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Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Ice Processes in the Susitna River Study
Study Plan Section 7.6

Initial Study Report
Part C: Executive Summary and Section 7

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

HDR

June 2014

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APPENDICES

EXECUTIVE SUMMARY

Ice Processes in the Susitna River Study 7.6	
Purpose	Historic records and field data collected by this study will provide a complete understanding of the ice processes of the Susitna River and how they might change under proposed project operation. The data will be used to model the Middle Susitna River (PRM 103.8 to 186.8) using both one- and two-dimensional models under existing conditions and future proposed project operational scenarios to determine the changes and impacts on the river ice regime and hence on habitat.
Status	The study has completed its second year of collecting freeze-up observations and third year of breakup observations. Planned data collection is now complete. Numerical modeling of the Middle Susitna River has begun for existing conditions. A white paper reviewing other cold region hydroelectric projects and their effects on the ice regime has been produced (see Appendix C). A Proof of Concept demonstration was conducted to determine the adequacy of the 1D/2D modeling approach in providing input from various modeling efforts to the fish habitat criteria analysis (see Appendix D and ISR Study 8.5 Appendix N).
Study Components	Study components include field data collection of river ice processes including freeze-up, break-up, winter hydrology (discharge, stage, ice thickness etc.), and open leads; review of other cold region hydroelectric projects and their effects; modeling of the Middle Susitna River (PRM 103.8 to 186.8) using both one- and two-dimensional models under existing conditions and future proposed Project operational scenarios to determine the changes and impacts on the river ice regime; and coordinating and providing input on ice conditions to other modeling efforts.
2013 Variances	No significant variances have been made. Minor variances pertaining to the originally proposed time-lapse camera locations in Section 4.2 of the RSP have been made to provide for improved coverage and views of freeze-up and break-up processes.
Steps to Complete the Study	The components of the study that remain to be completed are the calibration of the River1D (one-dimensional) river ice processes model for existing conditions, including updates to geometric data from 2014 field studies; simulations of existing and proposed Project operational scenarios for the 50-year hydrologic record during ice-covered periods using the River1D model; development of detailed River2D (two-dimensional) models of the Focus Areas (FA) to determine depth and velocity during ice-covered periods using cold, warm, and average representative years of the hydrologic record; and model accuracy and error analyses for the River1D and River2D modeling efforts.

Ice Processes in the Susitna River Study 7.6	
Highlighted Results and Achievements	The Ice Processes in the Susitna River Study (Study 7.6) has documented three break-up seasons (2012, 2013, and 2014) and two freeze-up seasons (2012 and 2013) finding that the 2012 and 2014 break-up were both rather mild while the 2013 break-up was both late and more severe than normal. Conditions leading into freeze-up for both 2012 and 2013 were characterized by much higher than normal discharges coupled with very cold air temperatures at the onset of freeze-up. These field observations coupled with those of the 1980s provide a wide range of conditions suitable for simulation using the River1D and River2D models. The study has also demonstrated that the increase in stage associated with the progression of the freeze-up ice cover is responsible for flooding of side channels and sloughs, potentially important for fish overwintering habitat. The riverine modeling Proof of Concept has shown that it is viable to use the River1D model to provide input to the detailed River2D Focus Area models for assessing the impacts of ice on flow depth and velocity.

7. COMPLETING THE STUDY

7.1. Proposed Methodologies and Modifications

To complete this study, AEA will implement the methods in the Study Plan except as described in Sections 7.1.1 and 7.1.2. These activities include:

1. Complete the ice-covered calibration of the River1D river ice processes model for existing conditions, including updates to geometric data from 2014 field studies (RSP Section 7.6.4.6).
2. Using the calibrated River1D model, simulate existing and proposed Project operational scenarios for the 50-year hydrologic record during ice-covered periods (RSP Section 7.6.4.7).
3. Develop detailed River2D models of the Focus Areas (FA), calibrate the models and use them to simulate depth and velocity during ice-covered periods using cold, warm, and average representative years of the hydrologic record (RSP Section 7.6.4.8).
4. Conduct model accuracy and error analyses for the River1D and River2D modeling efforts (RSP Section 7.6.4.9).

In its April 1 2013 SPD, FERC recommended that AEA conduct one additional reconnaissance flight in January 2014 to document open leads at the same time as the field data collection to document freeze-up conditions. This additional observation flight did occur resulting in a pair of open lead observation flights in 2014; one at the end of the freeze-up period and another at the beginning of the breakup period to fully characterize the open leads.

All other data collection tasks identified in the Study Plan including ice thickness measurements, aerial reconnaissance flights during freeze-up and breakup, and discharge measurements were completed in 2014.

A white paper reviewing other cold region hydroelectric projects and their effects on the ice regime has been produced (see Appendix C). A Proof of Concept demonstration was conducted to determine the adequacy of the 1D/2D modeling approach in providing input from various modeling efforts to the fish habitat criteria analysis (see Appendix D and ISR Study 8.5 Appendix N).

7.1.1. Decision Points from Study Plan

There were no decision points in the FERC-approved Study Plan to be evaluated for this study following the completion of 2013 work.

7.1.2. Modifications to Study Plan

Time Lapse Cameras

The Study Plan had indicated that time lapse cameras would be located at FA-151 (Portage Creek) and FA-184 (Watana Dam). Lack of Cook Inlet Regional Working Group (CIRWG) land access in 2013 prevented the placement of these proposed cameras. These cameras were intended to provide observations throughout the freeze-up and breakup period to assist in the analysis of ice processes. A remote telemetered camera at ESS55 near the mouth of Portage Creek installed by the Fish and Aquatics Instream Flow Study (Study 8.5) provided an equally useful view of the FA-151 (Portage Creek) area and the images from this camera will be used as a substitute for the planned time lapse camera, fully meeting the study objectives. The ice conditions at the Watana Dam site were obtained only through the aerial video flights during freeze-up, the open lead surveys, and breakup. The number of flights and video coverage obtained during the freeze-up through breakup period in 2013-2014 provided adequate coverage of the ice processes and ice-covered conditions at the FA-184 (Watana Dam) site to meet the study objectives.

7.2. Schedule

In general, the schedule for completing the FERC-approved Study Plan is dependent upon several factors, including Project funding levels authorized by the Alaska State Legislature, availability of required data inputs from one individual study to another, unexpected weather delays, the short duration of the summer field season in Alaska, and other events outside the reasonable control of AEA. For these reasons, the Study Plan implementation schedule is subject to change, although at this time AEA expects to complete the FERC-approved Study Plan through the filing of the Updated Study Report (USR) by February 1, 2016, in accordance with the ILP schedule issued by FERC on January 28, 2014.

With regard to this specific study, all data collection is complete and will be reported in the USR. A summary of the 2014 ice break-up observations will be developed in 2014.

The plans for 2014 and 2015 are to continue development and calibration of the River1D and River2D models with appropriate updates to geometry as new field data becomes available. The models will be used to simulate existing conditions as well as the proposed Project operations scenarios for both open water and ice covered conditions.

