissolved oxygen (DO) were not made at every availability and utilization sampling point. Prior to 2013 field sampling, it was anticipated that the variability in these parameters would be fairly minimal, so three measurements per (50m) site were assumed adequate to represent the available habitat. Also, during field sampling, some utilization locations that were near existing water quality measurements were not uniquely sampled. For the spawning HSC/HSI modeling presented in this Initial Study Report (ISR), the following steps were taken to ensure that water quality data at each utilization and availability sampling location was estimated in the most accurate and consistent manner possible. Importantly, this process is not final, and may be revised prior to final HSC/HSI curve development for the USR.

For each utilization sampling location where VHG and water quality parameters were not directly measured, water quality values were assumed to be equivalent to those sampled at the nearest measured point. For each availability sampling location (typically three systematic random cross-channel locations on each of 5 systematic transects), water quality values were either:

1) Sampled water quality data at that point;
2) Sampled water quality on nearest point on the same transect; or
3) Linearly interpolated from water quality values on adjacent transects.

3.2 Univariate Models

The random site effect model attained lower AIC (superior fit) than the fixed model without site effects for every comparison, as expected, due to large differences in overall spawning among sites. Other results are discussed for each habitat variable below.

3.2.1 Depth

Select sites had higher overall mean spawning levels than random sites as expected, but the best-fit model did not include interaction between depth and the site group factor. Without the site factor, the best-fit model with a random effect for sites included a 4th order polynomial for depth. However, the 4th order polynomial model is not an ecologically reasonable shape, as shown in Figure 1. The 3rd order polynomial is a more reasonable selection, and this model still showed very strong evidence for the predictive value of depth (Table 1; Difference between null model AIC and 3rd order polynomial model AIC (deltaAIC) = 56 - 17 = 39).

3.2.2 Velocity

Select sites had higher overall mean spawning levels than random sites as expected, but the best-fit model for velocity did not include interaction with site group factor. Without the site group factor, the best-fit model with a random effect for sites included a 4th order polynomial for velocity. However, this model had an unusual bimodal shape without ecological interpretation, so it was not considered a viable model. The next best fit model was the quadratic model (Table 2). There was strong evidence for the predictive value of velocity (Null model deltaAIC = 9.8 – 0.7 = 9.1).

3.2.3 Substrate

Dominant substrate is not generally thought to be the best predictor of spawning activity. Sometimes subdominant substrate and percent dominant are included in HSC/HSI analyses, resulting in many categories for utilization or preference estimation. Estimating mean values for a large number of categories from a relatively small dataset is not likely to produce consistent defensible results. Upon exploratory review of the data, it was clear that the largest differences among substrates for spawning could be found when substrate groups were formed as follows:

Group 1: Bedrock, boulder or all fine substrate (no observed spawning)

Group 2: Cobble dominant or subdominant with no gravel (some spawning)

Group 3: Gravel dominant or subdominant (most spawning)

This three-level substrate factor was used for this analysis.

For substrate, the best fit model included interaction with site group – indicating that there were some differences in the effect of substrate for random versus select spawning locations. However, the plot in Figure 3 shows that the interaction is related to the higher level of spawning at select sites, allowing a larger drop-off due to lack of spawning substrate (i.e., probability is bounded below by zero). Because this interaction does not impact the interpretation of substrate as a predictor, it may not be of concern. The main effect model with substrate group had very strong evidence of predictive value (Table 3; Null model deltAIC= 118).

3.2.4 Upwelling

Samples were classified as upwelling if the measured VHG was positive. Less than 6% of sampled locations during the 2013 HSC survey had negative VHG, and there was less spawning at these locations than for VHG neutral sites. Rather than estimate three proportions with lower precision, downwelling and neutral sites were combined into a “no-upwelling” category.

For the upwelling group, interaction with site group was not significant. Without the site group in the model, there was evidence that the presence of upwelling is predictive of chum salmon spawning. (Table 4; Null model deltaAIC= 3.3).

3.2.5 Water Temperature

Polynomial models with order higher than two are not ecologically reasonable for water temperature, so only linear and quadratic models are considered. For water temperature, the best fit model did not include interaction with site group. Without site group in the model, the null model with no relationship between probability of spawning and water temperature was superior in fit to both the quadratic and linear models (Table 5). There was no evidence that water temperature is predictive of chum salmon spawning.

3.2.6 Dissolved Oxygen

Polynomial models with order higher than two are not ecologically reasonable, so 3rd and 4th order polynomials are not fit for dissolved oxygen. There is no evidence of interaction between site group and dissolved oxygen in predicting fish presence. The best fit model without the site group factor is the null model (Table 6), therefore there was no evidence of a predictive relationship between DO and chum salmon spawning preference.

3.2.7 Conductivity

Polynomial models with order higher than two are not ecologically reasonable, so 3rd and 4th order polynomials are not fit for conductivity. There was no evidence of interaction between site group and conductivity in predicting fish presence. Without site group, the null model is the best-fit model: there was no evidence that conductivity has predictive value for chum salmon spawning preference (Table 7).

3.3 Multivariate Models

3.3.1 Model fitting

Based on the univariate model results, only depth, velocity, substrate, and upwelling would be included in the multivariate model. Using all of these variables, there is no evidence that multicollinearity is an issue of concern based on generalized variance inflation factors (Table 8). The highest VIF is 1.11, indicating that confidence intervals around predicted coefficients may be 11 percent inflated.

The best fit main effects model including random and select site data is the combination of depth (3rd order polynomial), velocity (2nd order polynomial), substrate group, and upwelling (Table 9). There were two interaction terms, interaction between upwelling and depth, and interaction between substrate group and depth that substantially improved the fit of the main effects model (AIC >2 Units better), and thus require further consideration.

The plot in Figure 4 shows the interaction effect between depth and upwelling that is driving the improved model fit. According to the 2013 HSC data, upwelling is not preferred for spawning when surface water depths are greater than 2 feet. Without a solid ecological interpretation, there is some possibility that this interaction is an artifact of the difficulty in sampling VHG in deeper water. This issue will be investigated further prior to the Updated Study Report.

The plot in Figure 5 shows the interaction effect between depth and substrate group that improves the fit of the model. The 2013 HSC data indicate that the presence of gravel substrate was less important in shallow water than in deep water. This interaction will be further tested with additional data prior to the USR.

3.3.2 Preliminary HSC Multivariate Model for Chum Salmon Spawning

The model presented here is the preliminary HSC model for chum salmon spawning. This model does not include the interaction terms discussed above. This model is only for sites with either dominant or subdominant gravel or cobble; other substrates are assigned a suitability of zero. This model will be refined based on additional data or revised methods.

The preliminary model for chum salmon spawning is:

$$\log\left(\frac{p}{1-p}\right) = C_k + 4.33 * depth - 1.91 * depth^2 + 0.246 * depth^3 + 1.52vel - 0.714vel^2 + \gamma_{site} + \varepsilon,$$

where

p is the probability of chum salmon spawning,

k indexes four intercept values for substrate/upwelling combinations:

$C_{UPGR} = -3.5$ (gravel dominant or subdominant with upwelling present),

$C_{UPCO} = -5.1$ (no gravel, but cobble dominant or subdominant with upwelling present),

$C_{NOGR} = -4.4$ (gravel dominant or subdominant with no upwelling present),

$C_{NOCO} = -5.4$ (no gravel, but cobble dominant or subdominant with upwelling present),

γ_{site} is the random effect for site, and

ε is random error (assumed normally distributed).

The random site effect and the random error term are included in the above model to highlight the intention of the model, which is to discriminate among habitats based on physical features. The non-modeled differences among sites are included in the random site effect, and other variance is included in the random error term. It is important to note that this model is not intended to be predictive of the level of spawning that will occur in a particular location.

The model is displayed as a function of depth and upwelling/substrate at a constant velocity (median velocity = 0.28 ft/sec) in Figure 6, and as a function of velocity and upwelling/substrate at a constant depth (median depth = 1 ft) in Figure 7. Note that these models are not displayed beyond the conditions under which spawning was observed (spawning observed at depths between 0.20 - 3.3 feet and velocities up to 2.2 ft/sec). Suitability criteria beyond these conditions have not yet been determined and cannot be determined using statistical methods.

4. RESULTS – COHO SALMON FRY

4.1 Data Considerations

The appropriate availability data to use for each species/lifestage analysis was carefully considered. The intention was to quantify the habitat available to the species and lifestage during the sampled time when they were observed. For coho salmon fry, the following availability data were not included in the analysis presented here:

- Data collected after September 14, when the last fry of any species was observed in the system;
- Data collected at pedestrian survey sites, since fry could generally not be observed;
- Data collected from site locations where coho salmon fry were never observed; and
- Data collected from Focus Areas during a time period when no coho salmon fry were observed anywhere in that Focus Area, either by HSC crews, Fish Distribution and Abundance crews, or Early Life History crews.

After this elimination, there were 734 availability observations to match with 99 observed coho salmon fry observations.

4.2 Univariate Models

The random site effect model attained lower AIC (superior fit) than the fixed model without site effects for every comparison, as expected, due to large differences in fry observations among sites. Other results are discussed for each habitat variable below.

4.2.1 Depth

There is strong evidence for a predictive effect of depth. The quadratic model for depth with a random effect for site has AIC 15 units less than the null model (Table 10). According to these data, the preferred habitat for coho fry has surface water depth near 1.5 feet.

4.2.2 Velocity

The best fit polynomial model predicting coho fry presence from velocity is a 4th order polynomial, which has AIC 3.5 less than the null model – indicating some predictive strength (Table 11). However, this model is bimodal, indicating that there may be multiple processes involved in the results. Due to fish ecological theory and exploratory data analysis, the impact of velocity on habitat suitability is greatly reduced when cover is present. This relationship is best explored using multivariate analysis (see Section 4.3), but to test the necessity for the continued investigation of velocity as a predictor, the velocity model was fit to a subset of the data where there was no adjacent cover of any type. As shown in Table 11, a quadratic model with velocity has high predictive evidence over the null model (deltaAIC = 13; preferred velocity near 0.35 ft/sec). Interaction between cover and velocity was considered in the multivariate analysis presented in Section 4.3.

4.2.3 Cover/Turbidity

The probability of observing coho salmon fry in the presence of the different types of cover is displayed in Table 12. Because there was no increase in probability observed for boulder cover, this cover type was excluded as a cover category. Because there are often multiple cover types at the same location, they cannot be individually assessed, so the remaining forms of cover were combined into one factor – cover or no cover,

Turbidity can also be utilized as cover by juvenile fish, but there appears to be decreased coho salmon fry utilization in turbid water. The data also indicate that cover becomes less important in turbid water areas (Figure 5). This relationship is important to consider in HSC models to avoid inflating the relationship between cover and suitability in turbid water or to avoid underestimating the relationship in clear water. Habitat use studies completed during the 1980s Susitna River Study reported an inflection point at approximately 30 NTU for juvenile Chinook salmon use of turbidity of cover (Schmidt et al. 1984). However, the plot in Figure 5 suggests that a break point of 50 NTU may be more relevant to these data. Unfortunately, there were very few coho salmon fry observations in turbid water areas (11 observations with NTU>30; 6 with NTU>50) in 2013, so these models are not likely to be stable. The use of 30 NTUs was therefore retained as the turbidity boundary because of this data limitation.

In order to get the strongest predictive model of fish preference, cover and turbidity were combined into a 3-level factor: No cover in turbid water (lowest preference); cover in clear water (highest preference); and the combined category of cover in turbid water or no cover in clear water (moderate preference). For this “univariate” comparison, the models with cover alone, turbidity alone, and the combined factor were compared. The best fit model was for the combined cover/turbidity factor, and there was strong evidence that this factor is predictive of coho salmon fry habitat suitability (Table 13; deltaAIC = 19).

4.2.4 Upwelling

For coho salmon fry, upwelling was tested as a two-level (positive vs. neutral or negative) factor. There was strong evidence that upwelling is a good predictor of coho salmon fry habitat suitability (Table 14; deltaAIC=11).

4.2.5 Water Temperature

There was strong evidence that surface water temperature is predictive of coho salmon fry presence (Table 15), and the best fit model is a declining probability as temperature increases. Although water temperature is retained for multivariate modeling, there is not a strong ecological basis for a decline in suitability over this range of temperatures. This variable may be reconsidered for inclusion in future modeling efforts.

4.2.6 Dissolved Oxygen

The best fit univariate model was decreasing suitability with dissolved oxygen, and the quadratic model is a curvilinear decreasing relationship (Table 16). Since these relationships do not make ecological sense, dissolved oxygen was not retained in the multivariate analysis.

4.2.7 Conductivity

The null model was the best fit model for conductivity (Table 17), indicating there is no evidence that conductivity is predictive of suitability for coho salmon fry.

4.3 Multivariate Models

4.3.1 Model fitting

Based on the univariate model results, depth, velocity (interacting with cover), cover (interacting with turbidity), upwelling, and water temperature would be included in the multivariate model. Using all of these variables as main effects, there is no evidence that multicollinearity is an issue of concern based on generalized variance inflation factors (Table 18). The highest VIF is 1.18, indicating that confidence intervals around predicted coefficients may be 18 percent inflated. The largest inflation is likely due to correlation between upwelling and water temperature – areas of upwelling tend to have lower water temperatures in the summer. Therefore, predictive relationships between water temperature and coho salmon fry presence may be due to other characteristics associated with upwelling.

The 20 lowest AIC models including all main effects and a single interaction term are displayed in Table 19. The best fit model includes all main effects and interaction between the cover/turbidity factor and velocity. The interaction between the cover/turbidity factor and upwelling is included in the second model, with deltaAIC = 1.3.

4.3.2 Preliminary HSC Multivariate Model for Coho Salmon Fry

The model presented here is the preliminary HSC model for coho salmon fry. This model will be refined based on additional data or revised methods.

The preliminary HSC model for coho salmon fry is best displayed as three models; one for each cover/turbidity category:

$$\log\left(\frac{p_{C.NT}}{1-p_{C.NT}}\right) = -2.31 + 0.150 * Upwell + 2.65 * depth - 0.830 * depth^2 + 3.90 * vel - 1.83 * vel^2 - 0.113 * Wtemp + \gamma_{site} + \varepsilon,$$

$$\log\left(\frac{p_{NC.T}}{1-p_{NC.T}}\right) = -3.69 + 0.150 * Upwell + 2.65 * depth - 0.830 * depth^2 + 0.966 * vel - 1.83 * vel^2 - 0.113 * Wtemp + \gamma_{site} + \varepsilon,$$

$$\log\left(\frac{p_{other}}{1-p_{other}}\right) = -2.38 + 0.150 * Upwell + 2.65 * depth - 0.830 * depth^2 + 0.500 * vel - 1.83 * vel^2 - 0.113 * Wtemp + \gamma_{site} + \varepsilon,$$

where

$p_{C.NT}$ is the probability of coho salmon fry presence in clear water with cover present,

$p_{NC.T}$ is the probability of coho salmon fry presence in turbid water with no cover present,

p_{other} is the probability of coho salmon fry presence in clear water with no cover present or turbid water with cover present,

$Upwell$ is equal to 1 if upwelling is present and 0 otherwise,

γ_{site} is the random effect for site, and

ε is random error (assumed normally distributed).

The random site effect and the random error term were included in the above model to highlight the intention of the model, which is to discriminate among habitats based on physical features. Differences among sampled locations that are not explained by the fixed effects in the model are partitioned into random differences among sites and other random error. It is important to note that this model is not intended to be predictive of the number of fry that will occur in a particular location.

The model is displayed as a function of velocity and cover/turbidity group at a constant depth (median depth = 1 ft) in Figure 9, and as a function of depth and cover/turbidity group at a constant velocity (median velocity = 0.2 ft/sec) in Figure 10. Note that these models are not displayed beyond the conditions under which coho fry were observed (fry observed at depths between 0.20 - 3.2 feet and velocities up to 1.65 ft/sec). Suitability criteria beyond these conditions have not yet been determined and cannot be determined using statistical methods.

5. DISCUSSION

The models developed and presented as part of this ISR evaluation have included site as a random effect. There are at least two alternatives that may be considered. One is to allow a random effect for each visit to each site. This may be a more reasonable option, particularly if there are multiple years of data at the same site locations. The second alternative is to use no random effects. There is wide variability in fish use among sites, but sites cannot be included as a fixed effect in the model, since this would preclude predicting suitability of sites not visited. Leaving the site (and sampling time/year) out of the model completely puts site variability into the error term unless a habitat-based fixed variable is added that explains variability at the site level. These alternatives will be more thoroughly investigated prior to determining final HSC models.

Macrohabitat type has not been included in HSC modeling for the ISR, although differences in habitat preference among macrohabitat types are possible. There are several reasons it has not been included. First, good model fitting would require similar levels of replication within each macrohabitat type. For example, although sampling was designed to capture a range of habitats, most spawning occurred in side channels and side sloughs, leading to large imbalance in sample size (i.e., for “1” spawning locations) among habitat types. Second, including macrohabitat as a fixed effect in suitability criteria would presume that fish preference for each macrohabitat would be static under all possible future flow conditions. This decision will be re-evaluated prior to selection of the final HSC model.

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7. TABLES

Table 1. Comparison of logistic models predicting chum salmon spawning based on depth (ft). All models include a random effect for site.

Model	Coefficients					Degrees of Freedom	AICc	deltaAIC
	Intercept	Depth	Depth^2	Depth^3	Depth^4			
4th Order	-6.7	13.2	-12.2	4.6	-0.6	6.0	991	0
3rd Order	-4.3	3.8	-1.6	0.2		5.0	1008	17
Quadratic	-3.7	2.2	-0.5			4.0	1011	20
Linear	-3.0	0.7				3.0	1023	32
Null	-2.0					2.0	1047	56

Note: Model coefficients predict ln(p/(1-p)).

Table 2. Comparison of logistic models predicting chum salmon spawning based on mean column velocity (ft/sec). All models include a random effect for site.

Model	Coefficients					Degrees of Freedom	AICc	deltaAIC
	Intercept	Vel	Vel^2	Vel^3	Vel^4			
4th Order	-2.3	3.7	-6.6	4.9	-1.2	6	1037	0
Quadratic	-2.2	1.7	-0.7			4	1037	0.70
3rd Order	-2.2	0.9	0.3	-0.3		5	1039	1.8
Null	-2.0					2	1047	9.8
Linear	-2.0	0.1				3	1048	12

Note: Model coefficients predict ln(p/(1-p)).

Table 3. Comparison of logistic models predicting chum salmon spawning based on substrate group (gravel, cobble, other). All models include a random effect for site.

Model	Substrate	Degrees of Freedom	AICc	deltaAIC
Substrate Group	+	4	928	0
Null		2	1046	118

Note: Model coefficients are ln(p/(1-p)) for gravel= -1.1, cobble = -2.3, other = -25

Table 4. Comparison of logistic models predicting chum salmon spawning based on upwelling group (upwelling or no upwelling).

Model	Upwelling	Degrees of Freedom	AICc	deltaAIC
Upwelling Group	+	3	1043.2	0
Null		2	1046.5	3.3

Note: All models include a random effect for site.

Table 5. Comparison of logistic models predicting chum salmon spawning based on water temperature (degrees C).

Model	Coefficients			Degrees of Freedom	AICc	deltaAIC
	Intercept	WTemp	WTemp^2			
Null	-1.99			2	1046.50	0.0
Linear	-2.13	0.0244		3	1048.40	1.9
Quadratic	-5.28	1.07	-0.0804	4	1048.50	2.0

Note: All models include a random effect for site.

Table 6. Comparison of logistic models predicting chum salmon spawning based on DO (mg/L).

Model	Coefficients			Degrees of Freedom	AICc	deltaAIC
	Intercept	DO	DO^2			
Null	-1.93			2	1029.6	0
Linear	-2.25	0.0346		3	1031.6	2.0
Quadratic	-5.83	0.754	-0.0350	4	1033.2	3.6

Note: All models include a random effect for site.

Table 7. Comparison of logistic models predicting chum salmon spawning based on Conductivity (µS/cm).

Model	Coefficients			Degrees of Freedom	AICc	deltaAIC
	Intercept	Cond	Cond^2			
Null	-1.93			2	1029.6	0
Linear	-2.01	0.000698		3	1031.6	2.0
Quadratic	-1.17	-0.0155	0.000053	4	1031.6	2.0

Note: All models include a random effect for site.

Table 8. Estimated generalized variance inflation factors for chum spawning multivariate generalized linear model with all potential predictors.

Predictor	GVIF	Df	GVIF^(1/(2*Df))
Substrate Group	1.02	2	1.01
Depth	1.05	1	1.02
Velocity	1.24	1	1.11
Water Temperature	1.18	1	1.08
Upwelling	1.08	1	1.04

Table 9. Comparison of multivariate generalized mixed logistic models for chum salmon spawning preference including depth, velocity, upwelling, and substrate

Depth	Depth^2	Depth^3	Substrate Group	Upwell Group	Vel	Vel^2	df	AICc	DeltaAIC
+	+	+	+	+	+	+	9	884.3	0
+	+		+	+	+	+	8	888	3.7
+	+	+	+	+			7	889.7	5.5
+	+	+	+	+	+		8	891.8	7.5
+	+	+	+		+	+	8	892.6	8.4
+	+		+	+			6	892.8	8.5
+	+		+	+	+		7	894.8	11
+	+		+		+	+	7	896.6	12
+	+	+	+				6	899	15
+	+	+	+		+		7	900.9	17
+			+	+	+	+	7	901.9	18
+	+		+				5	902.3	18
+	+		+		+		6	904.3	20
+			+	+			5	905.3	21
+	+	+		+	+	+	8	905.9	22
+			+	+	+		6	907.3	23
+	+			+	+	+	7	908.4	24
+			+		+	+	6	909.7	25
+	+	+		+			6	913.2	29

Notes:

"+" indicates variable is included in model.

Top 20 best fit models are displayed.

All models included random effect for site.

Table 10. Comparison of logistic models predicting coho salmon fry presence based on depth (ft).

Model	Coefficients					Degrees of Freedom	AICc	deltaAIC
	Intercept	Depth	Depth^2	Depth^3	Depth^4			
2nd Order	-3.4	2.3	-0.74			4	567.0	0.0
3rd Order	-3.5	2.6	-1.0	0.055		5	569.0	2.0
4th Order	-4.3	6.4	-5.9	2.4	-0.36	6	569.2	2.2
Null	-2.1					2	582.0	15
Linear	-2.1	-0.018				3	584.0	17

Note: All models include a random effect for site.

Table 11. Comparison of logistic models predicting coho salmon fry presence based on velocity (ft/sec).

Data		Coefficients					Degrees of Freedom	AICc	deltaAIC
	Model	Intercept	Vel	Vel^2	Vel^3	Vel^4			
All	4th Order	-2.8	9.3	-24	21	-6.0	6	577.5	0.0
	Null	-2.1					2	581.0	3.5
	2nd Order	-2.4	1.6	-0.9			4	581.3	3.8
	Linear	-2.2	0.3				3	582.1	4.7
	3rd Order	-2.5	2.7	-2.8	0.75		5	582.6	5.1
No Cover	2nd Order	-3.0	8.0	-13			4	285.2	0.0
	3rd Order	-3.2	10	-21	7.0		5	286.2	1.0
	4th Order	-3.4	18	-61	71	-30	6	286.9	1.7
	Linear	-2.3	-1.0				3	296.5	11
	Null	-2.54					2	297.8	13

Note: All models include a random effect for site.