7.3. Conclusion

In 2012-2014, the Ice Processes in the Susitna River Study (Study 7.6) concentrated on developing an understanding of the ice processes in the Susitna River through review of historic information, new field observations, and the initial development of a River1D model of the Middle River. Field data collection will be completed in 2014 and this data has proved to be sufficient to continue and complete all required ice modeling work. A Proof of Concept (POC) demonstration was conducted to determine the adequacy of the 1D/2D modeling approach in providing input from the various modeling efforts to the fish habitat criteria analysis. As reported in the Instream Flow Study ISR (ISR Study 8.5 Appendix N), the POC showed that 1D reach-based models can provide suitable input data for the 2D detailed Focus Area models at a range of required resolutions necessary to provide input to the fish habitat modeling and meet the Study Objectives. The study will provide a basis for impact assessment, which will inform the development of any necessary protection, mitigation, and enhancement measures. The Ice Processes in the Susitna River Study (Study 7.6) will continue to interact and coordinate with the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6), Fish and Aquatic Instream Flow Study (Study 8.5), Riparian Instream Flow Study (Study 8.6), and Groundwater

Study (Study 7.5) to obtain and share data and to provide ice processes input data to other resource studies with winter components.

PART C - APPENDIX C: WHITE PAPER: REVIEW AND COMPILATION OF EXISTING COLD REGIONS HYDROPOWER PROJECT OPERATIONS AND EFFECTS

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Ice Processes in the Susitna River Study (7.6)

Initial Study Report

Part C - Appendix C

White Paper: Review and Compilation of Existing Cold Regions Hydropower Project Operations and Effects

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

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Prepared by

HDR

June 2014

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1. ABSTRACT

This White Paper was prepared to describe the existing ice regime on the Susitna River and how the natural processes of ice formation, growth, and breakup impact fish habitat and other resources along the river. In addition, the paper reviews the documented impacts of hydropower development on other northern rivers resulting from changes to the natural hydrologic cycle, changes to the ice regime, and the resulting changes to fish habitat and other resources. Numerical modeling has been used to predict potential changes and impacts from the development of hydropower projects in northern regions. A review of past modeling efforts for a number of developments is provided along with an assessment of the applicability of these numerical modeling methods to the Susitna River.

2. OVERVIEW OF EXISTING ICE PROCESSES ON THE SUSITNA RIVER

The Susitna River travels about 320 miles as it flows south and west from its glacial source on the southern slope of the Alaska Range (Figure 2-1). The river can be loosely divided into three main sections: the Upper River (UR) from its glacial source at about project river mile (PRM) 320 to the proposed hydropower dam site at PRM 187; the Middle River (MR) from the dam site to the confluence of the Chulitna River at PRM 102; and the Lower River (LR) from the Chulitna River downstream to the mouth at Cook Inlet. Within each of the three major sections, the river is further discretized into several reaches with various geomorphic characteristics; the Upper River into six such sections, the Middle into eight, and the Lower into six. The geomorphic delineations divide the river into large-scale geomorphic reaches with relatively homogeneous characteristics, including channel width, entrenchment ratio, sinuosity, slope, geology/bed material, single/multiple channels, channel branching index, and hydrology (inflow from major tributaries). In very general terms, the Upper River is single channel with many small islands and bars in the channel center. Depths can vary with some sections quite wide and shallow with many bars. From the Denali Highway crossing at PRM 292 to the Oshetna River confluence at PRM 235, the river is relatively flat with a slope of about 7 feet/mile. In the proposed reservoir reach from the Oshetna River to the Dam Site at PRM 187 the slope is about 11.5 feet/mile. The Middle River is the steepest reach and is generally a single channel but also has several center islands and island complexes with side channels, sloughs, and tributary confluences that are important fish spawning and rearing habitat. While the Middle River slope is 13.5 feet/mile between the Dam Site at PRM 187 and the Chulitna River confluence at PRM 102, it also contains a very steep section within Devils Canyon; a 10.5 mile reach with a slope of 32.5 feet/mile. The Lower River flattens significantly below the confluence of the Chulitna River at PRM 102 and the Talkeetna River at PRM 100.5. The river is highly braided with a myriad of channels, side channels, sloughs, and multiple islands and bars throughout and has a slope of about 3.5 feet/mile.

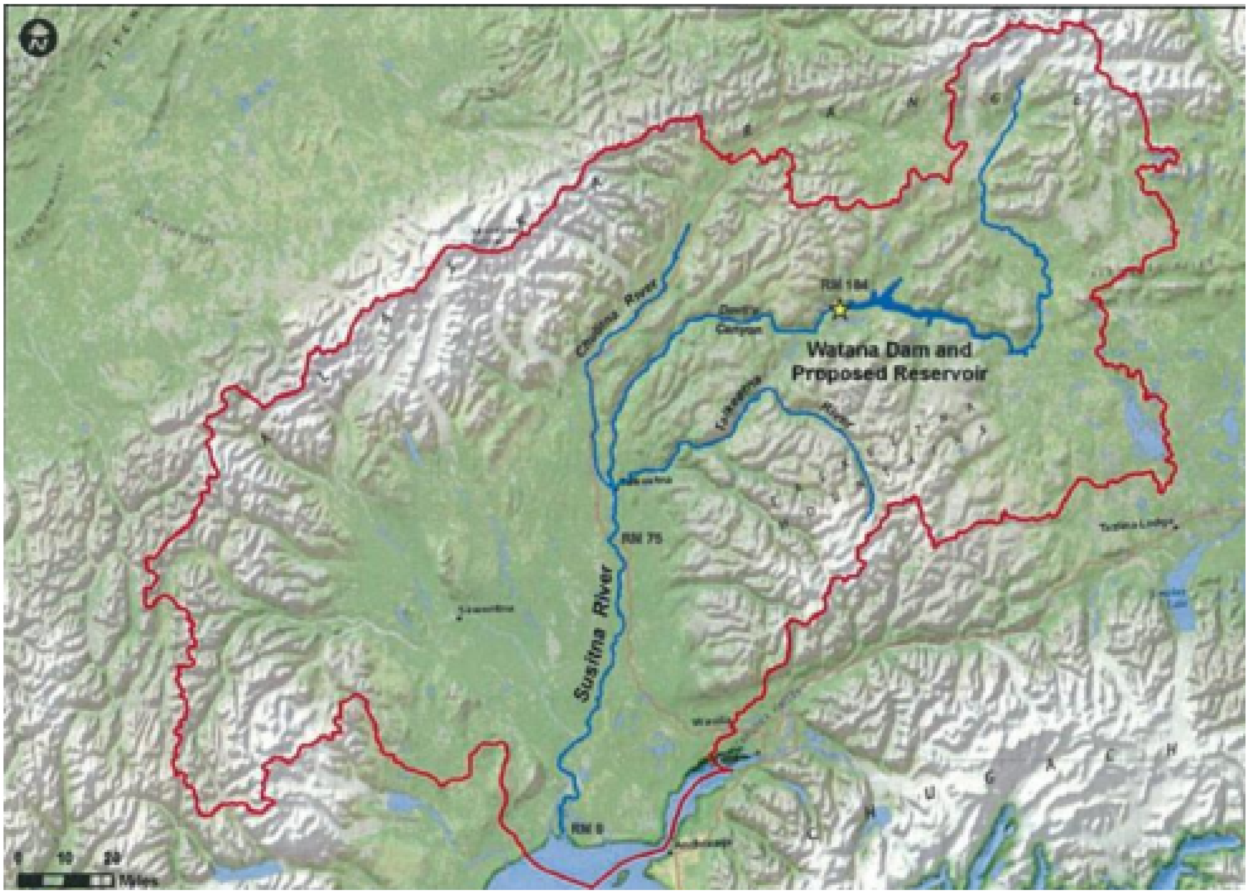

Figure 2-1. Map of the Susitna River Basin.