Table 12. Summary of observed cover and habitat preference of coho salmon fry observed in 2013 HSC sampling.

Cover Type		Cover Absent	Cover Present
Boulder	Number of Sites	768	65
	Percent Utilized by Fry	12%	7.7%
Aquatic Vegetation	Number of Sites	656	177
	Percent Utilized by Fry	9.9%	19%
Overhanging Vegetation	Number of Sites	793	40
	Percent Utilized by Fry	11%	28%
Undercut Bank	Number of Sites	826	7
	Percent Utilized by Fry	12%	29%
Wood	Number of Sites	786	47
	Percent Utilized by Fry	11%	26%
Any	Number of Sites	534	299
	Percent Utilized by Fry	8.1%	19%
Any Except Boulder	Number of Sites	590	243
	Percent Utilized by Fry	7.6%	22%

Table 13. Comparison of logistic models predicting coho salmon fry presence based on the presence of cover and turbidity.

Model	df	AICc	deltaAIC
Cover/Turbidity	4	563.0	0
Cover	3	569.8	7
Turbidity	3	573.9	11
Null	2	582.0	19

Note: All models include a random effect for site.

Table 14. Comparison of logistic models predicting coho salmon fry presence based on the presence of upwelling (2 level factor).

Model	df	AICc	deltaAIC
Upwelling (2 levels)	3	571.2	0
Null	2	582.0	11

Note: All models include a random effect for site.

Table 15. Comparison of logistic models predicting coho salmon fry presence based on surface water temperature (degrees C).

Model	Coefficients			Degrees of Freedom	AICc	deltaAIC
	Intercept	Wtemp	Wtemp^2			
Linear	-0.082	-0.18		3	569.7	0
2nd Order	1.9	-0.58	0.019	4	570.5	0.8
Null	-2.1			2	582.0	12

Note: All models include a random effect for site.

Table 16. Comparison of logistic models predicting coho salmon fry presence based on dissolved oxygen (mg/L).

Model	Coefficients			Degrees of Freedom	AICc	deltaAIC
	Intercept	DO	DO^2			
Linear	0.91	-0.30		3	515.2	0
2nd Order	3.9	-1.1	0.045	4	516.1	0.9
Null	-2.0			2	523.1	7.9

Note: All models include a random effect for site.

Table 17. Comparison of logistic models predicting coho salmon fry presence based on conductivity (uS/cm).

Model	Coefficients			Degrees of Freedom	AICc	deltaAIC
	Intercept	Cond	Cond^2			
Null	-2.1			2	582.0	0
Linear	-2.0	-0.0013		3	583.8	1.9
2nd Order	-1.9	-0.0040	0.000010	4	585.8	3.8

Note: All models include a random effect for site.

Table 18. Estimated generalized variance inflation factors for coho salmon fry multivariate generalized linear model with all potential predictors.

Predictor	GVIF	Df	GVIF^(1/(2*Df))
Cover	1.09	1	1.09
Turbidity	1.05	1	1.05
Depth	1.01	1	1.01
Velocity	1.04	1	1.04
Water Temperature	1.17	1	1.17
Upwelling	1.18	1	1.18

Table 19. Comparison of multivariate generalized mixed logistic models for chum salmon spawning preference including a combined cover/turbidity factor, depth, velocity, upwelling, and water temperature.

Cover/ Turb	Depth	Depth^ 2	Upwell	Vel	Vel^2	Wtemp	Interaction	df	AICc	DeltaAIC
+	+	+	+	+	+	+	CovTurb:Vel	12	517.4	0
+	+	+	+	+	+	+	CovTurb:Upwell	12	518.7	1.3
+	+	+	+	+	+	+	Vel:Wtemp	11	519.5	2.1
+	+	+	+	+	+	+	Depth:Vel	11	523.2	5.8
+	+	+	+	+	+	+	Upwell:Vel	11	523.8	6.4
+	+	+		+	+	+		9	526.8	9.4
+	+	+	+	+	+	+	Depth:Upwell	11	527.4	10
+	+	+				+		7	527.4	10
+	+	+	+	+	+	+		10	528.2	10.8
+	+	+	+			+		8	528.7	11.3
+	+	+		+		+		8	529.4	12
+	+	+	+	+	+	+	CovTurb:Depth	12	529.5	12.1
+	+	+	+	+	+	+	Depth:Wtemp	11	529.9	12.5
+	+	+	+	+	+	+	Upwell:Wtemp	11	529.9	12.5
+	+	+	+	+	+	+	CovTurb:Wtemp	12	530.4	13
+	+	+	+	+		+		9	530.6	13.2
+	+	+	+					7	535.3	17.9
+	+	+	+	+	+			9	535.4	18
+	+	+		+	+			8	535.4	18
+	+	+						6	535.4	18

Notes:

"+" indicates variable is included in model.

Top 20 best fit models are displayed.

All models included random effect for site.

8. FIGURES

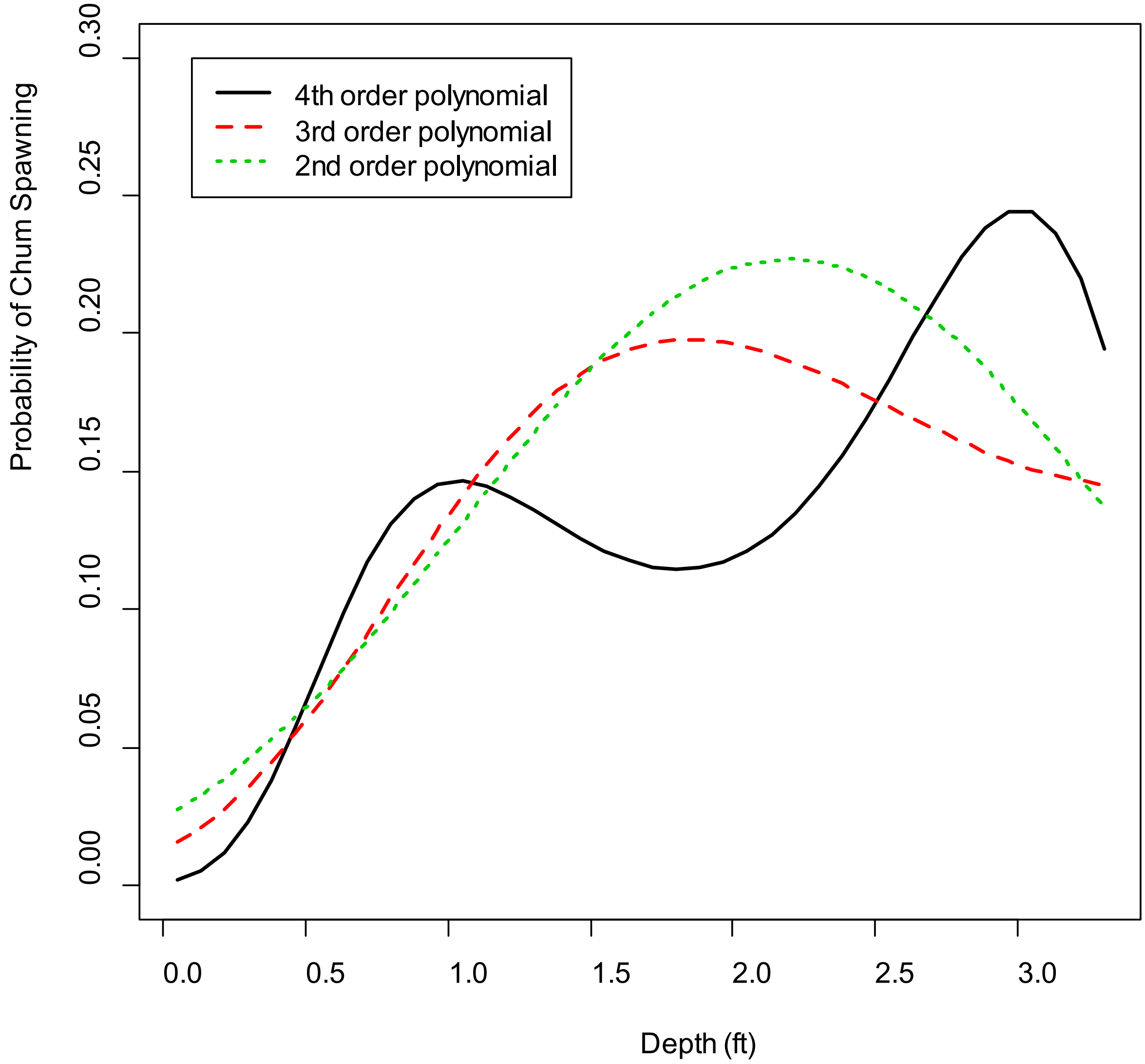

Figure 1. Modeled probability of chum salmon spawning as a function of surface water depth using three polynomial models.

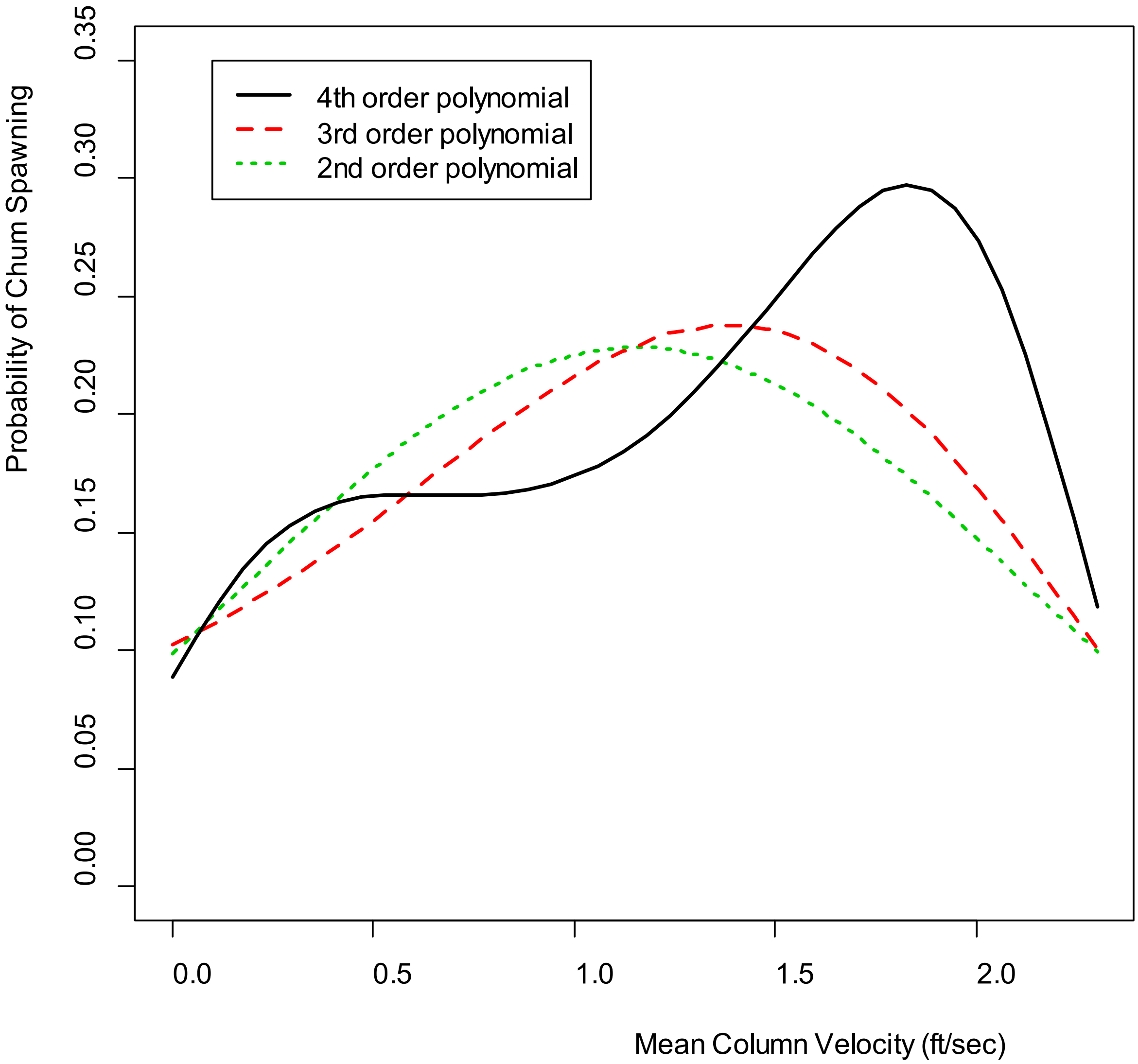

Figure 2. Modeled probability of chum salmon spawning as a function of velocity using three polynomial models.

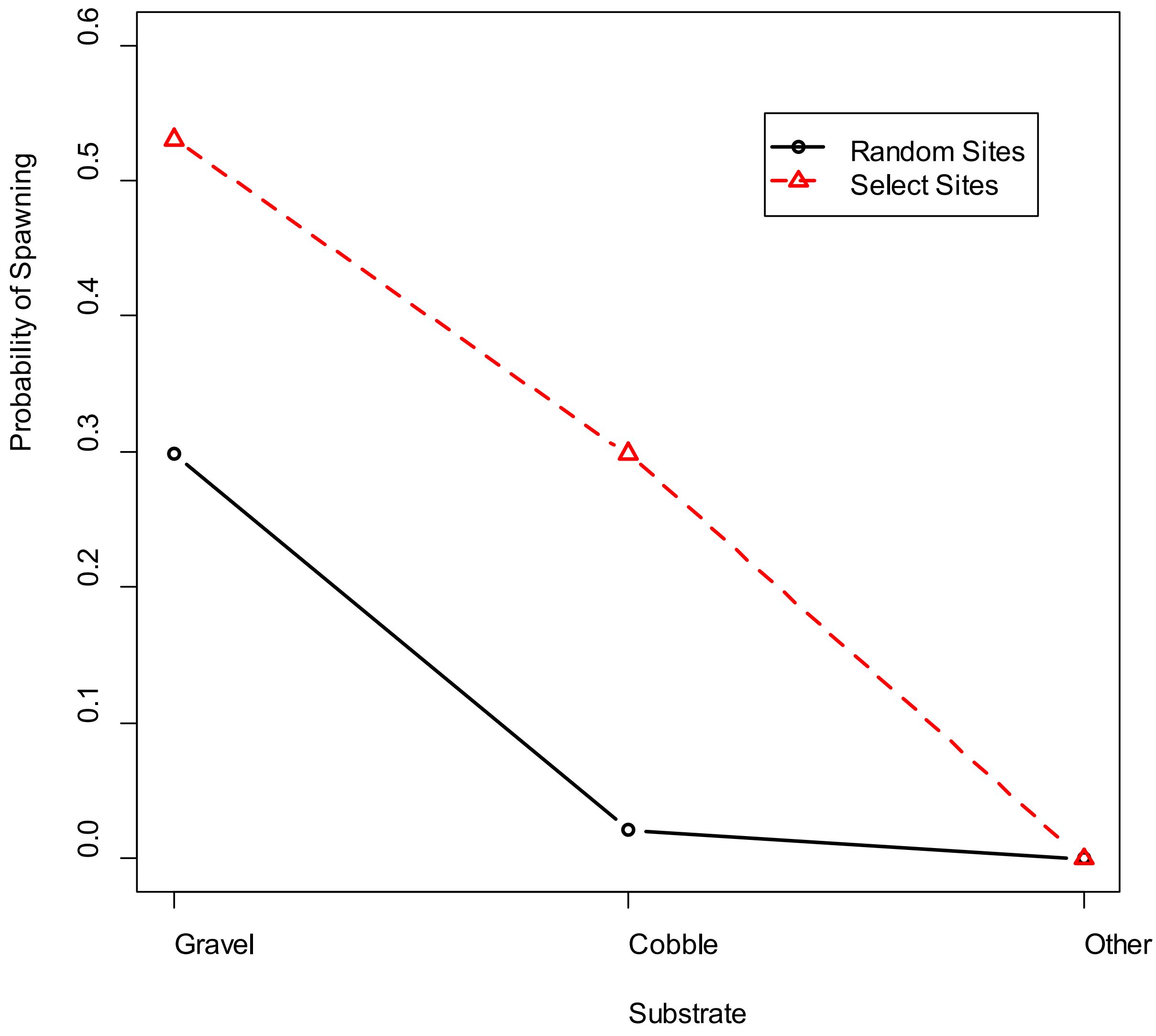

Figure 3. Observed probability of chum salmon spawning as a function of substrate group for random sites and select historical spawning locations.

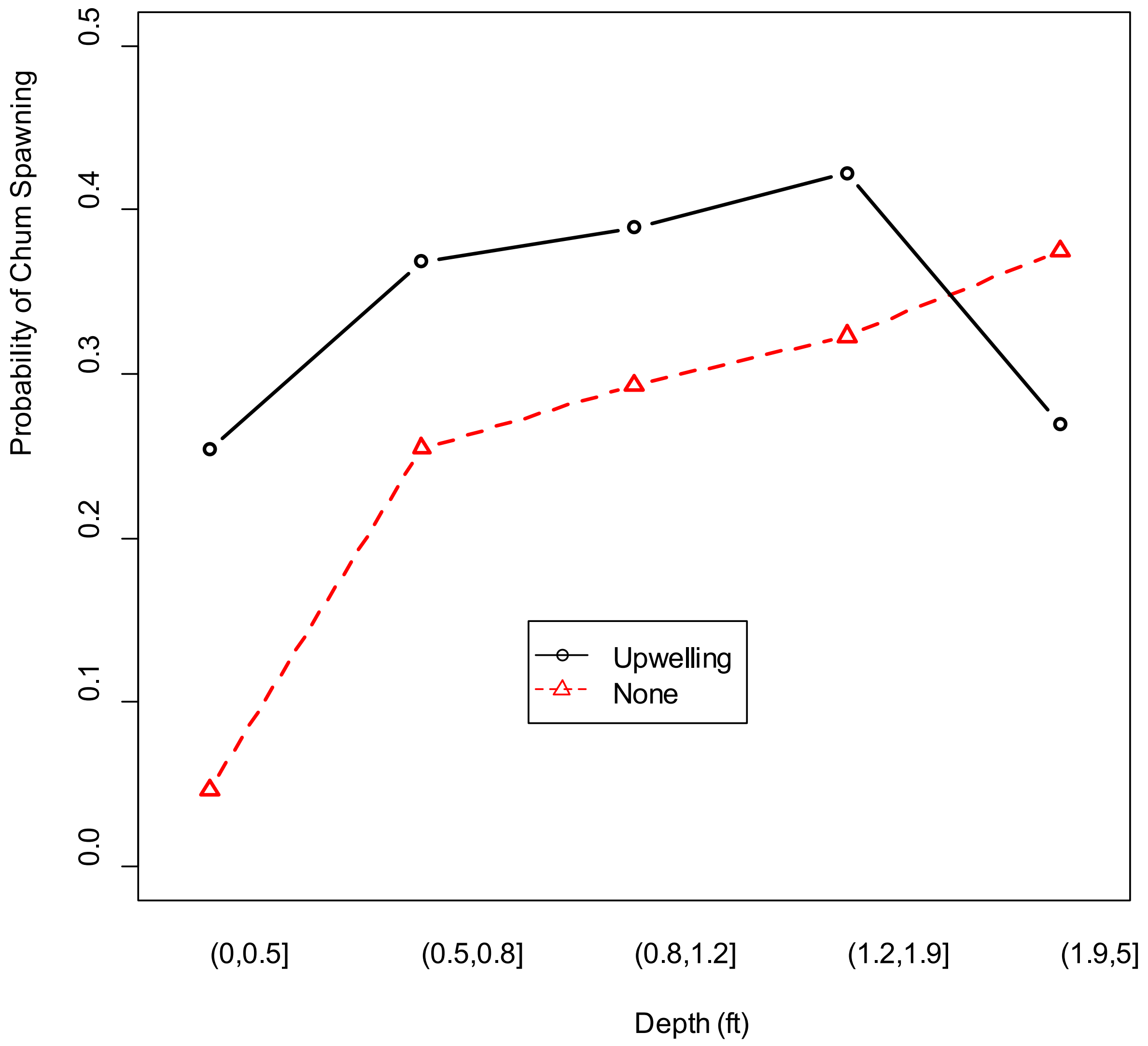

Figure 4. Observed probability of chum salmon spawning as a function of binned surface water depth for upwelling and non-upwelling sampling locations.

Note: Bin sizes were selected to provide roughly equal sample sizes in five bins.

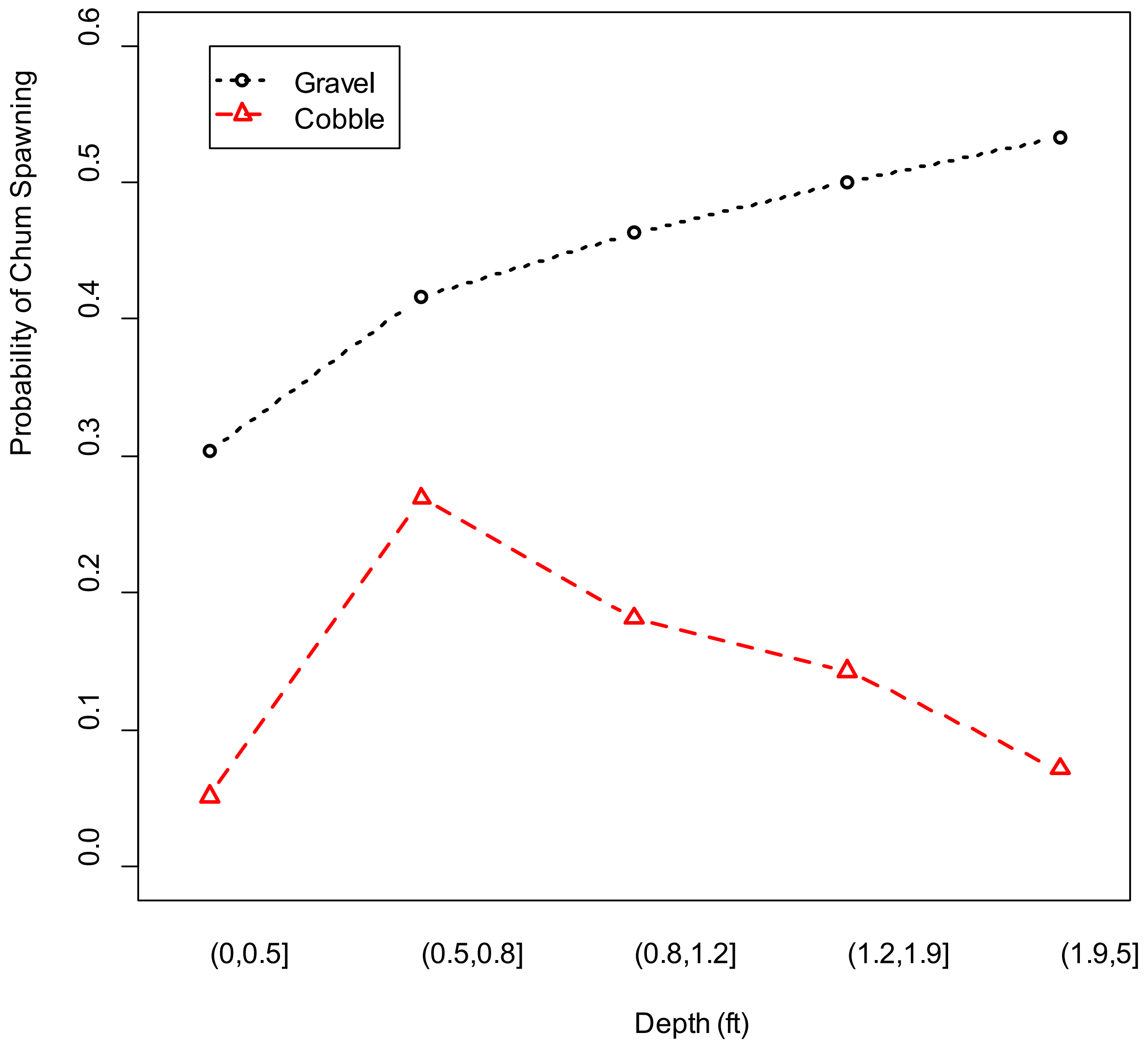

Figure 5. Observed probability of chum salmon spawning as a function of binned surface water depth for sites with gravel substrate dominant or subdominant versus sites with no gravel but cobble dominant or subdominant.

Note: Bin sizes were selected to provide roughly equal sample sizes in five bins.

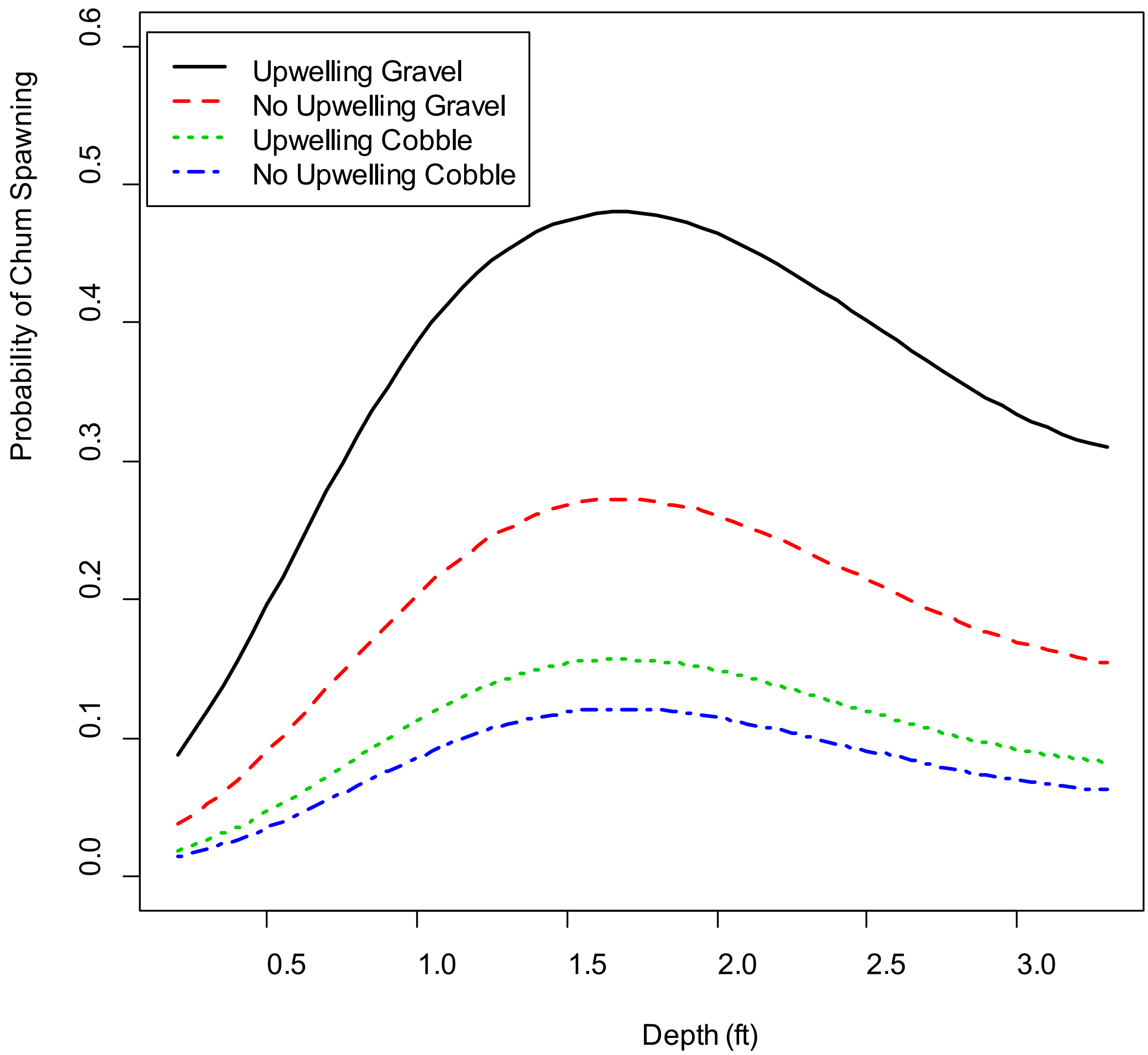

Figure 6. Modeled probability of chum salmon spawning as a function of depth and upwelling/substrate group at a constant velocity of 0.28 ft/sec.

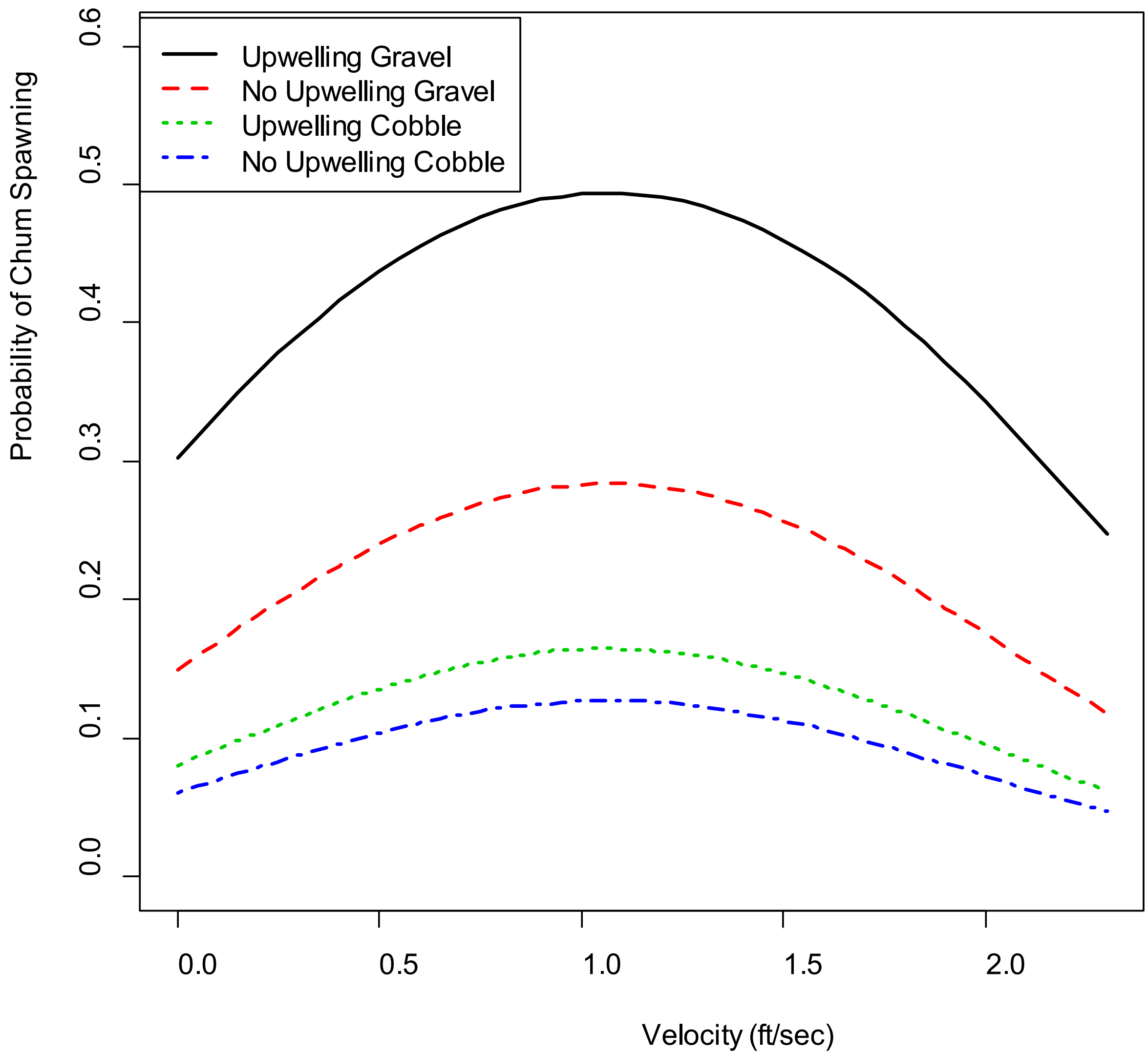

Figure 7. Modeled probability of chum salmon spawning as a function of velocity and upwelling/substrate group at a constant depth of 1 ft (the median).

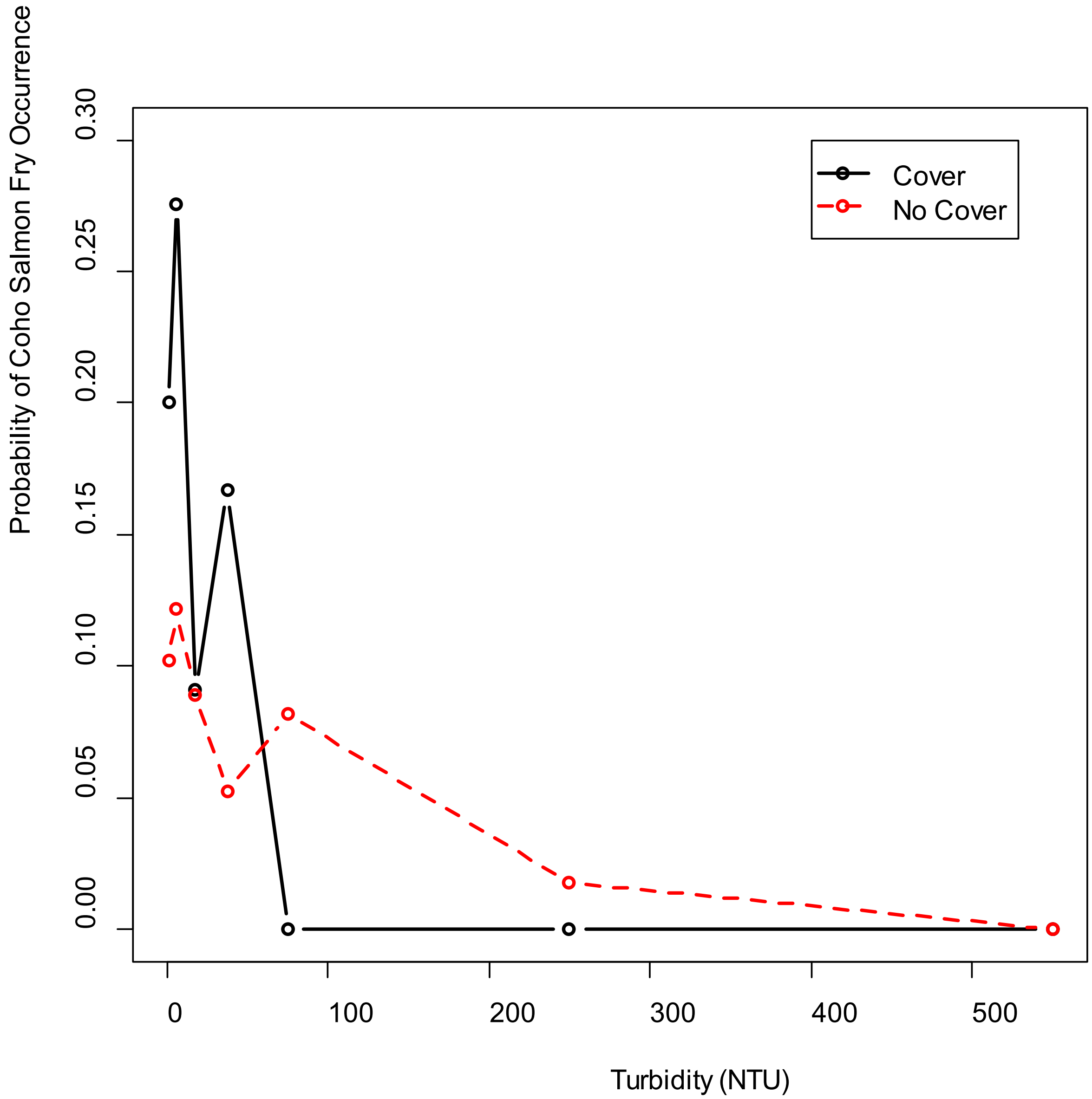

Figure 8. Observed probability of coho salmon fry habitat use as a function of binned turbidity when cover is or is not available.

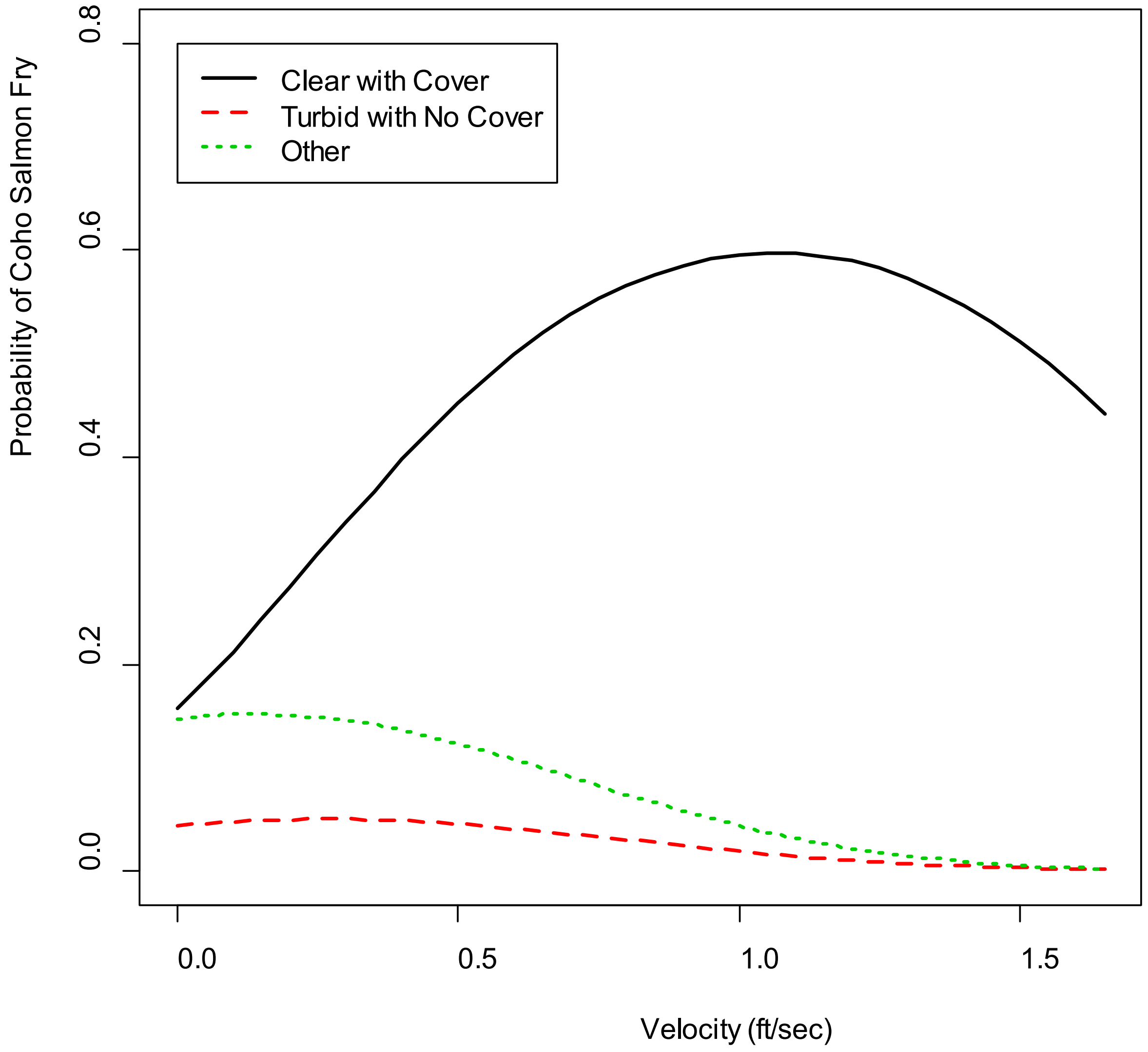

Figure 9. Modeled probability of coho salmon fry presence as a function of velocity and cover/turbidity group with upwelling present, at a constant depth of 1 foot, and a constant water temperature of 11.9 degrees C.

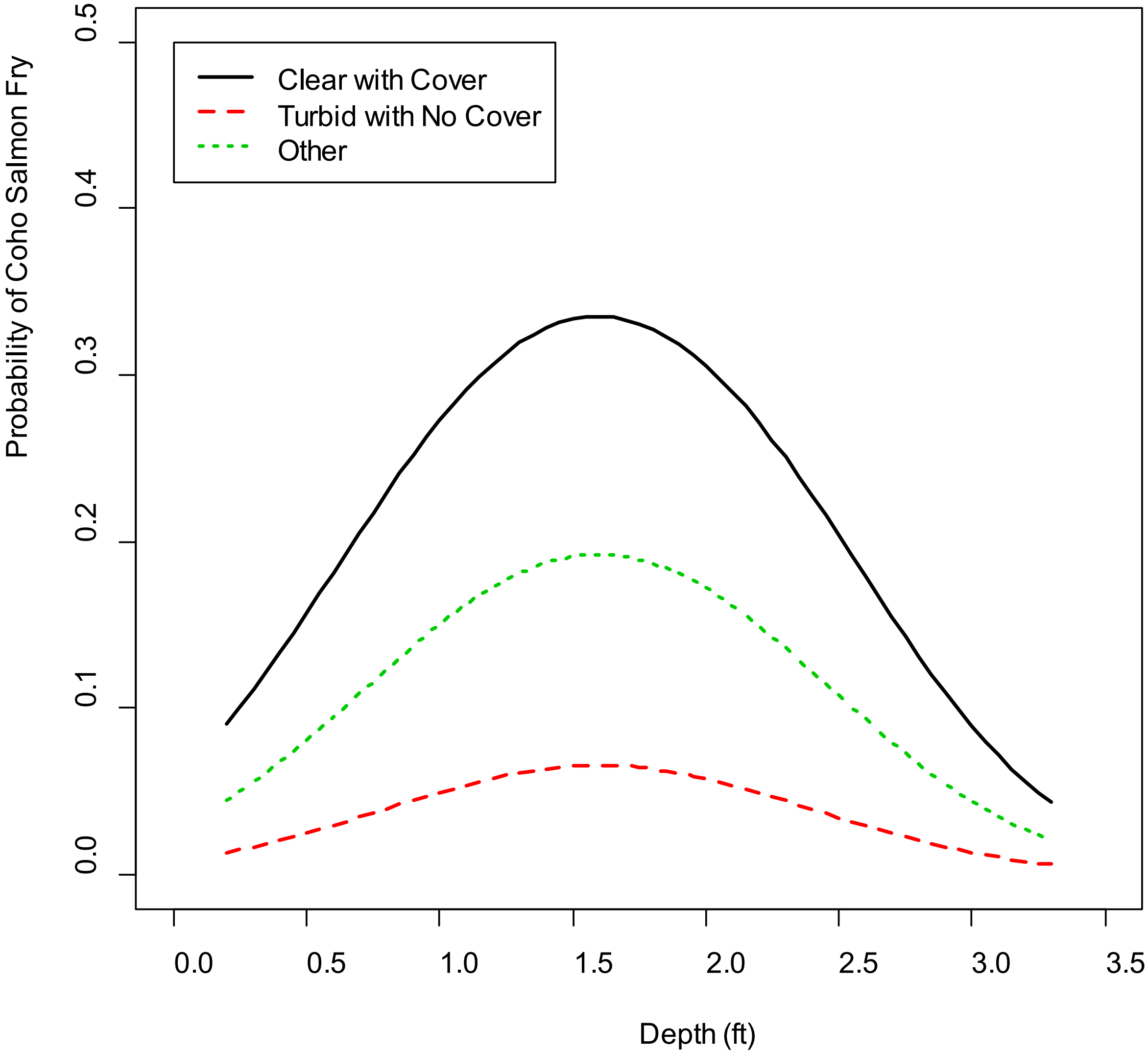

Figure 10. Modeled probability of coho salmon fry presence as a function of depth and cover/turbidity group with upwelling present, at a constant velocity of 0.2 ft/sec, and a constant water temperature of 11.9 degrees C.

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fish and Aquatics Instream Flow Study (8.5)

Initial Study Report
Part C - Appendix N
Middle River Fish Habitat and Riverine Modeling Proof of Concept

Prepared for
Alaska Energy Authority

SUSITNA-WATANA HYDRO
Clean, reliable energy for the next 100 years.

Prepared by

R2 Resource Consultants
Miller Ecological Consultants
Tetra Tech
HDR
GW Scientific
Montgomery Watson Harza

June 2014

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LIST OF ACRONYMS AND SCIENTIFIC LABELS

Abbreviation	Definition
1-D	one-dimensional
2-D	two-dimensional
ADCP	acoustic Doppler current profiler
AEA	Alaska Energy Authority
AFDD	Accumulated Freezing Degree Days
CSV	character-separated values
DSS	decision support system
EFDC	environmental fluid dynamics code
FA	Focus Area
FERC	Federal Energy Regulatory Commission
GIS	geographic information system
HEC-ResSim	Hydrologic Engineering Center reservoir system simulation
HSC/his	habitat suitability curves / habitat suitability information
IFS	Instream flow study
ILP	Integrated licensing process
ISR	initial study report
LiDAR	Light Detection and Ranging
OWFRM	Open-water flow routing model
OS	operational scenario
PHABSIM	Physical habitat simulation
POC	proof of concept
PRM	Project River Mile
Project	Susitna-Watana Hydroelectric Project No. 14241
RTK	real time kinematic
SPD	study plan determination
TIN	triangulated irregular network
TIR	thermal imaging radar
TT	technical team (subset of technical working group)
TWG	technical working group
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
VB	Visual Basic

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. Project operations will cause seasonal, daily, and hourly changes in Susitna River flows compared to existing conditions. The potential alteration in flows will influence downstream resources and riverine processes, including fish and aquatic biota and their habitats, channel form and function including sediment transport, water quality, groundwater/surface water interactions, ice dynamics, and riparian and wildlife communities (AEA 2011).