The season of ice processes on the Susitna River can be divided into three phases: ice cover formation, ice cover, and break-up. During the late fall, the climate is much colder and severe on the upper river than it is on the more temperate lower river. It is on the upper river that the ice season gets its start as the temperatures drop in September and October. With air temperatures on the upper river dropping to well below freezing, the turbulent high velocity water becomes thoroughly mixed and the water temperature drops to freezing. The entire river generates frazil ice which is carried through the higher velocity upper and middle river and into the braided lower river. As reported by Daly 1994, and outlined in Figure 2-2, the evolution of frazil ice entails three phases; formation, transformation and transport, and deposition or stationary ice cover. Formation is characterized by very cold air temperatures and turbulent open water conditions where the water becomes slightly supercooled and frazil ice forms as small disk-shaped crystals up to a few millimeters in size which is entrained in the full water depth. Transformation and transport follows formation and is characterized by the water at the freezing point and frazil ice in the form of flocs (small accumulations of several frazil crystals), surface flocculations or slush, anchor ice, and floes (Figure 2-3). Sizes range from several millimeters to several meters and the movement is generally at the water surface carried by the current. Floes may lose their structure as they pass through rapids or increase in size by joining with other floes (Figure 2-4). Often, many floes are extruded through a narrow section and break off in large floes (Figure 2-5). The final phase, stationary ice cover or deposition occurs as the water velocity slows, allowing the frazil ice, whether in pans or slush, to deposit at the leading edge of an ice cover or on the underside of a cover. Depending on the concentration of frazil ice and the hydraulics at the leading edge, juxtaposition covers may develop, consolidation covers (shoving and multi-layering of floes as shown in Figure 2-6), or freeze-up ice jams may form, significantly increasing the stage.

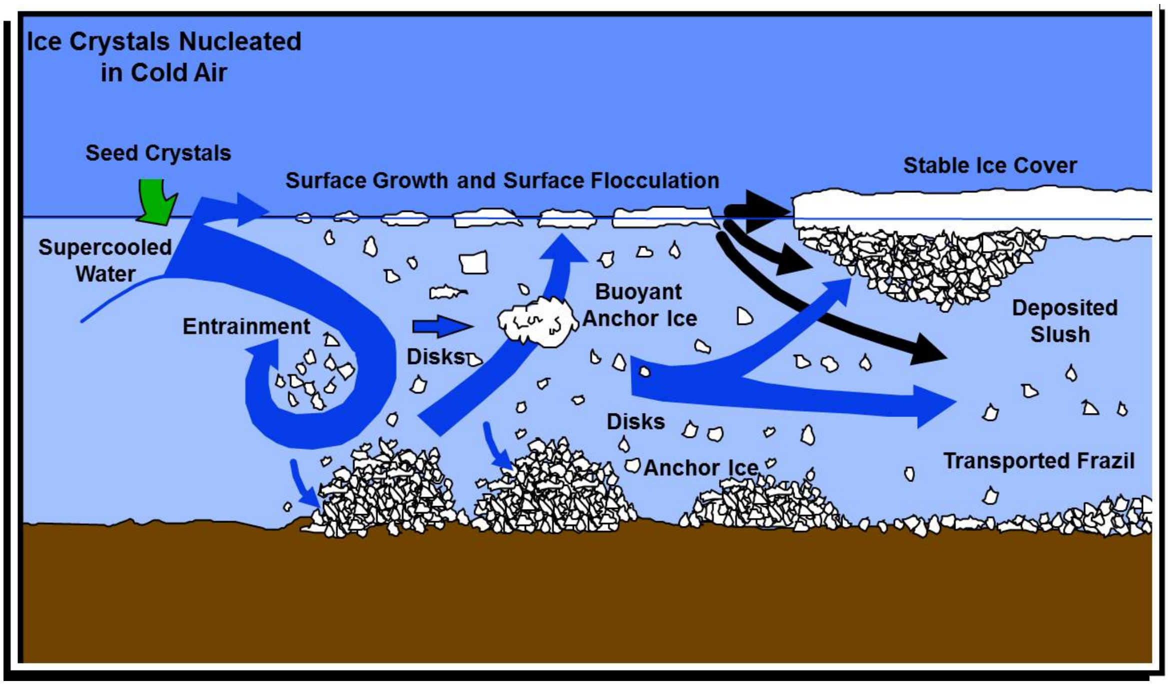

Figure 2-2. The Evolution of Frazil Ice, Adapted from Daly 2013 with Permission from Author.

Every phase of frazil evolution depicted in Figure 2-2 can be seen along the Susitna River during the ice cover formation phase. Flow near the river mouth slows due to the influence of Cook Inlet tides, sometimes reversing and flowing upstream due to the incoming tide. It is at this time, usually around the third week in October that the frazil ice floes and larger accumulations bridge across the lower river from bank to bank beginning the progression of a stationary ice cover. This ice bridging causes the continual flow of frazil ice to build up on the leading edge, which slows the river flow even more and causes the ice front to move upstream. The ice front typically reaches the town of Talkeetna, approximately 100 miles upriver from the mouth, sometime between November 1 and December 15. There are other locations along the middle and Upper River where ice bridging also occurs with ice covers progressing upstream. In addition, slower moving side channels and side sloughs often freeze over prior to the main channel of the river. The Devils Canyon reach in the middle river and Vee Canyon in the upper river will periodically jam with massive quantities of frazil ice but these jams typically fail and the canyon reaches remain open all winter able to continue to generate frazil ice. Figure 2-7 shows a plot of the progression of the ice cover along the river with time for the 2012 freeze-up, with the solid sections of the bars indicating ice cover and the uncolored sections indicating open water.

Figure 2-3. Frazil Flocs and Slush on the Middle Susitna River.

Figure 2-4. Frazil Pans on the Susitna River (Freeze-up 2013).

Figure 2-5. Frazil Ice Extruded into Large Pieces after Passing through Constriction on the Susitna River during Freeze-up 2013.

Figure 2-6. The Leading Edge of an Ice Cover Showing Consolidation (Shoving and Multi-Layering) on the Susitna River during Freeze-up 2013.