The potential operational flow-induced effects of the Project will be carefully evaluated as part of the licensing process. The Susitna-Watana Instream Flow Study (IFS; Stuidy 8.5) that will be conducted to characterize and evaluate these effects is described in a Study Plan that was reviewed by Licensing Participants, submitted to the Federal Energy Regulatory Commission (FERC), and approved in 2013 as part of the FERC Study Plan Determination. The Study Plan included a statement of objectives, a description of the technical framework that is at the foundation of the IFS, the general methods that will be applied, and the study nexus to the Project. The Study Plan is specifically directed toward establishing an understanding of important biological communities and associated habitats, and the hydrologic, physical, and chemical processes in the Susitna River that directly influence those resources. The focus of much of this work will be on establishing a set of analytical tools/models based on the best available information and data that can be used for defining both existing conditions, i.e., without Project, and how these resources and processes will respond to alternative Project operational scenarios. Implementation of the Study Plan began in 2013 with field data collection and initial model development.

In addition to Technical Workgroup Meetings held to review and discuss study implementation, an Instream Flow Study (IFS) Technical Team (TT) Riverine Modelers Meeting was held November 13-15, 2013. The November 2013 IFS-TT meeting was intended to provide a forum to review and discuss various riverine-related modeling and study integration efforts. The meeting was centered on the Middle River Segment and concentrated on discussing how the various modeling efforts will be used to address biologically relevant questions related to Project operational effects on fish and fish habitats. Although in November 2013 the various riverine models were still in development, questions arose during the meeting regarding scale, time steps, and decision points relative to different models and linkages between study components. (see http://www.susitna-watanahydro.org/wp-content/uploads/2014/02/2013.11.13Modelers_Notes.pdf). In response, a 3-day IFS TT Proof of Concept (POC) Meeting was held April 15-17, 2014. Notes from the POC meeting and copies of the 16 different PowerPoint presentations from the meeting are available at: http://www.susitna-watanahydro.org/meetings/past-meetings/. This Technical Memorandum provides a roadmap to the POC meeting and outlines the step-wise procedures being used to evaluate effects of Project operations on riverine processes and fish habitat.

The POC meeting was designed to advance the understanding of riverine process and fish habitat models by demonstrating the application of the models specific to two key biological metrics (effective salmon spawning/incubation habitat, and juvenile salmonid rearing habitat) at one Middle River Segment Focus Area (FA), FA-128 (Slough 8A). Modeling examples were developed for two scenarios – Existing Conditions and Operational Scenario (OS) – 1. Emphasis was placed on demonstrating the model process and example model results. The overall goal of the meeting was to PROVE via demonstration that the modeling process is CONCEPTUALLY sound (Proof of Concept) and can be broadly applied to other areas of the Middle River Segment.

The POC meeting was organized around an analytical framework described in ISR Study 8.5, and discussed at the August 16, 2012, TWG meeting and further discussed at the October 24, 2012, TWG meeting. Essentially all of the IFS-related resource studies were structured to fit within the context of this framework and were designed to address specific questions related to Project operations. This framework was presented again and discussed in detail during the November 13-15, 2013, IFS-TT Riverine Modelers Meeting where it served as the backdrop for the flow-specific resource models discussed during the meeting. The framework also served to introduce the Decision Support System that will be used for comparing operational scenarios across resource interests. The IFS analytical framework will continue to serve as a means to demonstrate interrelationships between riverine habitats and associated resource studies and models that will be used to address specific questions.

The IFS analytical framework identifies the linkages between the various riverine modeling components; however, it may also help to understand fish habitat and riverine modeling as a step-wise process involving:

1) System Inputs;
2) Reach Scale Modeling;
3) Focus Area Scale Modeling;
4) Fish Habitat Outputs; and
5) Decision Support System (DSS).

1.1. System Inputs

System inputs consist of the physical and hydraulic data used to conduct the various model runs (Figure 1). Although riverine process models may use different parameters, scale, and time steps, a web-based file sharing system is used by the riverine modelers to ensure consistency in channel morphology, hydrology, and other datasets. Translating the effects of reservoir and dam operations to downstream habitats is accomplished through the use of reach scale modeling of riverine processes. For purposes of riverine modeling, the Susitna River was stratified into three segments (i.e., Upper River extending above the dam site at PRM 187.1, Middle River encompassing the dam site to Three River Confluence at PRM 102.4, and Lower River extending below the Three Rivers Confluence). Each Segment was further stratified into large-scale Geomorphic Reaches with relatively homogeneous characteristics, including channel width, entrenchment, ratio, sinuosity, slope, geology/bed material, channel branching index, and hydrology. Reach scale modeling of channel, hydraulic, and water quality under open-water and ice conditions primarily consists of transect-based analyses that describe conditions over a 50-year or 61-year period of record. During 2012 and 2013, over 150 cross-sections were measured to characterize channel morphology, gradient and flow distribution across the channel. Finer scale modeling of channel features within geomorphic reaches will be accomplished using 2-D modeling of representative areas, termed Focus Areas (FA) within the geomorphic reaches. Ten Focus Areas were identified in the Study Plan and FA-128 (Slough 8A) was selected to demonstrate example modeling output for the POC meeting (R2 2014a).

Susitna River channel and hydraulic data were measured in 2012 and 2013 and provided to all modelers. Additional data will be collected in 2014 and 2015 to fill in any identified data gaps and measure three Middle River Focus Areas where permitting constraints previously limited access. In-channel position and elevation data were measured by real time kinematic (RTK) surveys and acoustic Doppler current profiler (ADCP) equipment was used to measure hydraulics. Overbank morphology was derived from Light Detection and Ranging (LiDAR) data collected in 2011 and 2013; additional LiDAR data will be collected in 2014 to increase the density and accuracy of overbank elevations. In addition to orthorectified and other aerial images and videos, modeling inputs included thermal imaging radar (TIR) to identify localized areas of water temperature differences and time-lapse photography at select stations. Substrate and fish cover were characterized as cells of homogenous particle size, large woody debris were mapped, and the substrate size distribution was calculated using the results of Wolman pebble counts.

Required model input data includes long-term reservoir inflow time-series data. For Watana Dam, the reservoir inflows will be a continuous 61-year record of daily flows for Water Years 1950 through 2010. Review of the 61-year record identified several years where constant daily flow values were apparently used to fill in weeks of missing data (Tetra Tech et al. 2014). While the periods of constant values do not significantly affect modeling of reservoir inflow and outflow, such constant values could affect comparisons between Existing Conditions and alternate operational scenarios for downstream riverine resources. A 50-year data set was identified by eliminating years containing days or weeks of constant flows. Reach-scale modeling will use the 50-year record; however, the extensive model run times for 2-D Focus Area modeling suggested a shorter time period would be appropriate. Three water years, which extend from October 1 through September 30, were selected to represent the range of hydrologic conditions for Focus Area scale modeling purposes (Tetra Tech et al. 2014 and ISR Study 8.5, Appendix J). The three representative years which include 1976 – Dry/Cold, 1985- Average, and 1981 – Wet/Warm, will provide a summary of Project effects for Focus Area scale modeling; additional years will be modeled where needed to evaluate specific hydrologic events. In addition to the hydrologic record for the mainstem Susitna River, required Reach Scale and Focus Area Scale modeling inputs include hourly records of tributary inflow. Tributary inflows in the Middle River were initially estimated using catchment area calculations. Since basin elevation, aspect, gradient, and other factors can affect such estimates, site-specific measurements of stage and flow are being collected at significant tributaries. These site-specific data will be used to estimate hourly tributary inflows for full 61-year period of mainstem flow records.

The Baseline Water Quality Study (ISR Study 5.5) will compile historical water quality data and the results of an ongoing program to collect site-specific water quality data. The combined datasets are used in the Water Quality Modeling Study (ISR Study 5.6) to predict water temperature and water quality conditions in the proposed reservoir and in the Susitna River downstream of the dam site. Both reservoir and riverine models are based on an Environmental

Fluid Dynamics Code (EFDC) framework. Using historical inflows, reservoir geometry, and meteorological data, water quality conditions in the proposed Watana Reservoir are modeled for temperature, dissolved oxygen (DO), fine suspended sediment and turbidity, chlorophyll-a, nutrients, ice, and metals. Understanding reservoir water quality is a necessary part of evaluating the effects of alternate operational scenarios on downstream resources and the results of the reservoir water quality modeling component are used to provide feedback to the reservoir operations model. For the POC analyses, reservoir water temperatures were simulated for 1974-1976 which represented a dry period with large pool drawdown, and 1979-1981, a wet period with small pool drawdown (Tetra Tech 2014a). The example results demonstrated that the vertical resolution of the model captures the thermal stratification and mixing processes and the model can be used to simulate multi-year periods with large pool level fluctuations.

Hourly outflows from the proposed Project are simulated using the USACE Hydrologic Engineering Center (HEC) reservoir system simulation model HEC-ResSim. Hourly reservoir operations are driven by a set of operating rules. For the POC meeting, Operating System-1 (OS-1) was used as a maximum load following scenario for illustration purposes (MWH 2014). Under OS-1, Project generation requirement was based on the total Railbelt electricity load and all load variability was assigned to the Project. The basic reservoir input data includes reservoir pool level elevations, reservoir storage, water surface area, and values for release capacities based on elevation including the spillway, valves, and the turbines. Release capabilities can be broken down by individual valve or spillway bay. For the POC meeting, hourly dam releases were developed for 1981 (Wet), 1985 (Average) and 1976 (Dry) years (MWH 2014). For each water year of interest, dam releases were modeled for a 15-month period including July through September prior to the start of the water year. This 15-month period provided a continuous record of flow releases necessary to conduct the effective salmon spawning: incubation analyses starting with salmon spawning in August through subsequent emergence the following spring. Output from the reservoir operations model includes reservoir elevations and daily and hourly outflow at the dam. Since the output of the reservoir water quality model (Tetra Tech 2014a) quantifies water quality parameters by reservoir elevation zone, the water quality condition of the daily and hourly dam releases can be identified and input to reach scale modeling of downstream riverine processes.

1.2. Reach Scale Riverine Modeling

Reach scale modeling of riverine processes was designed to translate the effects of dam releases to downstream habitats. For instance, the Open-water Flow Routing Model (ISR Study 8.5; Appendix K) will ultimately translate flow releases from the dam to stage and flow predictions to downstream measured cross-sections. Version 1 of the OWFRM was based on 88 cross-sections while Version 2, described during the POC meeting (R2 et al. 2014), was based on 167 cross-sections. The final version of the Open-water Flow Routing Model will be developed prior to the Updated Study Report (USR) and will include over 200 measured cross-sections in the Middle and Lower River.

The reach scale water quality modeling effort (ISR Study 5.6) consists of an EFDC framework with coarse 2-D coupled hydrodynamic, temperature, and water quality models for the entire river. Since the response of water quality processes are temperature dependent, water temperature was selected to demonstrate POC examples. The coarse resolution 2-D water temperature mesh consists of three to seven lateral cells extending 800 to 3,000 ft. longitudinally.

This spatial resolution is appropriate for decadal time scale simulations while finer resolution mesh was selected for Focus Area scale modeling. For the POC, reach scale changes in water temperature were simulated for periods 1974-1976 (dryer periods) and 1979-1981 (wetter periods) (Tetra Tech 2014b). The example results showed a general pattern of warmer temperatures in the winter periods and colder temperatures in the summer months for the OS-1 simulations. The model output was developed for Existing Conditions and an alternate operational scenario and calibrated with 2012 datasets; initial runs for the POC meeting demonstrated model stability and acceptable run-time performance for decadal time scale simulations.

The reach scale bed morphology model (ISR Study 6.6) extends downstream from the proposed dam site at PRM 187.2 and is designed to quantify aggradation, degradation, and changes in average water depth and velocity. Using the site-specific cross-section data and sediment inputs and bed gradation from site-specific field data and U.S. Geological Survey (USGS) sediment transport rating curves, the 1-D bed morphology model will be used to quantify aggradation, degradation, change in bed material gradation, water-surface elevation response and changes in average water depth and velocity. The reach scale bed morphology model will be used to quantify Existing Conditions and to estimate bed evolution over time with results presented for future conditions at the 25 year and 50 year time steps (2014c). Information on channel change at the 25 year and 50 year time steps will be used to identify changes in boundary conditions for Focus Area scale modeling. Since the POC meeting was intended to demonstrate model linkages under Existing Conditions, 1-D bed morphology results were not developed for the 25 year and 50 year time steps and geomorphology modeling was directed to Focus Area scale modeling.

The Open-water Flow Routing Model (R2 et al. 2014) and Water Quality Models (Tetra Tech 2014b) are primarily intended to characterize open-water conditions; however, proposed Project operations will also affect winter freeze-up, ice growth and breakup. Ice Processes (ISR Study 7.6) is developing a River1D hydraulic flood routing model to provide information on water temperature, frazil ice formation and transport, ice growth and accumulation, and ice jam formation and movement. River1D output will quantify ice processes at specific cross-sections to provide reach scale values and provide boundary conditions for finer scale Focus Area scale modeling. The River1D model was not scheduled for initial development until several months after the POC meeting so example outputs were developed for the POC meeting using the HEC River Analysis System HEC-RAS (HDR 2014a). The HEC-RAS simulant had similar geometry, flow routing, and ice jamming but did not have water temperature cool down, ice formation, or ice transport functions. Accumulated Freezing Degree Days (AFDD) values were calculated for the three representative years – 1976 – cold, 1981 – warm, and 1985 – average, and the progression of freeze-up was shown for the Middle River (HDR 2014a). Since the River1D model was not yet available, application of the HEC-RAS model to Focus Area scale modeling was introduced with the above mentioned caveats.

The results of the reach scale models will be used to characterize Existing Conditions and then predict the effects of the Project on riverine processes under alternate operational scenarios. Reach scale riverine process model results will include longitudinal changes in water temperature and other water quality parameters, mainstem channel aggradation or degradation, and changes in the longitudinal extent of ice formation. Reach scale modeling will identify longitudinal changes between cross-sections, but will have limited ability to identify changes between the main channel and lateral habitat features.

Riverine process modeling will be used to quantify Project effects at Year 0 of Project Operations, but reach scale, 1-D bed evolution modeling (ISR Study 6.6) will also be used to model future channel changes at Project Years 25 and 50. Predicting the effects of Project operations on riverine processes provides a means to quantify Project effects and identify potential mitigation strategies; predicting future changes in channel morphology provides the opportunity to identify potential strategies to avoid or minimize such future channel change.

1.3. Focus Area Scale Riverine Modeling

Reach scale modeling efforts will identify Project effects on riverine processes, but localized Focus Area scale modeling will be needed to identify Project effects on a finer scale. Up to ten Focus Areas, encompassing from 0.5 to 1.8 linear miles of the mainstem Susitna River, were selected to describe Middle River habitat conditions. Each Focus Area is the subject of intensive investigation by multiple resource disciplines including Water Quality (Study 5.6), Geomorphology Study (Study 6.5), Fluvial Geomorphology Modeling (Study 6.6), Groundwater (Study 7.5), Ice Processes (Study 7.6), Fish and Aquatics Instream Flow (Study 8.5) and Riparian Instream Flow (Study 8.6). Using 2-D mesh consisting of tens of thousands of elements per Focus Area, the effects of Project operations will be translated from main channel, reach scale effects to lateral habitats under Existing Conditions and alternate operational scenarios. For the POC meeting, Focus Area scale modeling linkages were demonstrated using FA-128 (Slough 8A) as an example.

FA-128 (Slough 8A) encompasses 1.6 linear miles of the Susitna River extending from PRM 18.1 to PRM 129.7. During the 1980s, extensive sampling occurred for both adult and juvenile salmon and four of the five species of salmon were observed spawning at Slough 8A (R2 2014b). Observations of spawning chum and sockeye salmon, rearing juvenile salmon, and adult resident fish were collected in the 1980s to support development of habitat suitability curves and other habitat suitability information (HSC/HSI). During 2013, fish distribution and abundance data (ISR Study 9.6) and HSC/HSI data (ISR Study 8.5) were collected at FA-128 (Slough 8A) to support Focus Area scale modeling; additional fish distribution and HSC/HSI data collection is expected at FA-128 (Slough 8A) prior to the USR (see http://www.susitna-watanahydro.org/wp-content/uploads/2014/03/2014-03-21TT_IFS_Presentation-HSC.pdf).

For the April 2014 POC meeting, water quality modeling at FA-128 (Slough 8A) centered on water temperature using a 2-D mesh of approximately 100 feet laterally and 300 feet longitudinally. Simulations were conducted for May through October for 1976 and 1981 and for Existing Conditions and Operating Scenario OS-1 within the FA-128 (Slough 8A) area (Tetra Tech 2014d). Preliminary simulations conducted for the POC meeting did not show significant temperature variations laterally across the Focus Area; however, observational data during July and August suggested that lateral habitats varied up to 2°C from main channel water temperatures. The variations may occur in response to longer water residence times and net warming which need to be calibrated into the 2-D model. Thermal Infrared (TIR) imaging suggested that lateral habitats may vary up to 3°C from main channel water temperatures during October; these variations may occur in response to groundwater upwelling which has been measured (see ISR Study 7.5), but not yet incorporated into the FA-128 (Slough 8A) model.

Fluvial geomorphology modeling at the Focus Areas scale centered on the use of SRH-2D modeling to calculate channel hydraulics at FA-128 (Slough 8A). The SRH-2D model was developed using RTK survey, bathymetric data, and LiDAR data to create a triangulated irregular network (TIN) to represent FA-128 (Slough 8A) channel elevations as a 2-D mesh (Tetra Tech 2014e). In addition to velocity and depth, shear stress and Froude number are calculated for mesh elements within the Focus Area. Screen shots of coarse and fine mesh grids showed the progression of detail needed to model lateral habitats at the level of detail needed to support fish habitat modeling. Water surface elevations and velocities were calibrated by adjusting Manning's n, but review of initial model results demonstrated the need to integrate groundwater/surface water relationships not explicitly addressed in SRH-2D. Because SRH-2D is a surface water model, areas are only wet if water flows from upstream or is ponded from downstream. In either case there needs to be a direct surface connection to flowing open water. Initial model results for FA-128 (Slough 8A) did not water lateral habitats and depressions that site specific observations and remote imagery showed to remain wetted during seasonal mainstem flow fluctuations. Site specific response functions developed from groundwater wells, surface water stage recorders and other field measurements, and observations, such as time-lapse photographs, were input into the FA-128 (Slough 8A) model to depict groundwater source inputs. The resulting model results demonstrated the ability of the SRH-2D model to depict channel hydraulics, although additional calibration details are expected before development of a calibrated and validated FA-128 (Slough 8A) model.

The Groundwater Study (Study 7.5) uses a combination of empirical analysis, numerical modeling, and informed expert opinion to evaluate the effects of Project operations on groundwater/surface water interactions. At the Focus Area scale, site-specific data collection efforts include groundwater wells, surface water hydrology stations, meteorological stations, time-lapse photography, and aerial and TIR imagery. Measurements include water level, flow, water temperature, and other water quality parameters indicative of groundwater flux. These data and analysis of modeling efforts will be used to quantify response functions at Focus Area features exhibiting groundwater/surface water interactions. Within FA-128 (Slough 8A), response functions were developed for Slough 8A, Half Moon Slough, and other side sloughs and side channels that exhibit upwelling from upland or riverine sources (GW Scientific 2014). In addition to FA-128 (Slough 8A), intensive groundwater data collection efforts are ongoing at FA-138 (Gold Creek), FA-115 (Slough 6A), FA-113 (Oxbow 1), and FA-104 (Whiskers Slough). The intent is to use the results of intensive investigation at select Focus Areas to understand groundwater processes and upscale those efforts to other Focus Areas where groundwater/surface water interactions are less complex.

The influence of groundwater upwelling is particularly important to the overwinter survival of incubating salmon eggs, juvenile salmon and resident fish. Focus Area scale modeling of ice processes is based on River2D modeling that uses a computational mesh of tens of thousands of elements. River2D includes the effects of a stationary ice cover on the hydraulics and uses a pseudo-groundwater model that tracks surface and subsurface water surface elevations. When water surface elevations intercept depressions, the depressions are watered even if there is no direct surface connection to mainstem flows. Using site specific data on ice thickness, surface water hydrology, water temperatures, and knowledge of ice and groundwater processes, response functions will be developed for specific features exhibiting groundwater/surface interactions during the winter period. Use of these response functions to calibrate River2D models will be different than calibration of the SRH-2D open water model but the intent is to depict hydraulic interactions at specific features throughout the period of interest. Examples of River2D model output showing a progression of ice growth at FA-128 (Slough 8A) were presented during the

POC meeting, but modelers cautioned that the FA-128 (Slough 8A) model had not been calibrated (HDR 2014b).

Focus Area scale modeling of riverine processes will identify the effects of Project operations on physical, hydraulic, and water quality attributes assigned to the individual 2-D mesh elements. While the effects of Project operations on water depths, velocities, and water temperature of those elements are important to determining the distribution and abundance of fish, fish habitat modeling is designed to translate those physical and hydraulic characteristics into different evaluations of fish habitat.

1.4. Fish Habitat Modeling

In coordination with the Licensing Participants, a variety of fish habitat evaluation metrics are being considered as part of the evaluation of Project effects (see http://www.susitna-watanahydro.org/wp-content/uploads/2013/11/2013-11-13ModelingMeetingFishHabIntegrationMatrix.pdf). Perhaps the most complex of the potential evaluation metrics is termed the Effective Spawning and Incubation Model, which evaluates the distribution of salmon spawning during late summer within the Focus Areas and tracks the fate of eggs within the salmon redds through incubation and subsequent emergence the following spring (ISR Study 8.5, Section 5.6.4.2). This evaluation metric requires the integration of the full suite of riverine process models at both the reach scale and Focus Area scale. For the POC meeting in April 2014, an example output of an Effective Spawning and Incubation model was displayed and discussed using FA-128 (Slough 8A) (MEC and R2 2014a). In addition, an example output of a Salmonid Rearing metric was displayed (MEC and R2 2014b). However; since not all reach scale and FA-128 (Slough 8A) models were fully developed in time for the POC meeting some assumptions regarding modeling outputs were incorporated into the POC fish habitat analyses to demonstrate model results. Additional details of fish habitat modeling at FA-128 (Slough 8A) are described in Section 2.0 below.

For the POC meeting, example results for one Focus Area (FA-128 (Slough 8A)) were displayed. However, each Middle River Geomorphic Reach, except for reaches immediately upstream and within Devils Canyon is represented by one or more Focus Areas. Thus, Focus Area results could be extrapolated to the Geomorphic Reach based on linear distance, macrohabitat linear distance, macrohabitat area, or possibly weighted by fish use (R2 2014c; ISR Study 8.5, Section 7.7)). Each option has inherent assumptions and uncertainties, but during the POC Meetings Licensing Participants suggested that the data requirements, assumptions, and in particular, the potential double-counting of fish use factors rendered that option as the least desirable for future extrapolation purposes. Even after results of the Focus Area modeling are extrapolated to their respective Geomorphic Reach, evaluating multiple fish habitat evaluation metrics, for multiple species, under representative hydrologic conditions, and for multiple operational scenarios will present a data management and analysis challenge for fish habitat and other resource interests.