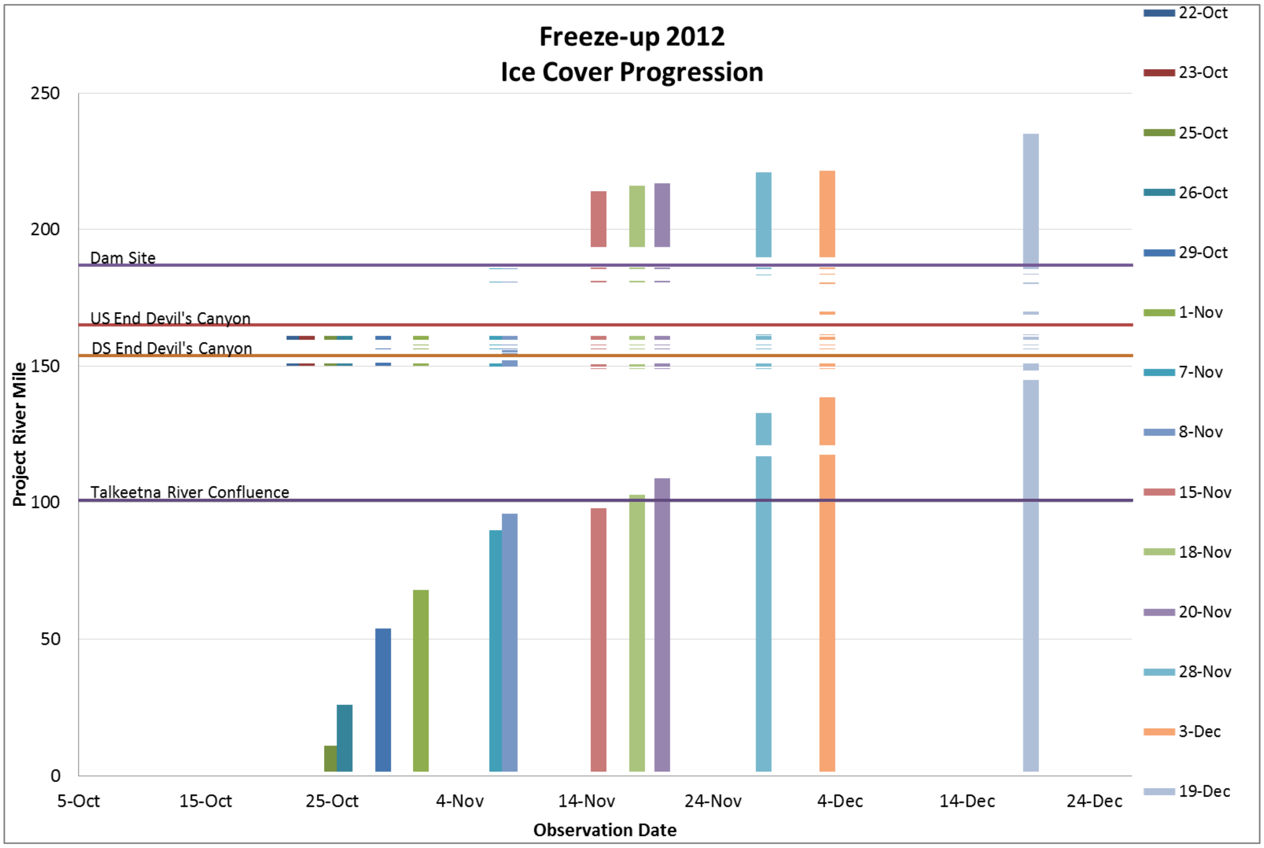

Figure 2-7. Progression of the Ice Cover in the Susitna River Freeze-up 2012.

As the ice cover progresses through a reach, there is a stage increase associated with the increased shear on the water flow due to the addition of the ice cover and the flow area that is blocked by the floating cover. The discharge in the river decreases throughout the late fall and winter, reaching a minimum sometime in mid- to late-March. The period of ice cover during the winter is also associated with thermal growth, accumulation of frazil beneath the cover in slower velocity areas, and some sections where the cover is depressed along the thalweg due to the receding discharge. The ice cover typically remains quite stable on the Susitna River during the winter with various velocity and thermal leads opening, growing, shrinking and closing, depending on the weather conditions. The highest velocity sections of the river flowing through Devils Canyon and Vee Canyon remain mostly open during the winter.

Break up of the ice cover begins when warming temperatures increase the discharge of meltwater into the river. The increased flow raises the river stage and lifts the ice cover, releasing it from the hold of the banks. In years when the thaw is gradual, there may be more of a thermal breakup with ice melting in place and few jamming events. For rapid thaws and large increases in discharge, the relatively strong ice cover can be broken quickly, resulting in a dynamic breakup. The broken ice moves downstream until the transport capacity of the channel is overcome by the ice supply and the ice begins to jam. Water levels rise quickly behind an ice jam during a dynamic breakup, sending water and ice into the side channels, sloughs, and floodplains. Due to melting and increasing discharge, the jams will eventually fail, sending a rush of water and ice downstream but often leaving large ice shear walls along the banks (Figure 2-8). This jamming/flooding/failure process repeats itself numerous times during the break-up process until the river finally flows unimpeded by ice. Breakup in the Susitna River can occur anytime between late April and late May.

Figure 2-8. Large Shear Walls Left along the Bank of the Upper Susitna River Following Jam Failure during Breakup 2013.

Figure 2-9 shows a typical plot of stage in the middle river (recorded at PRM 106.9 just upstream from Whiskers Slough) for the entire period from before ice cover forms in the fall of 2013 to after the ice cover breaks up in spring 2014. Prior to ice cover formation, the discharge and stage are low and receding. Beginning on November 20, 2013 the ice cover progressed through this reach, resulting in a significant increase in stage. As the discharge continues to recede and reach its minimum in mid- to late-March, the stage also continues to recede. Snowmelt causes an increase in discharge and stage beginning about April 15, 2014 with an ice jam forming just below the site on April 30 resulting in a 10 ft rise in stage. Following the jam failure, the stage recedes quickly as the water behind the jam passes downstream.