1.5. Decision Support System

Altering Project operational scenarios to benefit one fish species or lifestage may impact other fish species and lifestages. In addition, opportunities to benefit fish resources may impact other resource interests such as wildlife, recreation and Project economics (Figure 1). The use of a DSS is intended to reduce the complexity of information and focus attention on trade-offs involved in licensing decisions. A DSS will help Licensing Participants integrate multiple resource interests when evaluating potential modifications to alternate operational scenarios. The preferred DSS option must be quantifiable, spatially and temporally explicit, and should focus attention on attributes of highest priority for evaluation of operational scenarios. Final development of the DSS method is scheduled prior to the USR; however, Licensing Participants expressed early interest in the DSS process. During the November 2013 riverine modelers meetings, potential DSS options were reviewed to evaluate the benefits and potential impacts of alternative operational scenarios (R2 2013). Based on an evaluation of several approaches and discussion with the TWG, AEA decided to use the matrix method as the basis for decision-making, with the possible consideration of addressing uncertainties in a decision analysis framework (ISR Study 8.5, Section 7.8). During the April 2014 POC Meetings, further discussion focused on extrapolation of Focus Area modeling results which is a precursor to the use of a DSS.

2. FOCUS AREA FISH HABITAT MODELING

Example fish habitat model output for FA-128 (Slough 8A) was developed for the POC Meetings based on input from two 2-D hydraulic models, SRH-2D for open water conditions, and River2D for ice covered conditions. The fish habitat model and the linkages to other riverine modeling efforts were developed to demonstrate application of 2-D habitat in the Focus Areas. The POC illustrated the model inputs, procedures, and model outputs. The data used in this 2-D fish habitat analysis were for example purposes only; supporting models have not been calibrated and all modeling inputs and output elements are subject to change. The fish habitat modeling presentations at the POC Meetings demonstrated the computational procedures for Effective Spawning/Incubation analyses (MEC and R2 2014a) and Salmonid Rearing Habitat (MEC and R2 2014b). Fish habitat metrics were developed for Existing Conditions and Operating Scenario OS-1b, and for representative wet, average and dry years.

The 2-D habitat approach incorporates concepts from the traditional Physical Habitat Simulation (PHABSIM) analyses. The physical parameters are modeled using 2-D hydraulic models (SRH-2D and River2D), which are combined with suitability criteria for the species of interest to calculate usable area of habitat. The habitat area calculations are made using geographic information system (GIS) tools to combine hydraulic output data or other parameters such as groundwater, water quality, substrate, and cover with habitat suitability criteria. Data dependencies for the habitat modeling include output from hydraulic models for open-water and ice process simulations, data on channel morphology and substrate, groundwater data, water quality data, and biological information such as species periodicity, distribution and abundance, and HSC/HSI. The 2-D approach demonstrated during the POC resulted in both visual and quantitative results for the decision framework. (Figure 2).

In addition to the GIS component, a visual basic (VB) model was developed for more efficient computational approach. GIS is used to spatially join the physical parameters into a single data file with all parameters needed for the habitat analysis. The result of the spatially-joined parameters is a single geo-referenced data file that can be used in the VB model.

The 2-D habitat model relies on several physical process models or physical data sets as part of the analysis (Figure 2). These data sets include hydraulic data, substrate data, cover data, and groundwater data. In addition to these data sets other variables may be incorporated as part of the analysis if the habitat suitability criteria analysis shows they are important to deriving habitat function. Examples of this type of data include water quality such as water temperature and dissolved oxygen and turbidity.

2.1. Fish Habitat Modeling Data Inputs

2.1.1. Hydraulic Data

As noted above, hydraulic data are provided to the Fish Habitat models from the 2-D hydraulic models, SRH–2D for open water conditions and River2D for ice covered conditions. Both models have variable mesh sizes to simulate hydraulics for a range of flows in main channel, side channels and lateral habitats. These models are simulated at discrete discharges over a range of flow from low to high flow conditions. These models produce a geo-referenced mesh with predicted depth, velocity, water surface, bed elevation, and area of the mesh cell. Each cell in the mesh is geo-referenced and can be evaluated with GIS (Figure 3). Details of the hydraulic simulations for the open water time period were provided during the POC Meetings (2014e) and in Attachment A to the Revised Fluvial Geomorphology Modeling Approach. Technical Memorandum (Tetra Tech 2014f).

Hydraulic data for winter conditions under ice are derived from River2D hydraulic models. River2D produces the same output as SRH–2D in a geo-referenced framework. Data from both models is transferred in character-separated values (CSV) files that can be imported into GIS for further analysis (Table 1). These data are used in conjunction with the HSC/HSI functions to produce habitat area as a function of depth and velocity. Other parameters for the habitat suitability include substrate, cover, and groundwater.

2.1.2. Substrate Data

Substrate data were collected by field crews in the fall of 2013 at seven Focus Areas in the Middle River below Devils Canyon. The substrate was mapped onto aerial photographs from ground observation using the same categories for substrate as the HSC/HSI field crew. The aerial photo maps were digitized and shape files created for each Focus Area. The shape files provide substrate class in a geo-referenced format that can be joined to the hydraulic simulation data (Figure 4).

2.1.3. Cover Data

Cover data were also collected at the same time as the surficial substrate characterization. The location of large woody debris, aquatic vegetation, overhanging vegetation, and undercut banks were recorded onto aerial photos. The geo-referenced cover data were used to develop a GIS layer to join with the hydraulic output and substrate output (Figure 5). Cover data were not part of the habitat suitability criteria for effective spawning habitat but cover was a variable for juvenile rearing.

2.1.4. Groundwater Data

Groundwater data for the POC was developed from a combination of sources. These sources included TIR imagery, data from the groundwater study, and data from the HSC/HSI field efforts. The combination of these data sources were used to develop a GIS layer with spatially referenced groundwater upwelling throughout FA-128 (Slough 8A) (Figure 6).

2.2. Fish Habitat Modeling Procedures

2.2.1. GIS Data Processing

A GIS analysis tool was used to develop the composite data set for the Effective Spawning/Incubation habitat model and Salmonid Rearing Habitat model. The GIS tool was used to combine the outputs from the hydraulic modeling, substrate, cover, and groundwater. The data for substrate, cover, and groundwater for the POC was a static layer for each variable for all flows simulated with the hydraulic model. GIS was used to run multiple combinations of the hydraulic model output for the simulated flows for both open-water and ice processes. The result was a complete data set for each simulated flow that included hydraulics, substrate, cover, and groundwater.

2.2.2. Visual Basic Model

These data sets with all parameters included were then passed to the Visual Basic model for analysis. The Visual Basic model was programmed with the HSC/HSI for salmonid spawning and juvenile rearing. The model interface has checkboxes that allows the user to select the species and lifestage of interest for each habitat analysis. The model then combines the habitat suitability criteria with the hydraulic data sets to produce a geo-referenced habitat layer for each flow of interest (Figure 7).

The Visual Basic model produces a graphical output for quality control to quickly determine if there are errors in the calculation depicted for the study area. It also produces tabular output with all of the input data repeated in the calculation for each cell in the hydraulic mesh of habitat area for the species and lifestage of interest (Table 2).

2.3. Fish Habitat Modeling Example Outputs

2.3.1. GIS Habitat Model

The GIS habitat model is used: a) to preprocess data into a single data set for the VB model (for open-water hydraulics and ice processes); b) for spatial analysis to track fixed locations within the Focus Area to evaluate scour (Figure 8); and c) for a spatial depiction of the habitat at each simulated flow from the hydraulic models (Figure 9).

This spatial analysis capability of GIS provides the means to track specific cells within the model to determine whether a cell has scoured, has groundwater upwelling, or is dewatered. Each flow simulated with the hydraulic models can then be evaluated for potential spawning area and whether that spawning habitat remains viable through the incubation period to fry emergence from the gravel environment. Spawning habitat is tracked with output from the open-water hydraulic simulations until ice cover forms, approximately mid-October to early November. After ice formation, the hydraulic model for ice processes (HDR 2014b) is used to determine the incubation habitat until the time of emergence.

2.3.2. Incubation Habitat

Incubation habitat is tracked using a sequential approach. Once ice cover forms, the hydraulics are simulated by the River2D hydraulic model. The output from that model includes water surface elevation depth and velocity. Incubation habitat is determined using the open water models to track spawning locations until ice formation. All habitats that remained viable until ice formation is tracked using the same spatial analysis approach as applied to spawning habitat. Each cell in the model domain that had viable spawning habitat and ice cover is checked for water depth to determine if the cell is wet for each flow during the winter. Cells that remain wet and have groundwater upwelling are considered viable incubation sites.

Total incubation habitat is then the sum of all cells that are viable at the end of egg incubation. The analysis results in a habitat versus discharge relationship that can be used to evaluate temporal changes in habitat (Figure 10). Habitat time series can use the hourly flow data combined with the habitat versus discharge relationship to produce an hourly relationship of habitat for several flow scenarios (Figure 11).

2.3.3. Breaching Flow Analysis

A secondary analysis that can also be completed using the 2-D hydraulic model output is mainstem flow breaching side channel and slough habitats. During the winter period, lateral groundwater dominated habitats may be important to egg incubation and overwinter fish survival. If those lateral habitats are flushed with cold mainstem water, rearing and incubation conditions in those lateral habitats will be affected. During the summer, mainstem flow changes may increase or decrease available spawning and rearing habitat in side channel and sloughs depending on the timing, frequency, and duration of breaching. Breaching analysis was conducted for the POC Meetings by determining the elevation of the side channel inlet and the flow level that inundated the side channel. The hourly data from the Reservoir Operations Model was used to provide the water surface elevations and discharges to evaluate breaching of the side channel. By comparing the side channel inlet elevation with the water surface elevations and discharges provided from the hourly model it is possible to determine the timing, duration and frequency when the side channel or slough habitats are breached (Figure 12).

3. SUMMARY

The GIS approach combined with the VB model can be used to evaluate species and lifestages of interest where HSC/HSI data are available. During the presentations made at the April 2014 POC Meetings, the procedures to calculate salmon spawning/incubation and salmonid rearing habitat were demonstrated. Although all data and model inputs for the habitat analyses were not available at the time of the POC, example inputs were used to demonstrate linkages and compatibilities. The examples presented during the POC demonstrate that inputs from the variety of riverine process models can be incorporated into a 2-D fish habitat analysis for the Middle River Focus Areas. Additional coordination between riverine modelers will be needed to refine modeling procedures and linkages, and additional coordination between AEA modelers and Licensing Participants will explore and communicate modeling developments during study implementation. The POC demonstrated that the models and approaches being applied by AEA are conceptually sound and will provide the level of detail needed to evaluate Project effects.

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5. TABLES

Table 1. Example of partial data set from hydraulic model simulation.

Point_ID	Area_ft_2	Centroid_X_ft	Centroid__Y_ft	Bed_Elev_ft	Water_Elev_ft	Water_Depth_ft	Vel_X_ft_p_s	Vel_Y_ft_p_s	Vel_Mag_ft_p_s
53	36.688	1654360.130	3166658.700	571.765	572.087	0.322	0.009	0.022	0.024
54	36.680	1654360.950	3166664.650	571.902	572.087	0.185	0.044	0.011	0.046
55	36.742	1654366.190	3166657.930	571.817	572.087	0.270	0.007	-0.039	0.039
56	36.733	1654367.000	3166663.890	571.921	572.087	0.166	0.008	-0.078	0.078
57	36.870	1654372.250	3166657.160	571.918	572.087	0.169	0.005	0.017	0.017

Table 2. Example of partial data set from VB model simulation for salmonid rearing habitat FA-128 (Slough 8A).

Point_ID	Centroid_ X_ft	Centroid__ Y_ft	Water_Dep th_ft	Vel_Mag_ft _p_s	Channel Index	Area_ft_2	Bed_Elev_ft	Water_Elev_ft	DomSub	POC_ Upwell	cover_ bool	Salmonid Rearing Probability	Salmonid Rearing Area
49	1654348	3166660	0.020404	0.010515	1	36.51416	573.1084	573.1289	SC		0	0	0
51	1654354	3166659	0.993707	0.116019	1	36.63379	572.1332	573.1269	SD		0	0.0001	0.0044
52	1654355	3166665	0.808737	0.052125	1	36.61816	572.3178	573.1266	SD		0	0.0008	0.0311
53	1654360	3166659	1.362084	0.281676	1	36.68799	571.7648	573.1269	SD		0	0	0
54	1654361	3166665	1.224199	0.262006	1	36.68018	571.9024	573.1266	SD		0	0	0.0001
55	1654366	3166658	1.309675	0.256029	1	36.7417	571.817	573.1267	SD		0	0	0
56	1654367	3166664	1.205486	0.273985	1	36.7334	571.9209	573.1264	SD		0	0	0.0002
57	1654372	3166657	1.208162	0.19974	1	36.87012	571.9179	573.126	LC		0	0	0.0002
58	1654373	3166663	1.145034	0.273578	1	36.85498	571.9806	573.1256	LC		0	0	0.0005
59	1654378	3166656	0.943406	0.173549	1	36.86182	572.1819	573.1253	LC		0	0.0003	0.01

6. FIGURES

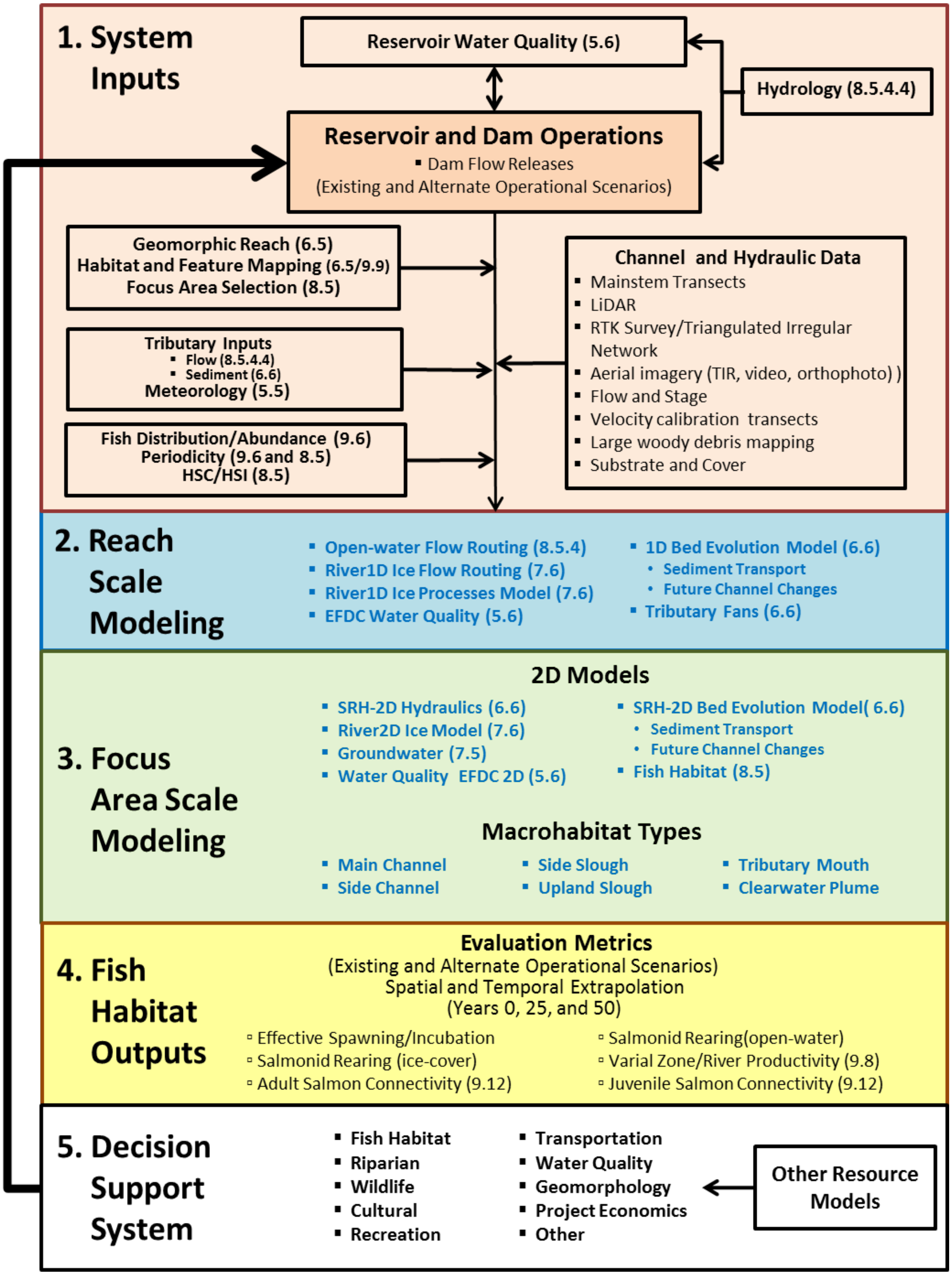


Figure 1. Instream Flow Study Framework showing stepwise progression of study elements.

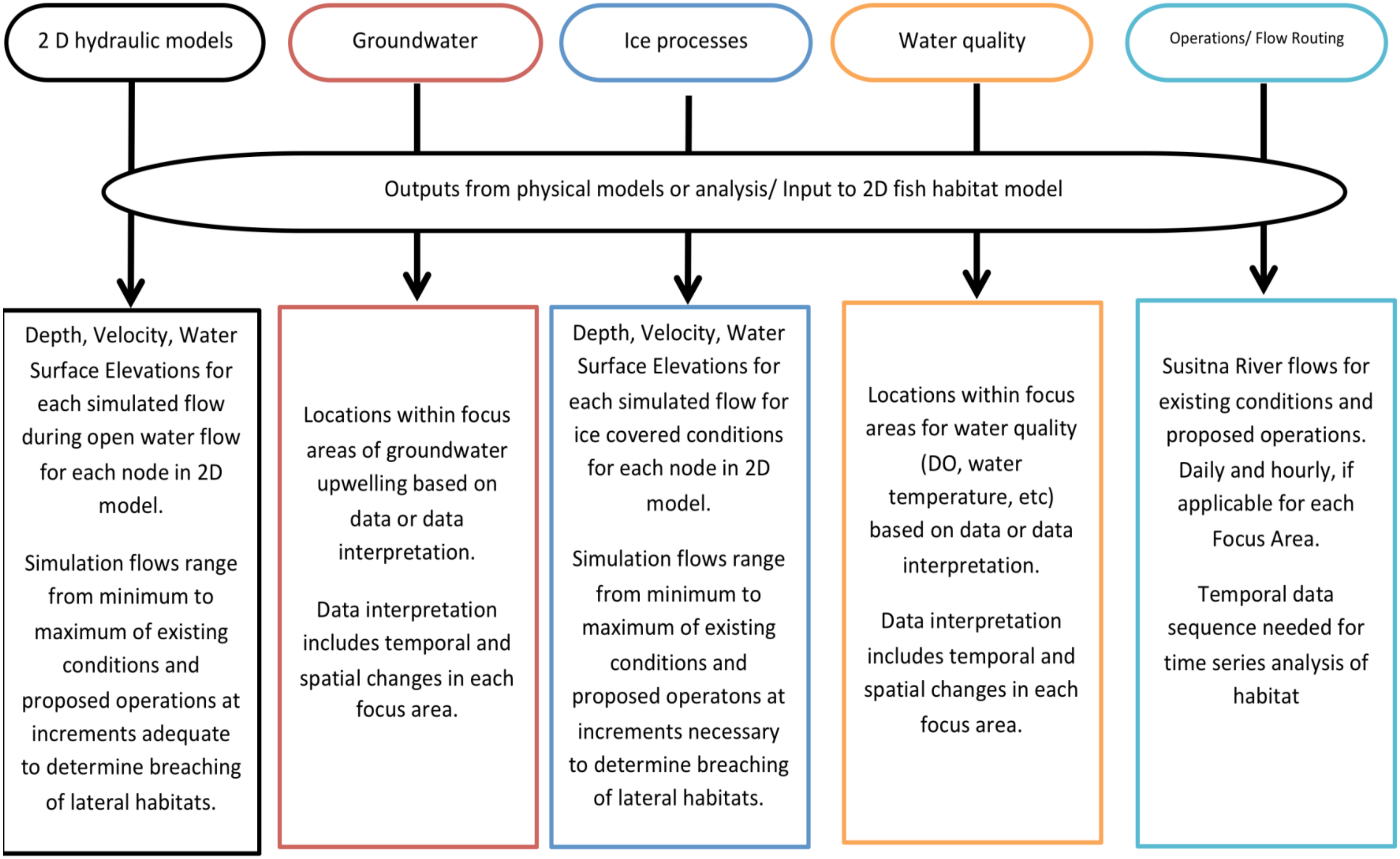


Figure 2. Physical process data dependencies and work flow for 2-D habitat analysis.

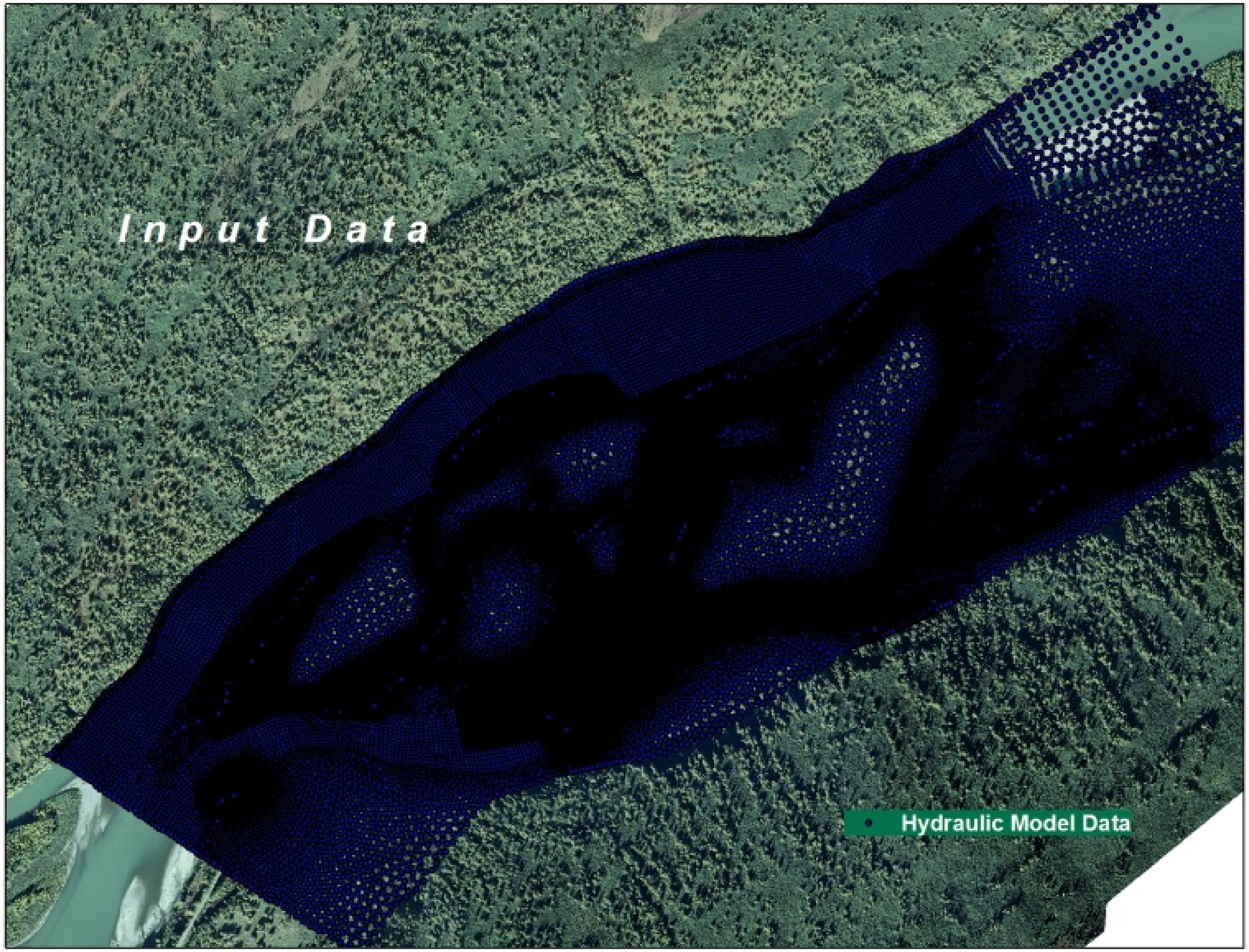


Figure 3. Example of hydraulic model mesh for FA-128 (Slough 8A).