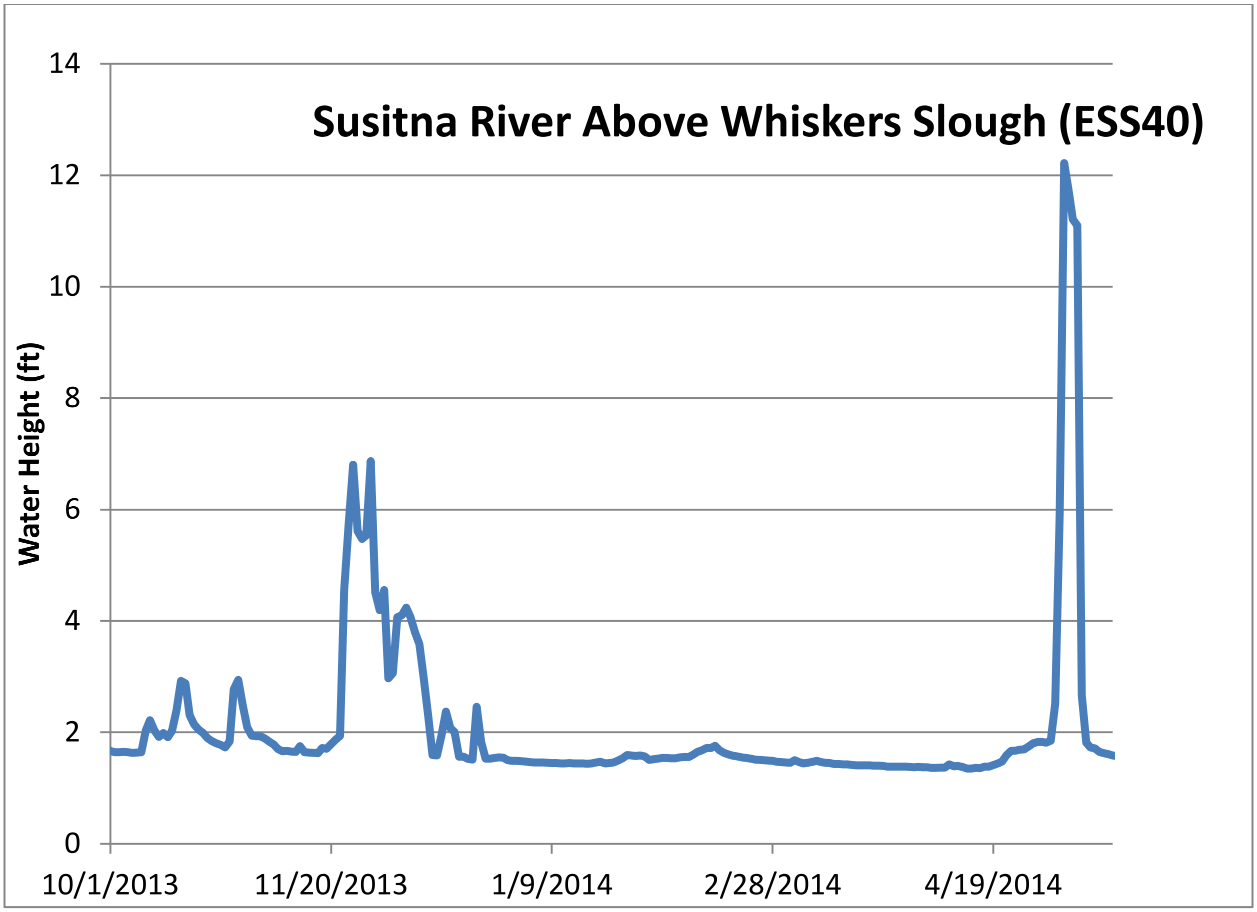

Figure 2-9. Plot of Stage at ESS40 (PRM 106.9).

3. IMPACTS OF ICE PROCESSES ON FISH HABITAT

Studies conducted by the Alaska Department of Fish and Game (ADG&G) (Vining et al. 1985) showed that river stage and discharge during the winter period can directly affect both spawning and egg incubation habitat. They found that the typical pattern of decreased discharge in the winter resulted in the off-channel spawning and rearing habitat to warm due to the decreased input of cold river water and the increased contribution of relatively warm upwelling ground water. Intergravel water temperatures were found 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 the influence of groundwater (Hoffman et al. 1983; Vining et al. 1985). This was again evident during the pilot winter studies completed in 2012-2013, as reported in ISR Study 8.5, Appendix L. During the time of stable ice cover, some slough habitats may remain ice-covered and thus become insulated from extremely cold air temperatures, while in others open thermal leads may develop resulting from upwelling groundwater (Figure 3-1). Warmer water associated with the groundwater upwelling increases the rate of embryo development and decreases the overall hatching time. If the river discharge and thus stage drops too low, however, the slough can completely dewater, leading to freezing of the substrate and mortality of the eggs and hatchlings. In contrast, if the river discharge and stage increases to a point where the slough entrances can be overtopped/breached, this can cause a decrease in water temperature due to the sudden addition of colder river water which can slow development and delay hatching.

Figure 3-1. Example of Thermal Upwelling Keeping Slough/Side Channel Open in the Middle Susitna River during March 2014.

Vining et al. (1985) reached several conclusions regarding winter conditions relative to spawning and incubation habitats which are repeated in their entirety here:

1. Dewatering and freezing of salmon redds were identified as the most important factors contributing to the high levels of embryo mortality found in habitats used for chum salmon incubation in the middle Susitna River. In general, these factors were most pronounced in side channel habitats and least pronounced in slough habitats which were protected from cold surface water overtopping and where upwelling was more prevalent.

2. Upwelling was the most significant physical variable affecting the development and survival of salmon embryos incubating in slough and side channel habitats of the middle Susitna River. The importance of upwelling to incubating embryos is due to the following reasons:

    a) It eliminates or reduces the likelihood of dewatering or freezing of the substrate environment from occurring;

b) It provides a relatively stable intragravel incubation environment, buffering it from variations in local surface water and climatic conditions; and,

c) It increases the rate of exchange of intragravel water over the embryos which enhances the replenishment of dissolved oxygen and the removal of metabolic wastes.

3. Because of the effects of dewatering and freezing, the amount of available habitat at the time when adult chum salmon are spawning is a poor indicator of the amount of actual habitat that is available as potential incubation habitat. Estimates of available incubation habitat must take into account the differential effects of dewatering and freezing in various habitat types.

4. The pattern of accumulation of thermal units for developing salmon embryos varies between spawning habitat types for the middle Susitna River. A general thermal regime describing the incubation period for each habitat type can be stated as follows:

a) Tributary habitats typically have intragravel water temperatures which are strongly influenced by surface water temperatures. This results in relatively high intragravel water temperatures during the fall and spring months with near freezing water temperatures during the intervening winter months;

b) Slough habitats generally have relatively high, and more stable intragravel water temperatures during most of the incubation period due to the influence of suitable upwelling sources;

c) Mainstem habitats are similar to tributary habitats; having winter intragravel water temperatures which are strongly influenced by surface water temperatures. However, they differ from tributary habitats by having colder water temperatures during the fall and spring periods; and,

d) In general, winter intragravel water temperatures in side channel habitats are quite variable and may reflect any of the patterns exhibited by the other habitat types depending upon the relative influences of and relationships between upwelling and surface water sources.

5. Significant mortalities of salmon embryos due to thermal stress are anticipated if altered discharges increase the incidence of cold mainstem water overtopping slough and side channel habitats having insufficient sources of warmer upwelling or local surface waters in the middle Susitna River during fall and winter. If post-project mainstem water temperatures are· substantially warmer than existing winter temperatures, this thermal problem associated with overtopping may be ameliorated.

6. Embryos fertilized on August 26, 1983 and placed in slough, side channel and mainstem habitats reached 100 percent hatch at approximately late January, late December and mid-April, respectively. Embryos in slough and side channel habitats were influenced by warmer upwelling water, whereas embryos in the mainstem were not.

7. In general, slough habitats of the middle Susitna River contain greater amounts of fine substrate (38%) compared to side channel, tributary and mainstem habitats (19%, 13%, and 12%

respectively). However, the substrate composition of established salmon redds in each habitat type contained fewer fines than the range of substrate material present in each habitat type of the middle Susitna River.

8. With the exception of slough habitats, dissolved oxygen (DO) levels in most incubation habitats of the middle Susitna River during the winter period are generally above the recommended levels. Although DO levels in intragravel water of slough habitats are generally lower, the potential adverse effects of low DO are most likely buffered by the influence of upwelling, depending upon site specific conditions.

9. The pH levels present in incubation habitats of the middle Susitna River (6.2 to 8.3) do not appear to be detrimental to embryo survival and development.

10. Conductivity values in incubation habitats of the middle Susitna River (24 to 290 µmhos) do not appear to have any direct adverse effects on incubation embryos.