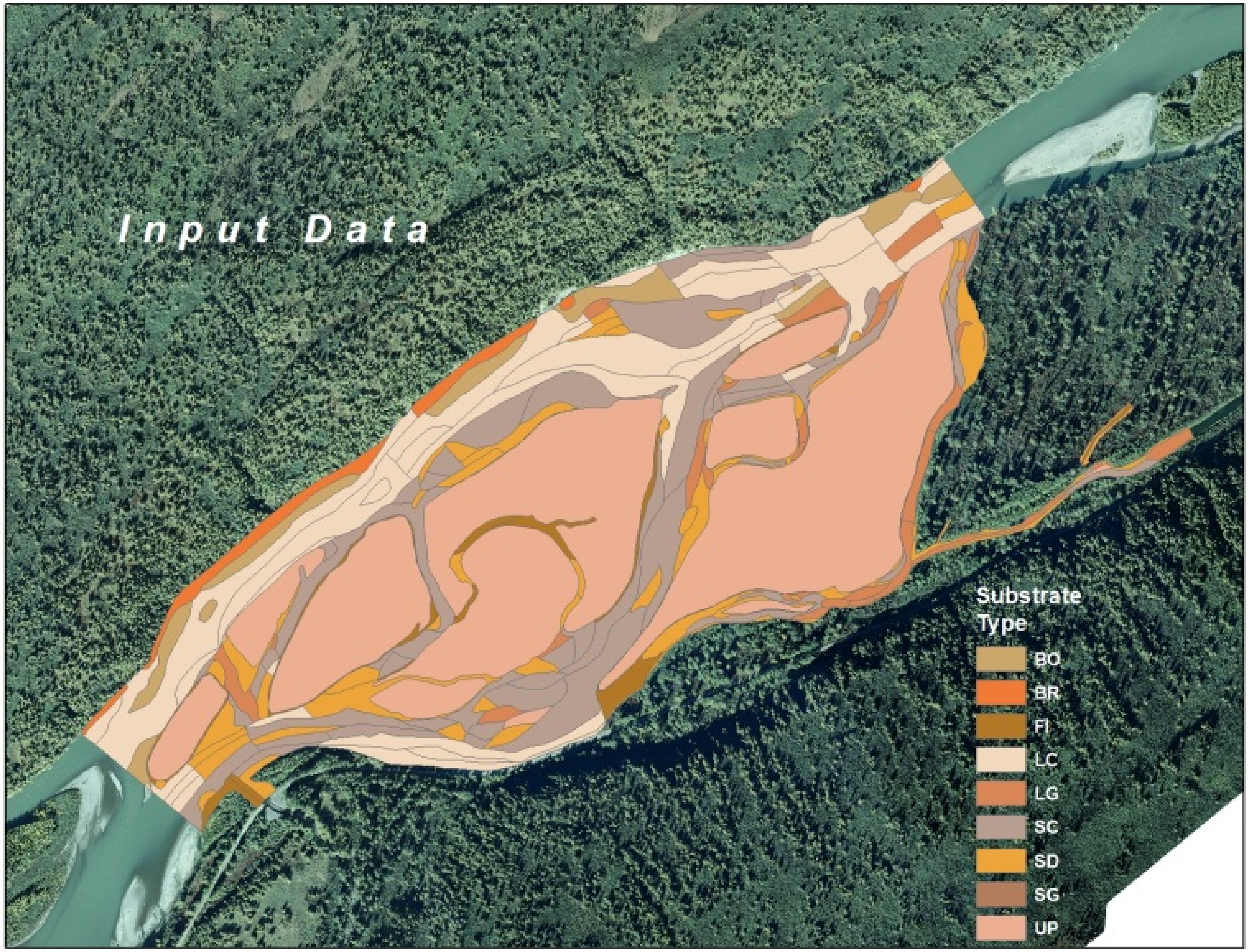


Figure 4. Example of substrate shape file derived from field substrate classification used for POC for FA-128 (Slough 8A).

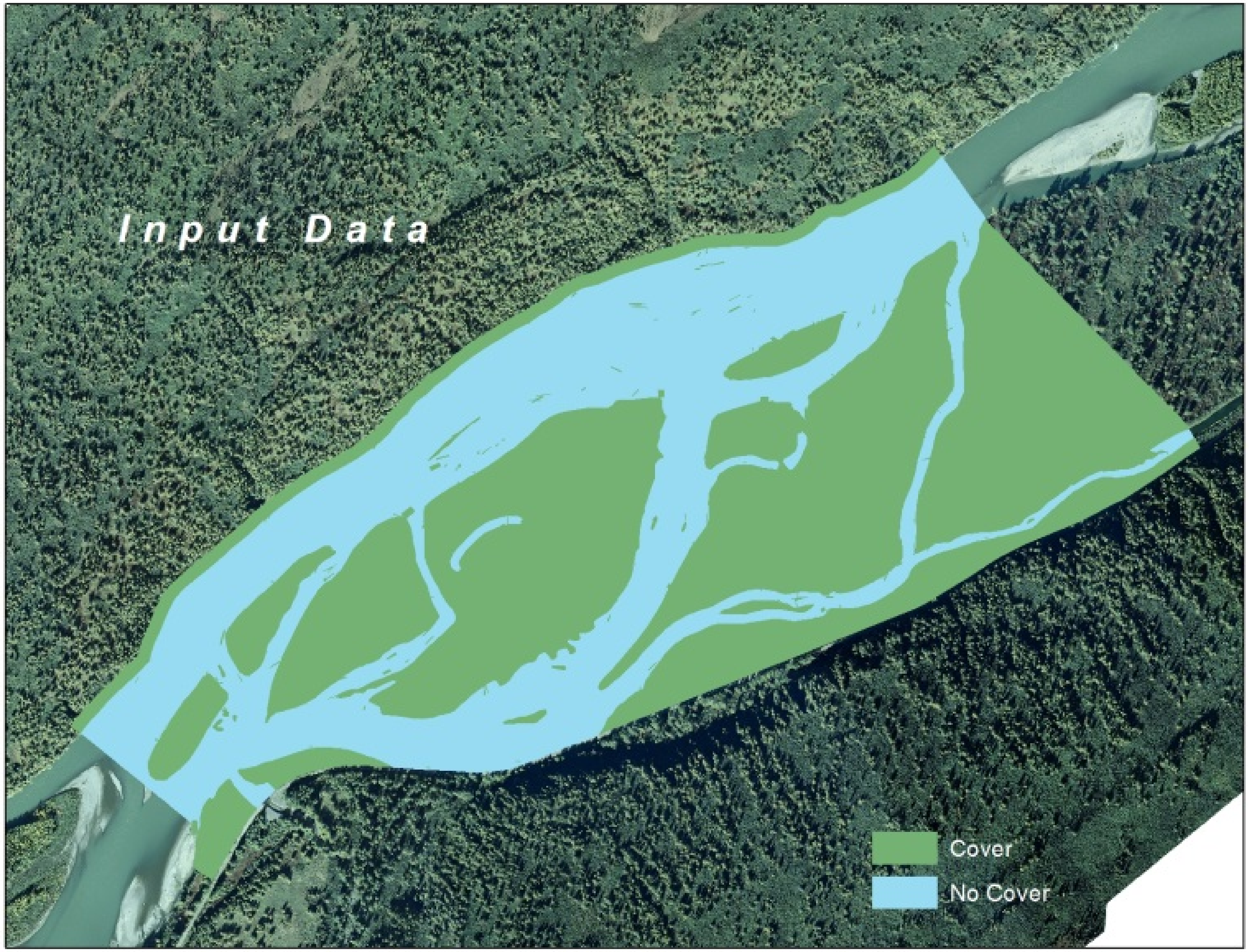
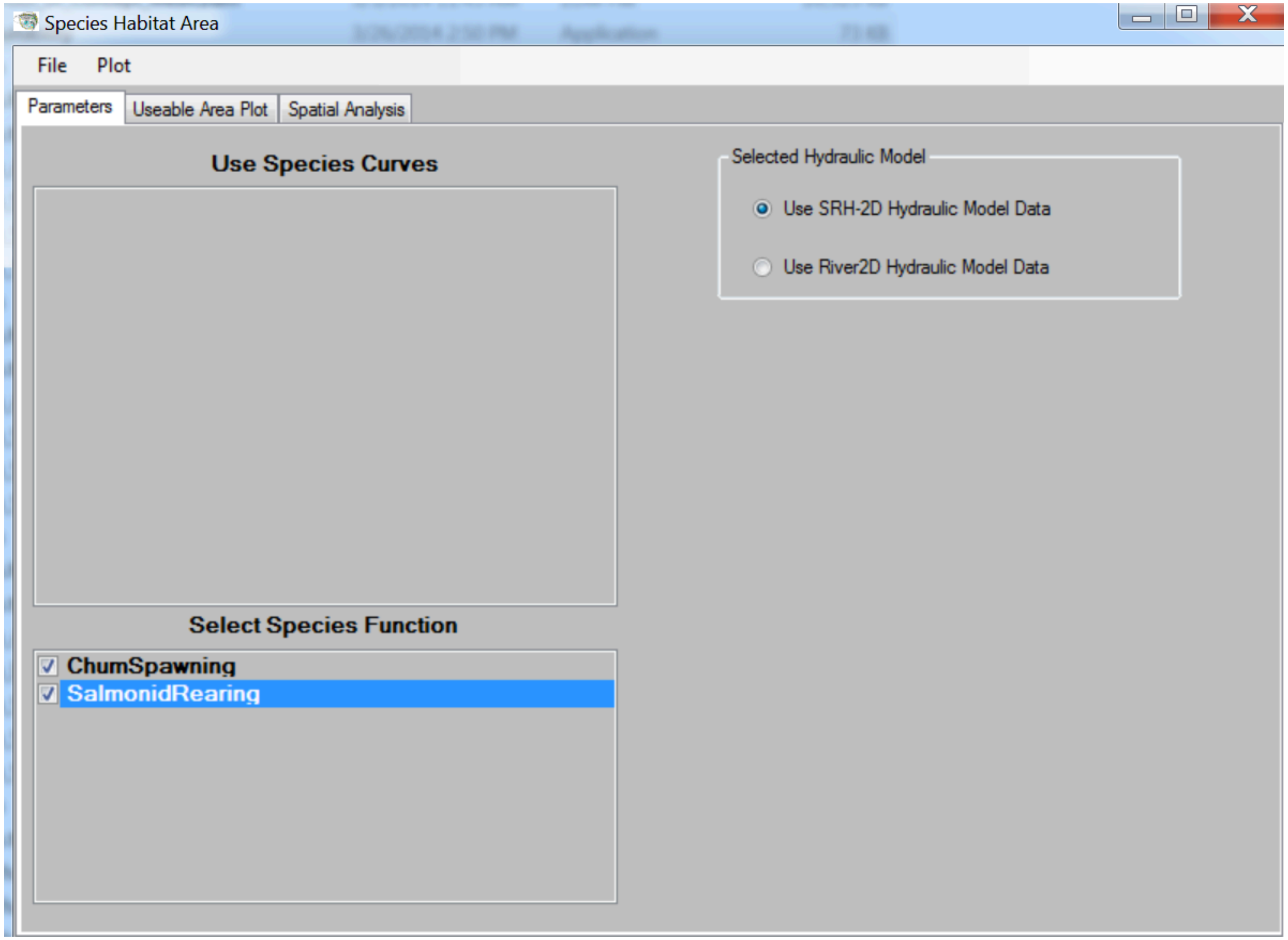


Figure 5. Example cover layer used for POC for FA-128 (Slough 8A).

Figure 6. Example of groundwater upwelling layer used for POC FA-128 (Slough 8A).



Selected Hydraulic Model

● Use SRH-2D Hydraulic Model Data

○ Use River2D Hydraulic Model Data

☑ ChumSpawning

☑ SalmonidRearing

Figure 7. Example screen shot of Visual Basic model interface.

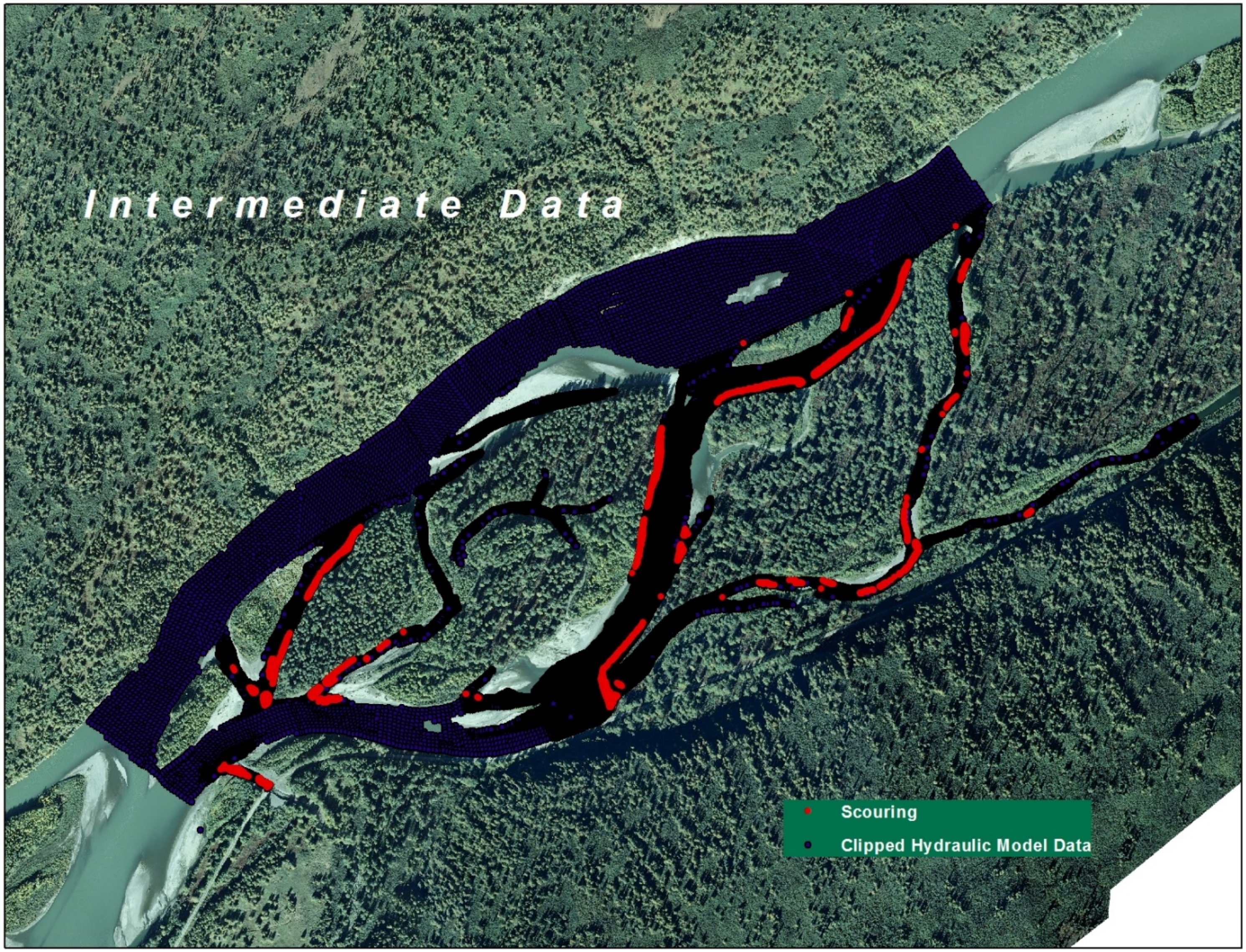


Figure 8. Example of scour analysis for effective spawning habitat FA-128 (Slough 8A).

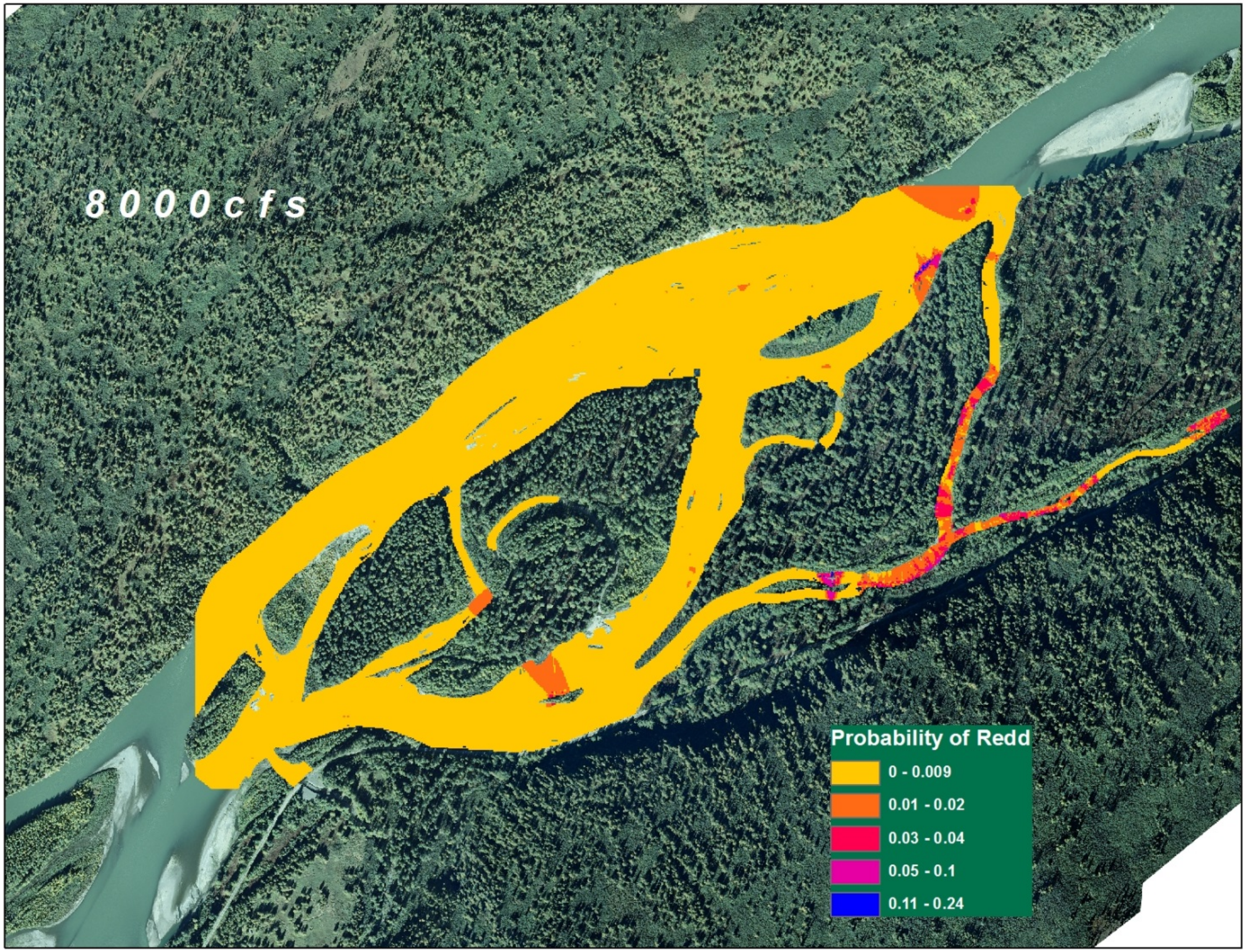


Figure 9. Example of GIS layer of spawning habitat at 8,000 cfs at FA-128 (Slough 8A).

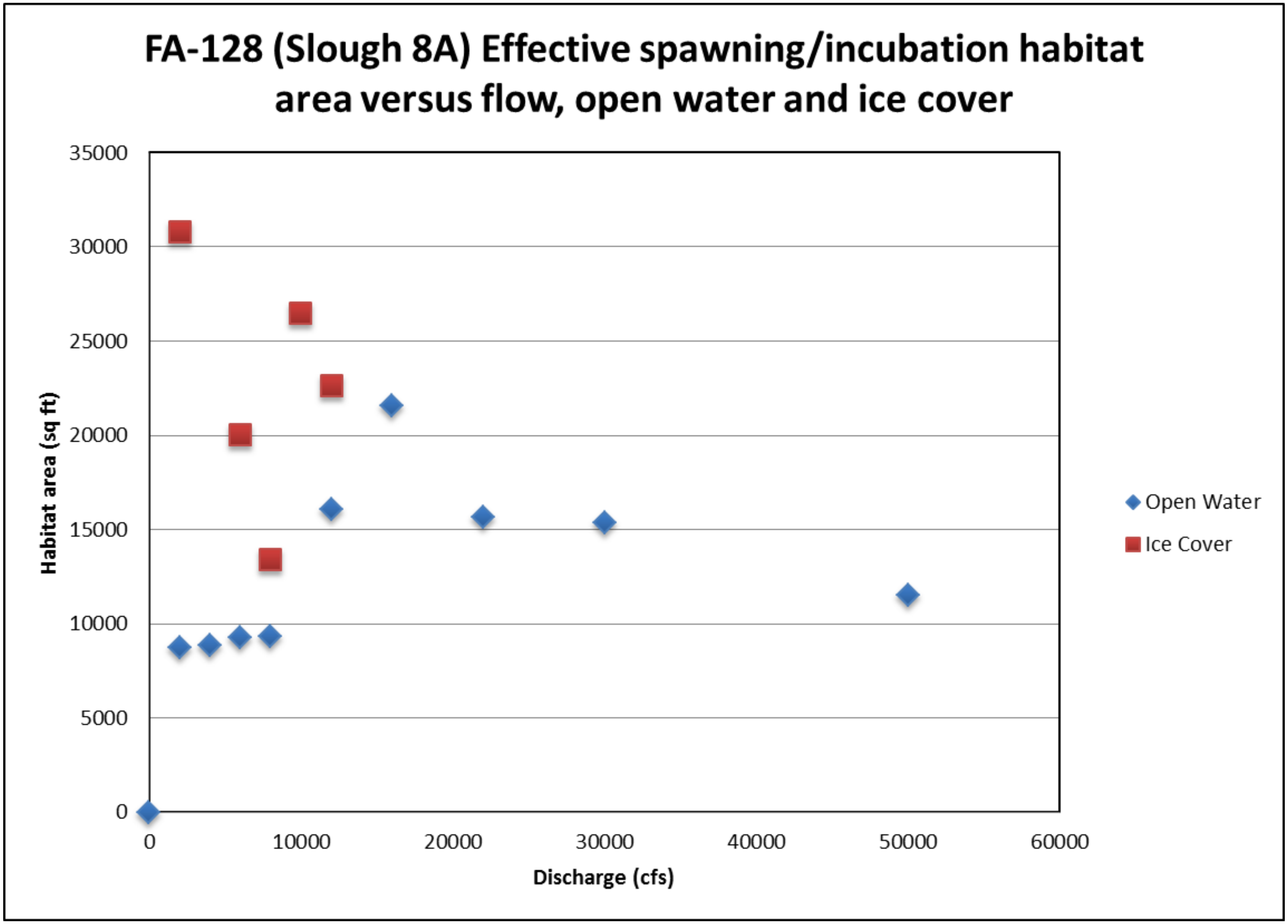


Figure 10. Example of habitat area versus discharge for effective spawning/incubation at FA 128 (Slough 8A).