The recommendations of this study focused on two main points. Spawning habitat identification in itself (available during the spawning period) is not sufficient to quantify valuable habitat because dewatering and freezing of the intragravel environment during the incubation period would result in making these areas non-viable. Thus the spawning areas must also be evaluated based on the effects of mainstem discharge and winter stage on dewatering and freezing of redd sites during the winter months. The second point was the importance of upwelling areas, as these provide a beneficial water temperature stability to the incubation and rearing habitats. It was recognized that while load following may introduce mainstem water into side channels and sloughs, that the dam releases (for some distance downstream of the dam) would likely be warmer than natural conditions.

ADF&G also conducted some studies related to overwintering habitat use of juvenile and adult fish in the Susitna River. Those studies were summarized in ISR Study 8.5, Appendix L and noted that 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).

Doyle et al. 1993 investigated the negative effects to Chinook, coho, and pink salmon as well as steelhead, rainbow, and bull trout of natural freeze-up and breakup events on the Nicola/Coldwater river system in British Columbia. They found that low discharge combined with very cold freeze-up periods could reduce the stage to levels that exposed redds to freezing, thus decimating that year class. They also found that during severe breakup events (1984 and 1991) on the Nicola River, the typical pattern of jamming/flooding/failure with large stage increases and flow into the floodplain followed by rapid stage drops resulted in juvenile chinook and rainbow trout being stranded on the floodplain between large ice pieces following jam failure. Doyle did report that when sloughs are temporarily overtopped, that the increased flow can rinse out accumulated fine sediment and introduce oxygenated water, thereby improving the quality of habitat. However, if this flood/release pattern is too dramatic, the flooding can wash fry out of the slough and leave them stranded on dry ground or wash them into the main channel.

4. EFFECTS OF HYDROPOWER PROJECTS ON ICE REGIME

The primary impact of a hydropower project on a river is to shift the annual discharge hydrograph from the natural seasonal cycle to the flows corresponding to the greatest demand for electricity production. Regulation of river flow patterns by a hydropower project tends to attenuate the extremes of the annual hydrograph, increasing the discharge during the normally low winter months due to the increased demand for power, and decreasing the peak warm weather flows by storing the water for times of higher power production demands. The general, theoretical effects of this reversal of the hydrograph on the ice regime of a river and for the Susitna River in particular are discussed in terms of the three phases of ice cover formation, ice cover, and break-up.

Ice cover formation is generally characterized by a period of decreasing discharge and falling air temperatures in natural river systems. For a regulated river, the period of decreasing air temperatures would also be associated with increased energy demand. A reservoir would be likely near its peak storage capacity at the beginning of freeze-up such that the discharge would be increasing during the freeze-up period. A dam not only catches the frazil ice that is moving downstream from upper reaches of the river but also results in increased water temperatures released from the dam. These two factors combine to reduce the amount of frazil generated and transported below the dam and slow the progression of any ice cover that develops downstream. The increased winter discharge both requires an increased cooling of the water to produce frazil and also delays the initial bridging of the downstream ice cover due to increased velocity. The increased discharge would also result in a higher stage level during freeze-up and as the ice cover progresses through an area, a higher freeze-up stage. The formation of the ice cover would occur later and the extent of ice cover would be less because of the increased water temperature downstream of the dam. For the Susitna River in particular, there would be little noticeable change in the initiation of an ice cover near the mouth and progression in the lower river other than an increase in stage and later initiation. The Susitna River has a fairly wide range of discharge (and thus stage) during freeze-up under natural conditions and the addition of a hydropower dam would result in more uniform conditions during freeze-up. For the middle river, however, the ice cover progression upstream from Talkeetna would be delayed and it would reach some upstream limit based on the water temperature released from the dam and discharge released. For a load following scenario, the maximum ice thickness and stage levels would correspond to the peak discharge levels but these would likely be attenuated as the distance from the dam and the extent of the ice cover increased. Conditions in the upper river would be different due to the dam and the sheet ice cover that would develop on the reservoir. Frazil ice accumulations and jams will develop at the upstream extent of the reservoir backwater on the mainstem and tributaries.

The season of stable ice cover would generally be shortened because of a later freeze-up and earlier breakup due to the increased discharge of warmer water as compared to without a hydropower project. Increased discharge throughout the winter will lead to the ice cover being formed at a higher elevation than natural conditions. Some entrance berms of sloughs may be overtopped continuously all winter by this increased stage of the river. The stage and ice elevation, however, will also be stable over the winter without the typical reduction seen during natural conditions. For the Susitna River in particular, the more stable discharge levels throughout the winter will result in constant stage and ice elevations in the lower river over the winter. For the middle river, there will be some variations in the maximum upstream extent on the ice cover and the leading edge may move up or downstream based on air temperatures over the winter. The effects of load following on stage, flooding of side channels and sloughs, and attenuation of flood peaks will be dependent on the distance from the upstream edge of the ice cover. The upper river/reservoir will operate with a falling level over the winter season with the extent of the reservoir backwater decreasing. This will result in the ice cover on the reservoir being grounded along the shoreline as the water level drops.

Break-up with a storage and release hydropower project would be much less dramatic than with a natural flow regime. The sometimes dramatic spring increase in discharge and resultant jamming will be attenuated by the dam. Also, if the freeze-up ice cover forms at a higher elevation, dynamic breakup may not occur and the ice cover should melt or decay gradually. A more gradual breakup and controlled discharge may lead to less spring overtopping of sloughs and off-channel areas compared to a natural flow regime. For the Susitna River in particular, large ice jamming events with the associated flooding, erosion, and infrastructure damage may be less frequent and less severe. The lower river would see little change from natural conditions due to the unregulated major tributaries joining the Susitna below the dam. The middle river would likely see a more controlled breakup or thermal meltout of the ice cover. Natural jamming conditions on the middle river result in channel erosion, floodplain sediment deposition, and riparian impacts which would occur less frequently under project conditions. The upper river/reservoir would begin to fill in April with the ice cover being lifted and previously grounded ice along the shoreline refloated as the reservoir level increases. Ice moving into the reservoir from the upper river and tributaries may cause jamming at the upstream extent of the reservoir backwater but since the reservoir level would be continually increasing, these jams would quickly be flushed into the reservoir.

5. IMPACTS OF OTHER NORTHERN REGION HYDROPOWER PROJECTS ON RIVER ICE REGIMES

Asvall 1995 reports that Norway, a country which produces approximately 99% of its electrical power requirements by hydropower (Figure 5-1), has seen changes caused by regulated river discharge. Ice roads once used for travel are no longer able to be used as early or for as long as before hydropower (in some cases power companies have been required to build bridges and roads to replace the lost transportation routes). Studies in Norway have also shown that the ice cover, once formed and stable, is less sensitive to the flow variations of load following than had been than feared. When the power market was liberalized in 1991, variations in power demands and prices resulted in extreme cases of load following which caused problems in several areas of the country. It was found that abrupt peaking caused extensive fish stranding and mortality. As a result, flow is regulated where fish are known to inhabit the rivers.

Freysteinsson 1995 reports that in Iceland, hydropower projects on the Thjorsa River (Figure 5-2) have produced changes in the annual hydrograph similar to those outlined above. The Thjorsa River system is very similar to the Susitna River in many ways, including its glaciated upper basin and silty sediment load. The Thjorsa River's year-round average discharge is approximately 10500 cfs compared to the Susitna River at Gold Creek with a year-round average of 9800cfs. The Thjorsa River, however, has larger natural wintertime flows due to groundwater flow through volcanic rock formations. The pre- and post-development average winter flows in the Thjorsa River are approximately 5300 cfs and 8400 cfs, respectively. The changes to the annual hydrograph has been found to produce decreased sediment load (clear water) below the dam, but also increased winter time scouring below the dam though an area that is primarily agricultural land use (claims by farmers but not documented with comparative observations). As expected, there is an increase in the water temperature for the portion of the river downstream from and closest to dam and thus more open water below dam and less frazil production. This effect on water temperatures and ice cover extended about 50 km downstream of the dam.

Figure 5-1. Tinnelva Hydropower Plant (Photo: Ånund Killingtveit, from http://www.forskningsradet.no).

Figure 5-2. Burfell Hydropower Project on Thjorsa River, Iceland (photo from http://www.hydroworld.com).

BC Hydro 2014 discusses regulation of the Peace River in Western Canada by the W.A.C. Bennett Dam and Peace Canyon Dam and Generating Station (Figure 5-3) has produced the expected impacts on the ice regime; the ice cover forms later and does not progress as far upstream. The W.A.C. Bennett Dam has a generating capacity of 2790 MW while the Peace Canyon Dam has a capacity of 694 MW. While the two generating stations operate in tandem, the reservoir elevation of Peace Canyon Dam is relatively constant, varying only about 10 feet each day. The town of Taylor, BC is located about 90 km downstream from the Peace Canyon Dam and in severe winters, the river freezes upstream from Taylor but never more farther than 70 km downstream of Peace Canyon Dam. Freeze-up and breakup ice jamming can result in flooding conditions in Taylor so BC Hydro has developed strategies to minimize flooding. During freeze-up, the discharge from the Peace Canyon Dam is kept at a constant high flow during ice formation to maximize the hydraulic capacity of the river. When the ice cover is formed, wider fluctuations in flow can be tolerated. Flooding in the town of Peace River (further downstream from Taylor) still occasionally occurs during break-up due to ice jams, however these events are typically caused by increased inflow from downstream tributaries. Strategies have been developed to regulate the flow of the Peace River to mitigate this break-up flooding.

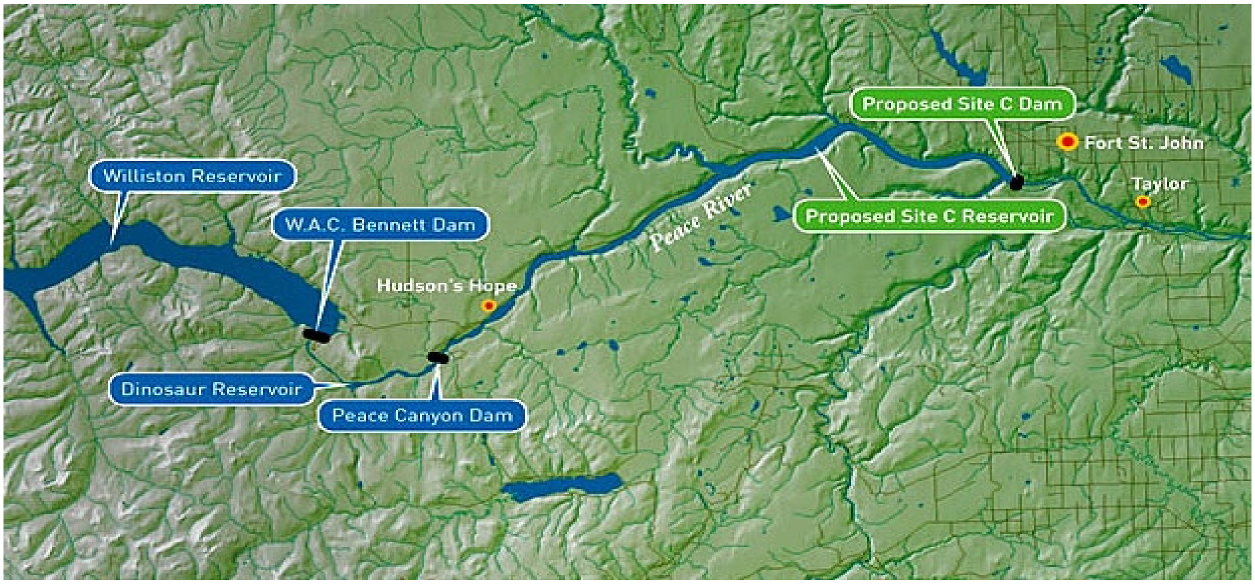

Figure 5-3. The Peace River showing the Locations of the W.A.C. Bennett and Peace Canyon Dams as Well as the Proposed Site C Dam (From bchydro.com).

Saucet 2002 reports that in Quebec, the Robert-Bourassa reservoir (Figure 5-4) and hydropower project (Phase 1) ended the natural flow conditions of the La Grande Rivière in 1978, causing increased winter discharge and lower discharge during ice-free periods. With the addition of the La Grande-1 generation station (LG-1) downstream of the reservoir in 1994 and the La Grande-2A station (LG-2A) at the reservoir, larger short-term flow variations were experienced. It was found that the ice cover was able to sustain large flow variations without failing. The main factor that controlled the ice cover extent below LG-1 was the temperature of the water discharged from LG-1. The leading edge of the ice cover downstream of LG-1, as well as the freeze-up and breakup dates, was not significantly affected compared to Phase 1 values.

Berkes 1982 investigated the impacts of the construction of the La Grande system on fish stocks in the lower La Grande River. The main species represented are whitefish (*Coregonus clupeaformis*) and cisco (*C. artedii*) which generally overwinter in the lower La Grande, migrating to brackish waters of the estuary of James Bay to feed and returning in the fall to spawn. The biological effects on these populations were found to be small and primarily due to the salt water intrusion into the winter habitat during low flows associated with filling of the Robert-Bourassa reservoir. It was also found that the absence of a large breakup flush contributed to a later migration of the fish to the estuary waters, impacting fishing practices of the local fisherman.

Figure 5-4. Hydro Quebec's Robert Bourassa Reservoir, Photo from Hydro Quebec.

6. IMPACTS OF NON-HYDROPOWER CHANGES ON RIVER ICE REGIMES

Tuthill 1999 describes flow control efforts to manage the ice regime for hydropower, navigation, and flood control. Through the past couple of decades, regulation of the flow of northern rivers has been utilized to force certain ice processes. In early winter, discharge may be reduced in order to promote rapid growth of a hydraulically smooth ice cover by juxtaposition of ice floes. After this cover has been formed, the discharge may be gradually increased back to open-water levels. The assisted and accelerated ice cover formation limits the stage increase (and thereby the flooding potential) that naturally occurs when an ice cover forms and then experiences secondary consolidation. While this tactic is often used in hydropower operations, it is also valuable for regions where freeze-up ice jams can induce flooding. A second potential benefit of early season flow control is that the rapid formation of an ice cover reduces the open water area and associated heat loss thereby limiting frazil production. This reduction in total ice volume can reduce the severity of breakup ice jam flooding. This is accomplished at Oil City, Pennsylvania on the Allegheny River where repeated breakup jam flooding caused extensive losses. The flow at Kinzua Dam upstream is reduced to quickly establish an ice cover on the river, reduce frazil ice formation upstream of and deposition downstream of Oil City, reducing the likelihood of severe breakup jam events. During the breakup period, there is some potential to use flow control to induce or prevent breakup at known ice jamming locations. The jamming location must be within a reasonable distance from the dam and the available flow release (or dam storage) enough to either induce ice cover movement (or prevent it).