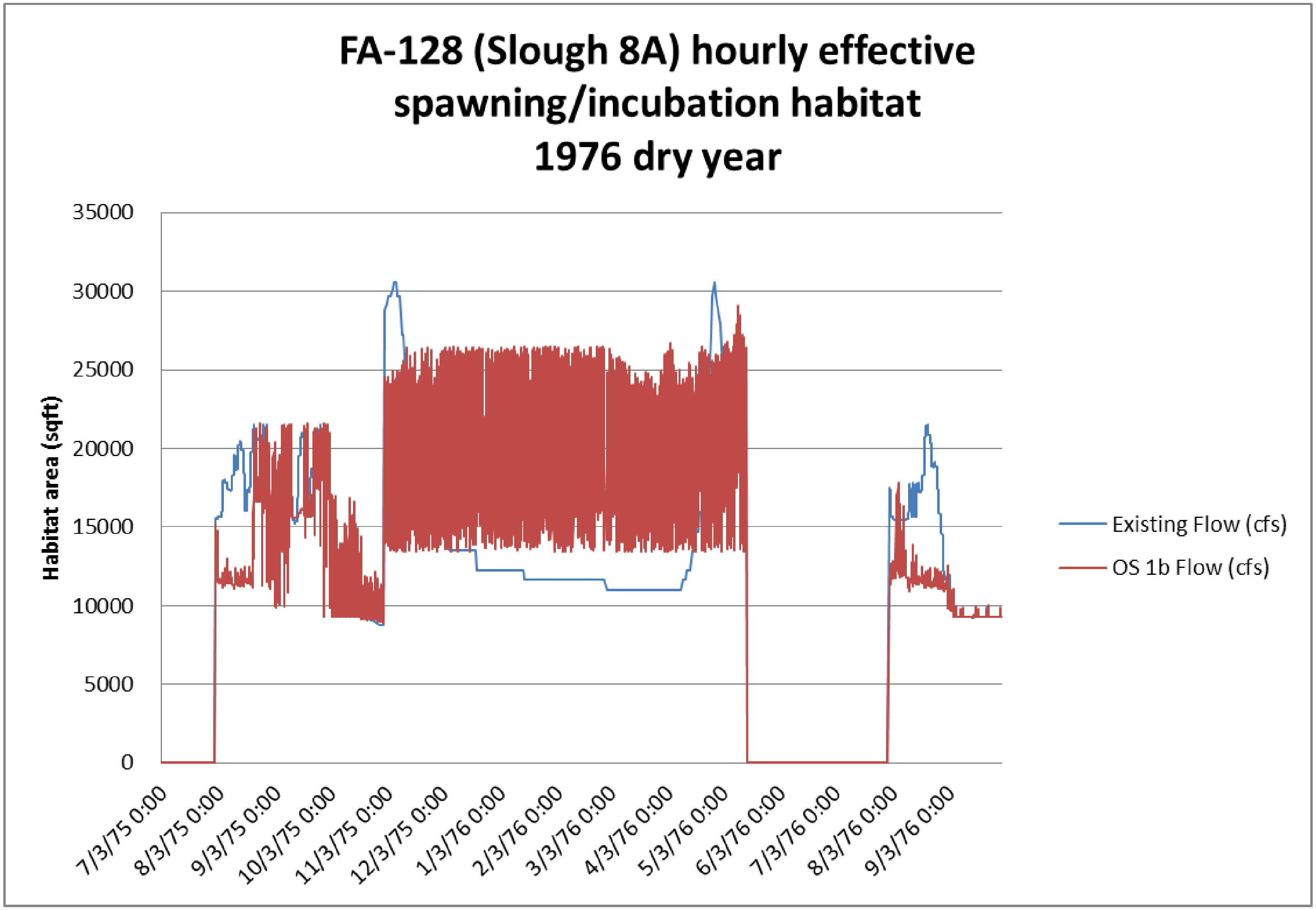


Figure 11. Example of hourly effective spawning/incubation habitat comparing Existing Conditions with OS-1b Project operations for 1976 (Dry Year) at FA-128 (Slough 8A).

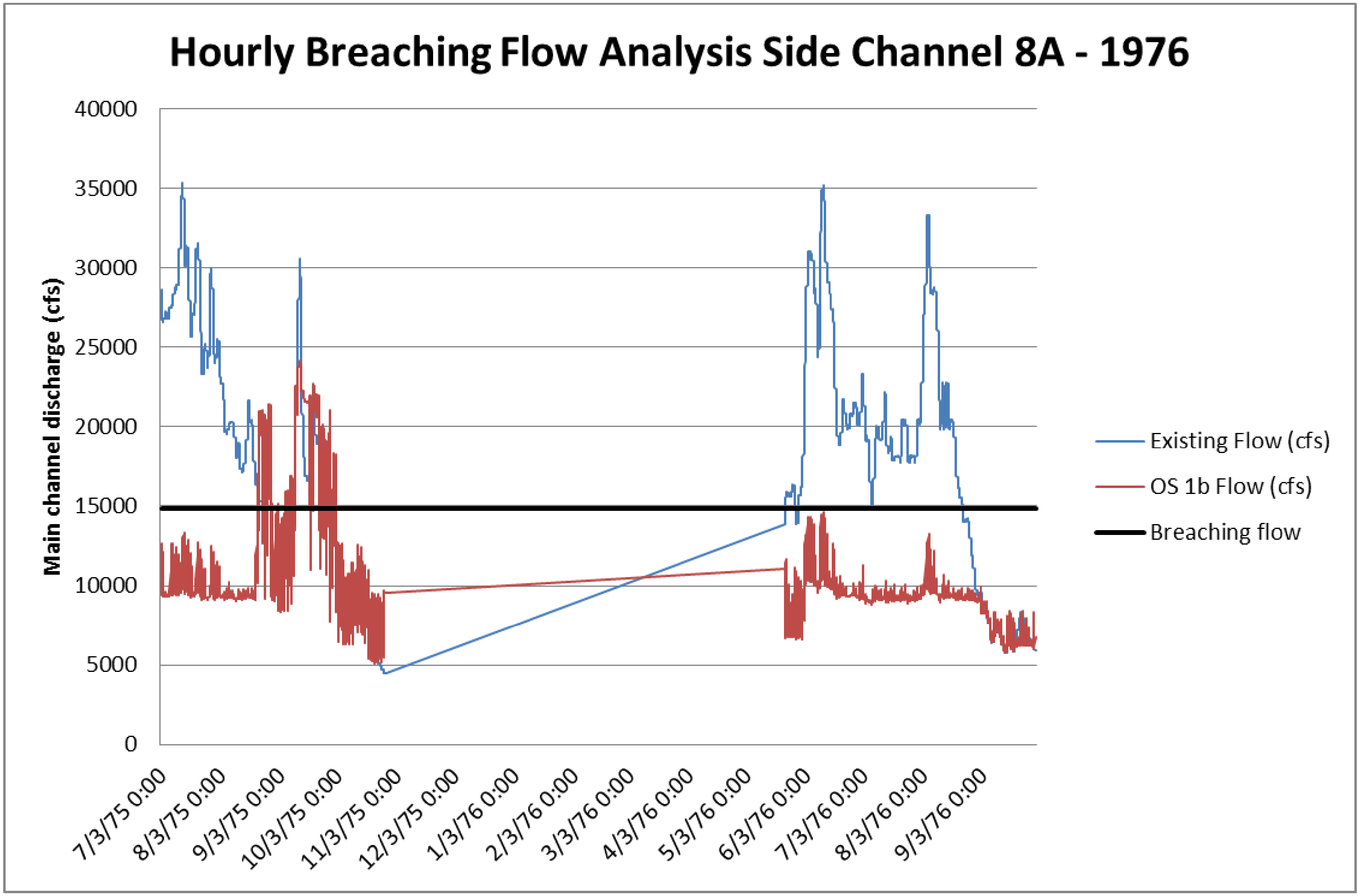


Figure 12. Example of breaching analysis results comparing Existing Conditions with OS-1b Project operations for 1976 (Dry Year) at FA-128 (Slough 8A).

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fish and Aquatics Instream Flow Study (8.5)

Initial Study Report
Part C - Appendix O
Fish Habitat Modeling in Lower River

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Golder Associates

June 2014

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LIST OF ACRONYMS AND SCIENTIFIC LABELS

Abbreviation	Definition
ADCP	Acoustic Doppler Current Profiler
cfs	Cubic feet per second
FA-IFS	Fish and Aquatics Instream Flow Study
ISR	Initial Study Report
LiDAR	Light Detection And Ranging
LR	Lower River
PHABSIM	Physical Habitat Simulation model
PRM	Project River Mile
USR	Updated Study Report
WSE	Water surface elevation

1. INTRODUCTION

The Fish and Aquatic Instream Flow Study (FA-IFS) for the Lower River Segment (LR) of the Susitna River is one component of the overall Study Plan for the FA-IFS program (Study 8.5). The basis, methodology and results of the preliminary hydraulic modeling are documented in ISR 8.5, Appendix I, for the Birch Creek site (PRM 93.3) and the PRM 97 site, which is a main channel site located at approximately PRM 97. In support of IFS Technical Team Proof of Concept (IFS-TT POC) Meeting held April 15-17, 2014 in Anchorage, Alaska, calibration of the Birch Creek and PRM 97 was refined using additional field data and results from other riverine process models that became available in 2014. Example fish habitat modeling results were completed and presented at the IFS-TT POC Meeting (Golder 2014).

2. HYDRAULIC MODEL CALIBRATION UPDATE

2.1. Data Updates

Provisional data to support model calibration became available after the completion of the preliminary model calibration described in ISR Study 8.5, Appendix I. Provisional data included 2013 LiDAR (ISR Study 6.6) and Version 2 of the Open-water Flow Routing Model (ISR Study 8.5, Appendix K). The HEC-RAS models used for the Lower River Fish Habitat modeling were updated and calibrations revised based on incorporating the new data. For the PRM 97 site, eight additional transects obtained from the 1-D Susitna River Open-water Flow Routing Model (Version 2) were added upstream and downstream of the PRM 97 Site for better representation of the river channel and to provide single channel flow conditions at the model boundaries. Calibration methods remained unchanged from what is described in ISR Study 8.5, Appendix I.

2.2. Hydraulic Model Calibration and Simulation Updates

Updates to the HEC-RAS model calibration were completed and are summarized in Table 1 through Table 3. Flow simulations were completed at the Birch Creek site and the PRM 97 site using the updated model calibration. Results of the simulations are provided in Table 4 through Table 6. For the Birch Creek site, simulations were conducted using both a low flow calibration and high flow calibration with an overlap in simulated flows. Since Project operations will not alter inflow from Birch Creek, the simulation discharge for Birch Creek was held constant to simulate changes to water levels that would occur across a range of discharges within Birch Creek Slough. An example simulation using a Birch Creek discharge of 35.1 cfs is presented in Table 5.

2.3. Flow Allocation Analysis

The model domains for the Lower River Fish Habitat IFS sites were comprised of discrete habitat areas of the main channel used to define a specific habitat area of interest. A whole river model was not proposed or developed for the Lower River Fish Habitat sites. As such, each Lower River Fish Habitat IFS site will be calibrated to the local flows measured within the model domain that will consist of a proportion of the total flow in the Susitna River at that location. The analysis of habitat change due to Project operations will be based on main channel flow scenarios. To allow for an analysis of the Project flow time series to be conducted at the Lower River Fish Habitat IFS sites, the flow within each study site must be determined as a proportion of main channel flow.

An example of how this process would be completed was presented at the IFS-TT POC Meeting. The relationship between Susitna River discharge and Birch Creek Slough discharge was established using two 1-dimensional HEC-RAS models that were developed for each location. The Susitna River model runs from PRM 98.4 upstream to PRM 91.6. Birch Creek Slough begins on the left bank (looking downstream) of the main channel approximately 1,000 feet upstream of cross-section PRM 94.8. Birch Creek Slough discharge re-enters the main channel approximately 1,000 feet below PRM 92.3.

The discharge relationship between the Susitna River and Birch Creek Slough was established by running the Susitna River Model for a range of discharges and interpolating the main channel water surface elevation (WSE) at the beginning and re-entry of Birch Creek Slough. The WSE at the Birch Creek Slough re-entry point was used as the downstream boundary condition of the Birch Creek model. The discharge in the Birch Creek Slough was iterated until the upstream WSE in the slough matched the WSE in the main channel. The relationship developed between Susitna River main channel discharge and Birch Creek Slough discharge is provided in Figure 1.

3. HABITAT MODELING

3.1. Birch Creek Slough Proof of Concept

The WSE results from the HEC-RAS model simulations were imported into PHABSIM. Velocity profiles were measured at each transect using a boat-mounted ADCP during the June 2013 survey as described in ISR 8.5 Section 4.6. ADCP velocities were sorted into equally spaced bins using a minimum of 20 vertical locations across the transect to define the velocity profile for import into PHABSIM. An example of the habitat modeling procedures and presentation of typical results and analysis was presented at the IFS-TT POC Meeting. Full details of the habitat modeling procedures and results will be provided n the Updated Study Report (USR) once the final habitat modeling is complete.

Velocity profiles were simulated using PHABSIM for each simulation discharge by applying a single-discharge velocity calibration approach. The June 2013 (high flow) field survey was completed with velocities measured at each fish habitat transect. The field approach for measuring velocity profiles at a single discharge followed the approved approach as described in the March 2013 filing (R2 2013). Substrate distribution across each transect was coded according to the substrate distribution maps presented in ISR Study 8.5, Appendix I. An example of the preliminary velocity modeling results is presented in Figure 2.

Coho salmon were selected as the example species for spawning habitat modeling since the Fish Distribution and Abundance Study (Study 9.6) results from 2013 found Coho Salmon utilizing the habitats in the vicinity of PRM 92.9; including within Birch Creek. Current periodicity and habitat suitability criteria / Habitat Suitability Index (HSC/HSI) models are not yet available for the Lower River. Therefore, periodicity and HSC models from the 1980s for Coho Salmon (Vincent-Lang et al. 1984) were applied to generate example weighted useable area (WUA) output for the Lower River. An example of weighted useable area curve results that could be expected from the Lower River modeling is presented in Figure 3.

The proposed assessment approach for the Lower River presented at the IFS-TT POC Meeting was to generate a habitat time series using the WUA output and the flow time series from the Open-water Flow Routing Model (Version 2). Using the Birch Creek Slough site as an example, the main channel flow time series was converted to a Birch Creek Slough flow time series using the Q-q relationship presented in Figure 1. A habitat time series was generated for Existing Conditions and an example Project Operational Scenario (OS-1) for a typical dry year (1976) and typical wet year (1981). The example juvenile Coho Salmon habitat time series results for 1976 and 1981 are presented in Figures 4 and 5.

4. CONCLUSIONS

The process for conducting habitat modeling in the LR was presented at the IFS-TT POC Meeting. An open-water HEC-RAS model was created for simulating water surface elevations at the fish habitat transects and within the Susitna River upstream and downstream of the study sites. Simulated WSE results were imported into PHABSIM and velocity modeling was conducting using a single-discharge calibration approach. Habitat modeling was completed using 1980s HSC models as an example. The LR fish habitat modeling is in progress and will proceed in a manner as outlined at the IFS-TT POC and in ISR Study 8.5, Section 7.6. Details of the habitat modeling procedures, calibration and simulation results will be presented when the final habitat modeling is complete in support of the USR.

5. LITERATURE CITED

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Vincent-Lang, D., A. Hoffman, A.E. Bigham, C.C. Estes, D. Hilliard, C. Stewart, E.W. Trihey, and S. Crumley. 1984a. An evaluation of chum and sockeye salmon spawning habitat in sloughs and side channels of the Middle Susitna River. Chapter 7 (339 pages) in Estes, C.C., and D.L. Vincent-Lang, eds., Aquatic habitat and instream flow investigations (May–October, 1983). Report No. 3, Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Prepared for Alaska Power Authority, Anchorage, Alaska. APA Document 1936.

6. TABLES

Table 1. Comparison of Surveyed and HEC-RAS Simulated Water Levels for June 2013 High Flow Calibration at Birch Creek Site.

Reach	Cross-Section ID	Channel Bed Thalweg Elevation	Average Survey Water Edge Elevation	Simulated Water Level	Water Level Difference (Simulated - Surveyed)
		m (ft)	m (ft)	m (ft)	m (ft)
Birch Creek Slough (Upstream Reach)	BCS T10	88.56 (290.55)	90.85 (298.05)	90.73 (297.67)	-0.11 (-0.38)
	BCS T9	87.86 (288.25)	90.68 (297.51)	90.6 (297.24)	-0.08 (-0.26)
	BCS T8	87.69 (287.7)	90.55 (297.08)*	90.56 (297.11)	0.01 (0.03)
	BCS T7	88.27 (289.6)	90.48 (296.83)	90.39 (296.56)	-0.08 (-0.28)
	BCS T6	87.88 (288.32)	90.35 (296.41)	90.29 (296.23)	-0.05 (-0.18)
Birch Creek Slough (Downstream Reach)	BCS T5	87.73 (287.83)	90.17 (295.83)	90.11 (295.64)	-0.06 (-0.2)
	BCS T4	87.88 (288.32)	89.99 (295.23)	89.95 (295.11)	-0.03 (-0.11)
	BCS T3	87.78 (287.99)	89.89 (294.9)	89.86 (294.82)	-0.03 (-0.08)
	BCS T2	88.07 (288.94)	89.62 (294.01)	89.62 (294.03)	0.005 (0.02)
Birch Creek	BC T6	88.98 (291.93)	90.21 (295.95)	90.21 (295.96)	0.005 (0.02)
	BC T5	88.63 (290.78)	90.195 (295.92)	90.21 (295.96)	0.02 (0.07)
	BC T4	88.63 (290.78)	90.24 (296.05)	90.2 (295.93)	-0.03 (-0.11)
	BC T3	88.71 (291.04)	90.22 (295.98)	90.2 (295.93)	-0.02 (-0.07)
	BC T2	88.48 (290.29)	90.24 (296.05)	90.2 (295.93)	-0.03 (-0.11)
	BC T1	88.52 (290.42)	90.19 (295.88)	90.2 (295.93)	0.02 (0.07)
			Maximum Difference		0.02 (0.07)
			Minimum Difference		-0.11 (-0.38)

Notes:

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

Table 2. Comparison of Surveyed and HEC-RAS Simulated Water Levels for September 2013 Low Flow Scenario at Birch Creek Site.

Reach	Cross-Section ID	Channel Bed Thalweg Elevation	Average Survey Water Edge Elevation	Simulated Water Level	Water Level Difference (Simulated - Surveyed)
		m (ft)	m (ft)	m (ft)	m (ft)
Birch Creek Slough Upstream Reach	BCS T10	88.56 (290.55)	89.62 (294.04)	89.59 (293.93)	-0.03 (-0.11)
	BCS T9	87.86 (288.25)	89.45 (293.46)	89.45 (293.47)	0.003 (0.01)
	BCS T8	87.69 (287.7)	89.43 (293.39)	89.43 (293.41)	0.005 (0.02)
	BCS T7	88.27 (289.6)	89.43 (293.4)	89.36 (293.18)	-0.07 (-0.22)
	BCS T6	87.88 (288.32)	89.39 (293.26)	89.21 (292.68)	-0.17 (-0.57)
Birch Creek Slough Downstream Reach	BCS T5	87.73 (287.83)	88.99 (291.97)	89.03 (292.09)	0.04 (0.12)
	BCS T4	87.88 (288.32)	88.94 (291.8)	88.94 (291.8)	0 (0)
	BCS T3	87.78 (287.99)	88.65 (290.85)	88.86 (291.54)	0.21 (0.69)
	BCS T2	88.07 (288.94)	88.52 (290.4)	88.52 (290.42)	0.005 (0.02)
Birch Creek Tributary	BC T6	88.98 (291.93)	89.54 (293.77)	89.37 (293.21)	-0.17 (-0.56)
	BC T5	88.63 (290.78)	89.36 (293.18)	89.22 (292.72)	-0.14 (-0.46)
	BC T4	88.63 (290.78)	89.21 (292.68)	89.16 (292.52)	-0.05 (-0.16)
	BC T3	88.71 (291.04)	89.1 (292.32)	89.1 (292.32)	0 (0)
	BC T2	88.48 (290.29)	89.03 (292.08)	89.06 (292.19)	0.03 (0.11)
	BC T1	88.52 (290.42)	89.01 (292.03)	89.05 (292.16)	0.04 (0.13)
			Maximum Difference		0.21 (0.69)
			Minimum Difference		-0.17 (-0.57)

Notes:

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

Table 3. Comparison of Surveyed and HEC-RAS Simulated Water Levels for June 2013 High Flow Calibration for PRM 97 site.

Cross-Section ID	Channel Bed Thalweg Elevation	Average Survey Water Edge Elevation	Simulated Water Level	Water Level Difference (Simulated - Surveyed)
	(m) (ft)	(m) (ft)	(m) (ft)	(m) (ft)
PRM 97 T3	92.4 (303.15)	97.13 (318.65)	97.44 (319.69)	0.31 (1.03)
PRM 97 T2	92.16 (302.36)	97.04 (318.36)	97.08 (318.5)	0.05 (0.15)
PRM 97 T1	92.28 (302.76)	96.99 (318.21)	97.04 (318.37)	0.05 (0.16)
		Maximum Difference		0.31 (1.03)
		Minimum Difference		0.05 (0.15)

Table 4. HEC-RAS Simulated Flow Scenarios for the Birch Creek Slough and Birch Creek Site.

Reach	Flow Simulation Scenarios (cfs)															
	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15
Birch Creek Slough Upstream Reach	141.3	211.9	423.8	565.0	635.7	882.9	1412.6	1765.7	2118.9	2472.0	2825.2	3531.4	4061.2	4590.9	5120.6	5650.3
Birch Creek	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3
Birch Creek Slough Downstream Reach	176.6	247.2	459.1	600.3	671.0	918.2	1447.9	1801.0	2154.2	2507.3	2860.5	3566.8	4096.5	4626.2	5155.9	5685.6

Table 5. HEC-RAS Simulated Water Surface Elevations for the Low Flow Calibration and High Flow Calibration at the Birch Creek Slough and Birch Creek Site.

Reach	Cross-Section ID	Low Flow Calibration WSE (ft)								High Flow Calibration WSE(ft)										
		Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5*	Scenario 6*	Scenario 7*	Scenario 5*	Scenario 6*	Scenario 7*	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15
Birch Creek Slough (Upstream Reach)	BCS T10	292.81	293.34	294.46	294.95	295.18	295.87	297.05	297.70	294.82	295.80	296.33	296.82	297.28	297.67	298.46	298.98	299.48	299.93	300.36
	BCS T9	292.39	292.91	294.00	294.49	294.72	295.41	296.56	297.21	294.42	295.37	295.93	296.39	296.82	297.24	297.97	298.49	298.95	299.38	299.80
	BCS T8	292.36	292.85	293.90	294.39	294.59	295.24	296.39	297.01	294.36	295.28	295.80	296.26	296.69	297.08	297.83	298.36	298.85	299.31	299.74
	BCS T7	292.16	292.65	293.67	294.09	294.29	294.88	295.93	296.52	294.03	294.88	295.34	295.77	296.16	296.52	297.21	297.67	298.13	298.56	298.95
	BCS T6	291.70	292.16	293.24	293.67	293.86	294.46	295.47	296.06	293.67	294.52	295.01	295.44	295.83	296.23	296.92	297.41	297.87	298.29	298.72
Birch Creek Slough (Downstream Reach)	BCS T5	291.34	291.70	292.52	292.95	293.11	293.70	294.75	295.31	292.98	293.86	294.36	294.82	295.21	295.60	296.33	296.78	297.24	297.67	298.06
	BCS T4	291.14	291.47	292.19	292.55	292.72	293.27	294.19	294.72	292.65	293.47	293.90	294.32	294.72	295.05	295.70	296.16	296.59	296.98	297.34
	BCS T3	290.98	291.27	291.86	292.19	292.36	292.81	293.64	294.13	292.45	293.21	293.64	294.03	294.42	294.75	295.41	295.83	296.26	296.65	297.05
	BCS T2	290.03	290.26	290.58	290.75	290.81	291.01	291.40	291.63	291.90	292.55	292.95	293.31	293.64	293.93	294.52	294.95	295.31	295.70	296.03
Birch Creek Tributary	BC T6	293.27	293.27	293.27	293.37	293.44	293.86	294.91	295.51	293.24	294.06	294.59	295.05	295.51	295.93	296.69	297.21	297.70	298.16	298.59
	BC T5	293.27	293.27	293.27	293.37	293.44	293.86	294.91	295.51	293.14	294.06	294.59	295.05	295.51	295.93	296.69	297.21	297.70	298.16	298.59
	BC T4	292.55	292.59	292.78	293.11	293.27	293.83	294.91	295.51	293.14	294.03	294.59	295.05	295.51	295.90	296.69	297.21	297.70	298.16	298.59
	BC T3	292.22	292.26	292.68	293.04	293.24	293.83	294.88	295.51	293.11	294.03	294.59	295.05	295.51	295.90	296.69	297.21	297.70	298.16	298.59
	BC T2	291.77	291.93	292.62	293.04	293.24	293.83	294.88	295.51	293.11	294.03	294.59	295.05	295.51	295.90	296.69	297.21	297.70	298.16	298.59
	BC T1	291.40	291.77	292.59	293.01	293.21	293.83	294.88	295.51	293.11	294.03	294.59	295.05	295.51	295.90	296.69	297.21	297.70	298.16	298.59

Notes:

1 Flow scenarios referenced are presented in Table 3.

2 Flow scenarios highlighted in yellow represent the overlap in flows simulated using both the low flow calibration and high flow calibration models.

Table 6. HEC-RAS Simulated Water Surface Elevations for the High Flow Calibration at the PRM 97 Site

Cross-Section ID	**Flow Simulation Scenarios (cfs)**									
	30017	35314	42377	49440	60035	74160	84755	95349	109475	120069
	Simulated Water Levels (ft)									
PRM 98.4	325.43	326.15	326.90	327.49	328.22	329.10	329.86	330.48	331.10	331.46
PRM 97	317.62	318.18	318.83	319.46	320.18	321.03	321.65	322.18	322.74	323.10
PRM 97 T3	317.16	317.72	318.34	318.93	319.65	320.44	321.03	321.56	322.05	322.38
PRM 97 T2	316.31	316.80	317.36	317.85	318.50	319.19	319.65	320.05	320.51	320.83
PRM 97 T1	316.17	316.67	317.22	317.68	318.34	319.06	319.52	319.91	320.41	320.70
PRM 96.2	314.07	314.53	315.06	315.45	315.94	316.50	316.86	317.19	317.65	317.95
PRM 94.8	304.49	304.95	305.38	305.84	306.30	306.76	307.09	307.45	307.84	308.04
PRM 94.0	295.70	296.46	297.54	298.52	299.87	300.95	301.57	302.10	302.66	303.08
PRM 93.2	293.41	294.00	294.75	295.28	296.00	296.72	297.21	297.70	298.26	298.65
PRM 92.3	290.65	291.11	291.67	292.13	292.81	293.50	293.96	294.42	295.01	295.41
PRM 91.6	284.09	284.68	285.37	285.96	286.78	287.73	288.32	288.91	289.67	290.26

Notes:

1 Yellow highlighted rows indicate fish habitat transects, all other transects represent flow routing model transect locations.

7. FIGURES

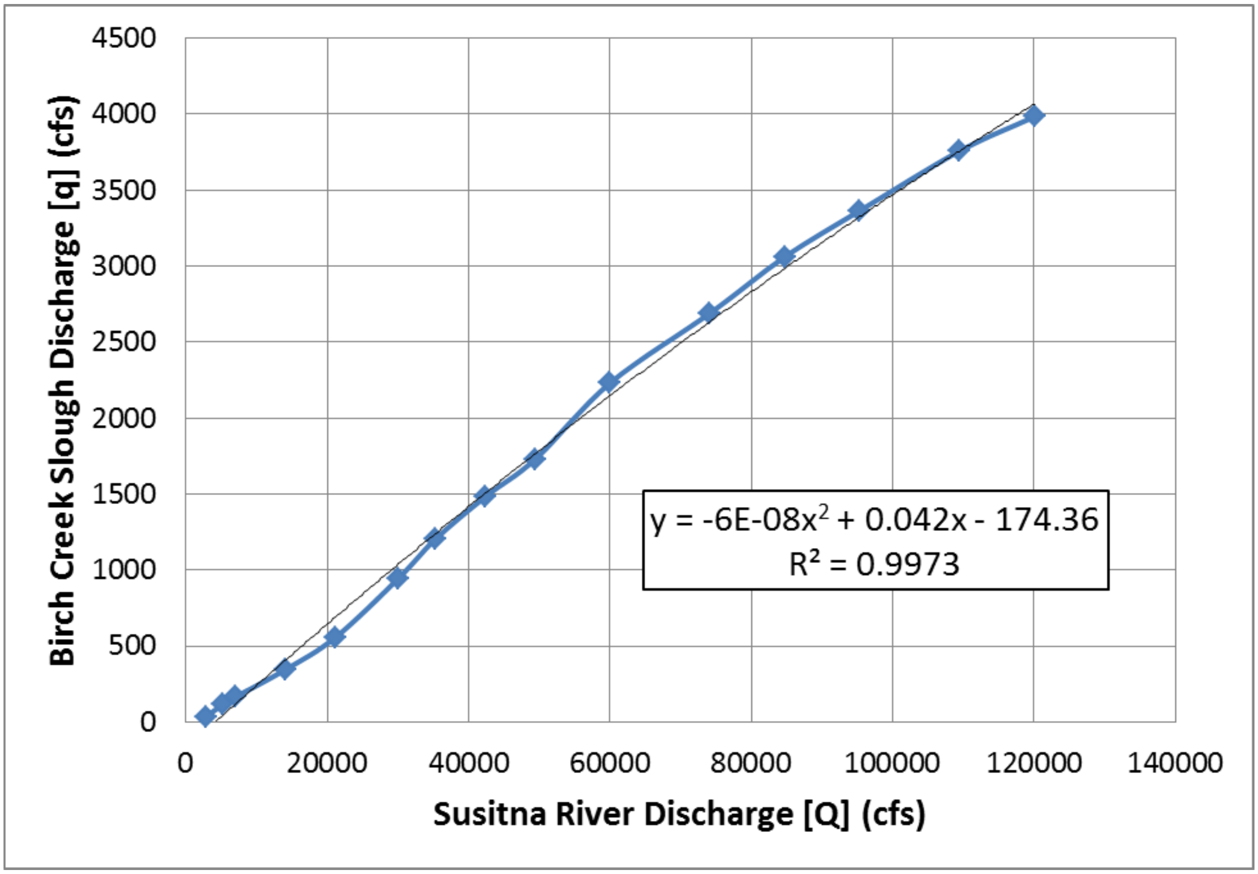

Figure 1. Discharge (Q-q) Relationship between Susitna River at PRM 94.8 and Birch Creek Slough.

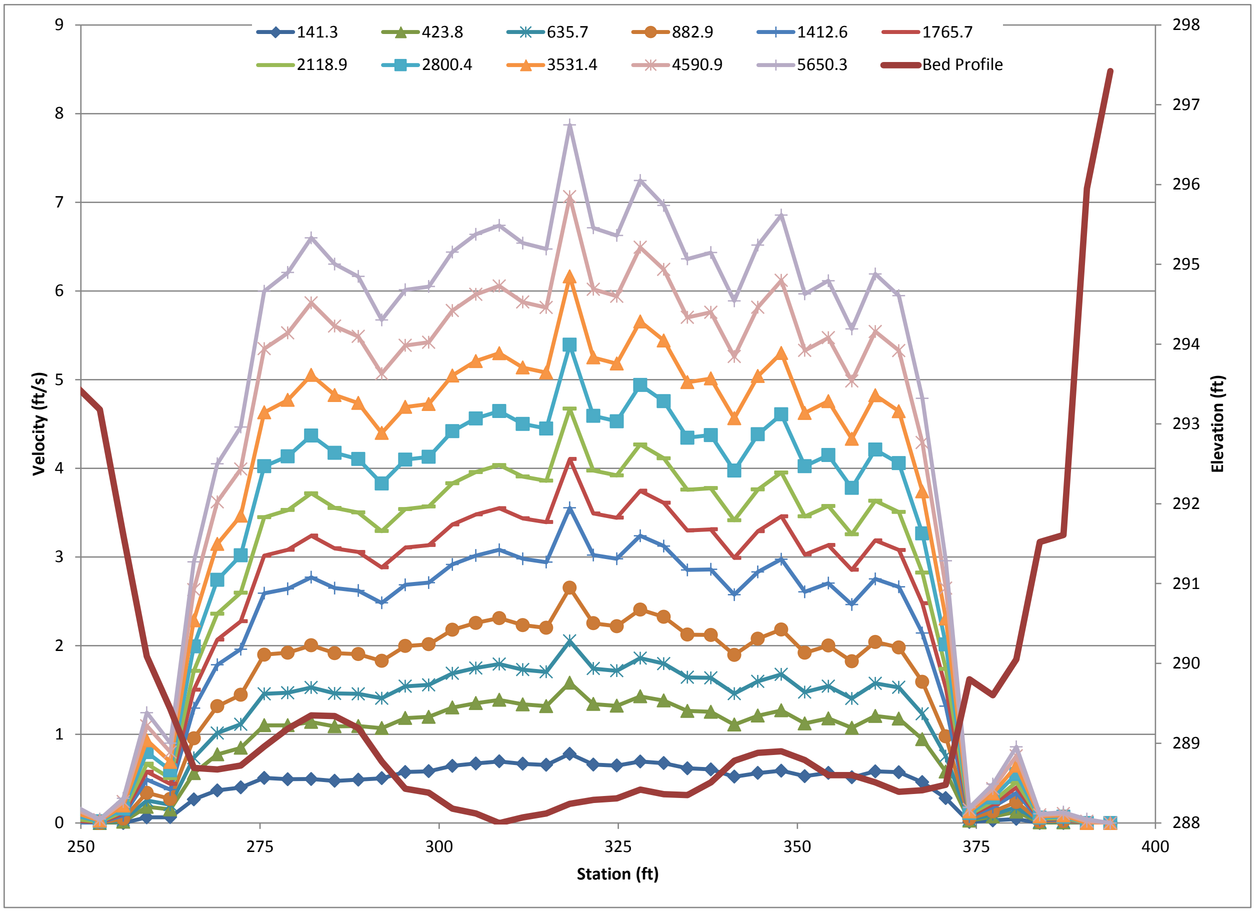

Figure 2. Example of velocity simulation results at a range of simulation discharges (cfs) for Birch Creek Slough (Transect BCS-3).

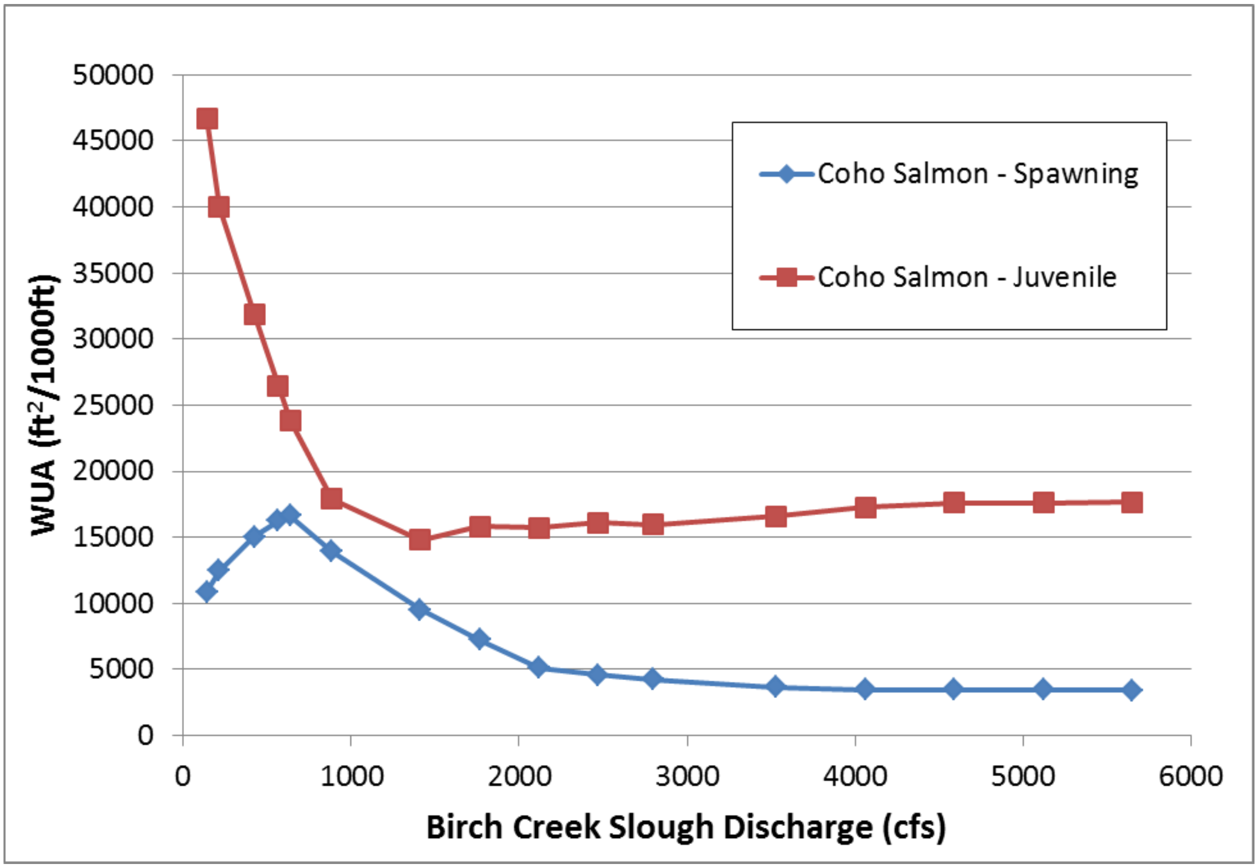

Figure 3. Birch Creek Slough (PRM 94.8) Example Weighted Useable Area Result.

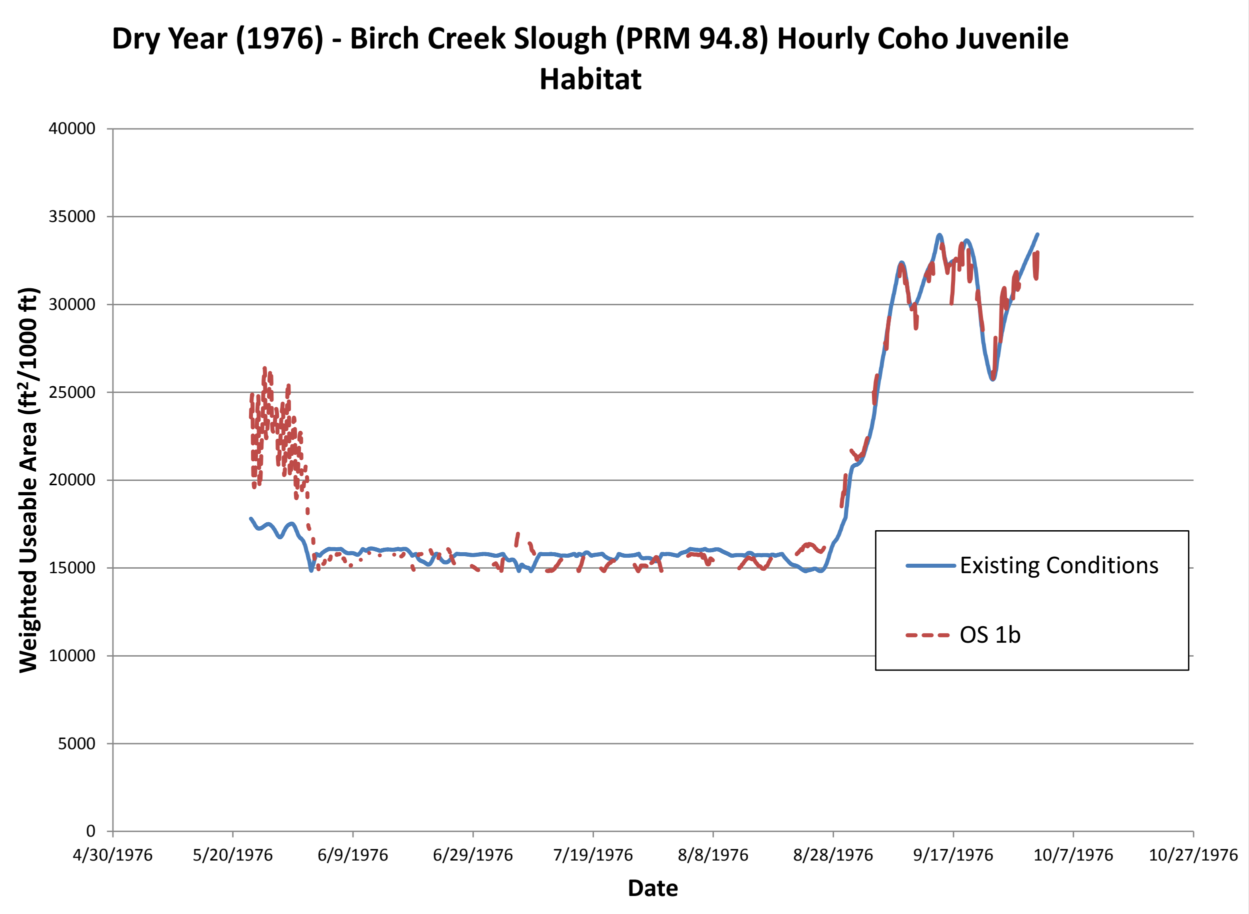

Figure 4. Birch Creek Slough (PRM 94.8) Habitat Time Series Example for Coho Salmon Juvenile in a Typical Dry Year (1976).

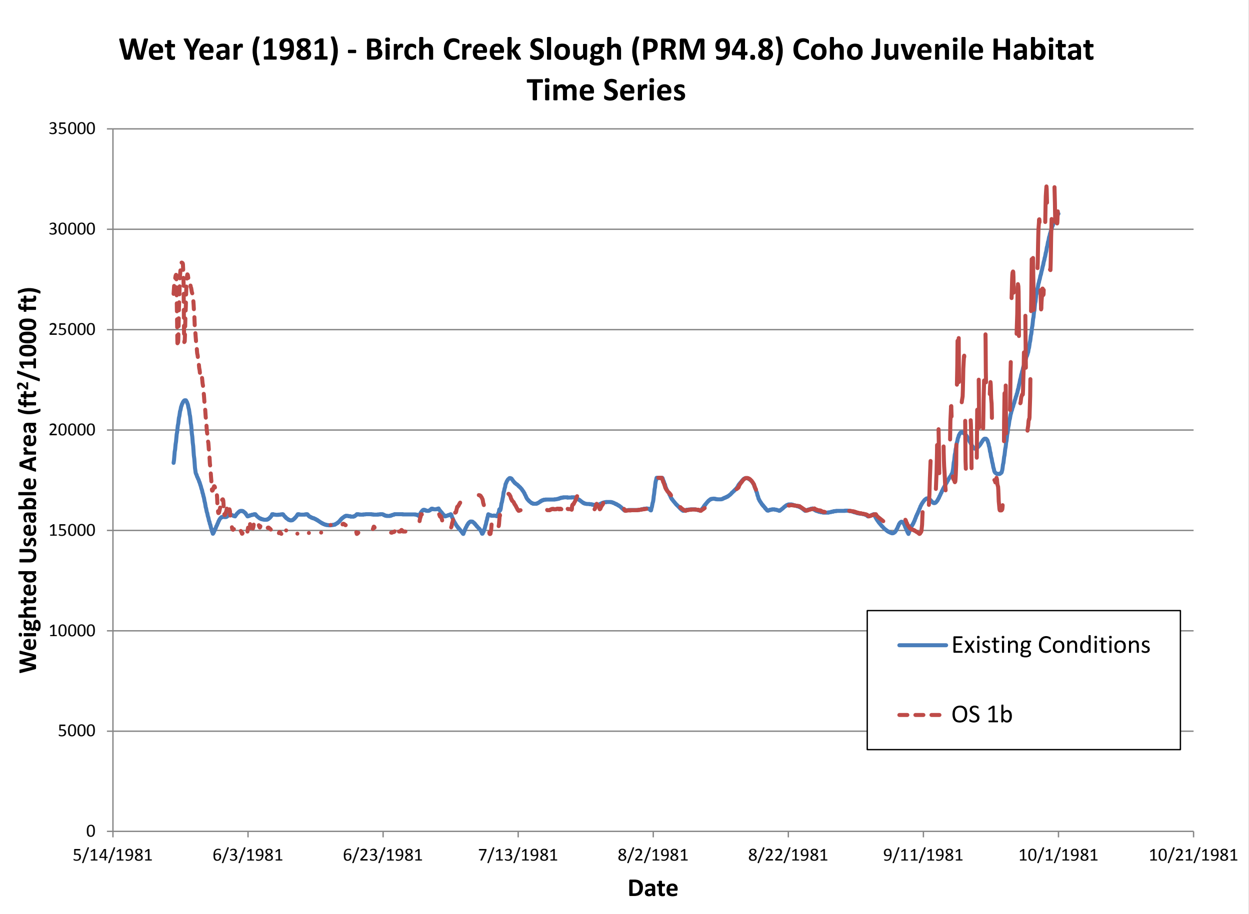

Figure 5. Birch Creek Slough (PRM 94.8) Habitat Time Series Example for Coho Salmon Juvenile in a Typical Wet Year (1981).