Flow regulation is also used to manage ice buildup in navigable waters. The ideal case in rivers with winter navigation is to develop and maintain stable ice covers on the sides of established navigation channels. Since the storage capacities of most river navigation systems is small, care must be taken to avoid excessive ice formation or excessive travel outside of navigation lanes. Individual lock and dam facilities along the Mississippi and Ohio Rivers and the Illinois Waterway have developed methods to use flow control and lock and dam gate manipulation to assist in the passage of excessive ice past the facility.

7. MODELING THE IMPACTS OF HYDROPOWER ON THE ICE REGIME

Many models have been developed or adapted to attempt to simulate the effects of ice on flow hydraulics. They range from the fairly simple 1-dimensional HEC-2 steady flow add-on routines such as ICETHK, which used static equilibrium ice thickness theory to estimate ice jam thickness to much more detailed and complicated 1-dimensional and 2-dimensional models of ice processes. Most models are based on some combination of theory and field observations. While some aspects of ice processes theory are well understood, such as the frazil ice evolution and transport, others are not. Anchor ice deposition and release mechanisms, the effect of water velocity on shore ice growth, and ice cover bridging are not fully defined and thus empirical solutions based on field observations are often employed. It must be recognized that while models are based on theory, simplifications to full equations and methods of discretization of those equations result in errors or integration/smoothing of results. All of the models described below have been successfully used to investigate the effects of an ice cover or jam on river hydraulics. General model descriptions and specific applications are provided below.

The US Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HECRAS) is a well known modeling system providing 1-dimensional hydraulic calculations for natural and constructed channels. HECRAS provides components for steady flow water surface profile computations; unsteady flow simulation; movable boundary sediment transport computations; and water quality analysis. A static ice cover can be modeled using both steady and unsteady simulations and a full ice jam force balance can be used to calculate jam thickness in a steady simulation. HECRAS is a public domain software.

The University of Alberta has developed River1D and River2D to investigate the effects of ice covers and jams on the hydraulics of rivers. River1D is a 1-dimensional hydraulic flood-routing model that can simulate steady or unsteady flows. It has the capability of full dynamic ice modeling including water temperature variation, frazil ice evolution and transport, anchor ice development, ice jamming, frazil deposition as hanging dams and undercover deposits, thermal growth and decay of ice covers, and breakup. River2D is a 2-dimensional depth-averaged finite element hydrodynamic model for the analysis of river depth and velocity and includes options for a stationary ice cover, water temperature variations, and water quality as well as a fish habitat module based on the PHABSIM weighted usable area approach. The model can be run in either steady or unsteady modes and has a pseudo-groundwater flow component that simplifies the wetting and drying of elements but also produces wetted areas for non-connected branches. The software is public domain.

The Comprehensive River Ice Simulation System Program (CRISSP) has both a 1-deimensional and a 2-dimensional version. The CRISSP-1D program simulates ice processes in natural rivers including water temperature variation, frazil ice and anchor ice evolution, surface ice transport, ice cover formation, surface and undercover ice transport and jamming, thermal growth and decay of ice, and break up. The hydraulic model is a one-dimensional unsteady flow model, which can be applied to flows with or without ice. The CRISSP-2D program simulates the same ice processes as CRISSP1D. The hydrodynamic module provides finite-element simulation of a two-dimensional unsteady flow model, which can be applied to flows with or without ice. A Lagrangian discrete parcel method with smoothed particle hydrodynamics is used to simulate the ice transport, which include the dynamics of surface ice motion and jamming. CRISSP is a proprietary model.

The MIKE-Ice add-in module was developed as a joint effort among Hydro-Quebec, the LaSalle Consulting Group, and the Danish Hydraulic Institute and is based ion the Danish Hydraulic Institute's MIKE11 software. MIKE11 is a steady and unsteady hydrodynamic flow model for branched and looped channels and floodplains. MIKE-Ice includes water temperature variation, frazil production and transport, ice cover formation, surface and undercover ice transport and jamming, thermal growth and decay of ice. The MIKE software is proprietary.

7.1. Modeling on the Peace River

Hicks et al. 2009 tested the ability of the River1D model to simulate the severe cold weather, rapid ice cover advance, and ice cover consolidation event and associated record flooding levels that occurred in January 1982. The consolidation was a result of a fairly rapid increase in flow rates from Peace Canyon Dam in response to the need from additional hydropower generation due to the extreme cold. It was found that the thermal ice processes component of River1D was effective in reproducing the rapid progression of the ice front and the dynamic ice component successfully reproduced the consolidation extent. The water level increases and ice thicknesses, however, were only about half of the actual reported and recorded values. It was thought that further refinements to the model to include undercover frazil transport and deposition would improve the thickness and water level estimates.

BC Hydro is moving forward with plans for another hydropower project, Site C, on the Peace River downstream of the Peace Canyon Generation Station. Extensive studies and modeling have been completed for this project in preparation of the Environmental Impact Statement that was filed in January 2013. Jasek 2012 reports that the impact of the project on the ice regime was modeled using CRISSP-1D for freeze-up modeling and the Peace River Thermal Ice Growth Model (PRTIGM) for modeling thermal ice growth. The models were run with data from 16 winters and the results were compared to the actual winter ice behavior. The model was then run to predict the ice behavior with the Site C project in place. The results of modeling the existing conditions for the 16 winters showed that the modeled upstream extent of the ice cover was within 10 km of the actual ice cover (with a couple of outliers near 30 km). The modeled arrival of the ice cover front to the Town of Peace River (290 km downstream of Site C) was within 3 days of the actual arrival; the modeled date of break-up was within 9 days of the actual breakup date. The modeled water levels assuming either a juxtaposition ice front progression or open water were within 0.5 m of the actual levels. The model could not be used to predict the extreme water levels caused by secondary consolidation of the ice cover. The results from the modeling of "with project" conditions indicated that the ice front progression and thermal ice formation necessary to support the weight of a person will be delayed an average of 3 days at the Town of

Peace River, with the delay increasing further upstream. The modeling also indicated that the freeze-up water levels would not change and the breakup timing and severity at the own of Peace River would not be changed by the project.

7.2. Modeling on the Nelson River

Bijeljanin and Clark 2011 investigated the flow and ice regime of the Upper Nelson River in Manitoba, modeling the freeze-up processes using the CRISSP-2D software. Three modules were used including the river hydrodynamics, thermodynamics (ice formation and growth), and ice dynamics. The software was calibrated for low, average and high flow rates from the 2001, 2002 and 2004-2009 seasons, and then used to simulate and predict the ice regime of 2009. The model results indicated water temperatures and areas where static surface ice would form and were in close agreement with the general observations at all flow conditions.

7.3. Modeling on the Romaine River

Theriault 2011 described studies performed on the Romaine River in Quebec where four hydroelectric generating stations are proposed. Of special concern are the ice conditions downstream of the Romaine-1 powerhouse, (the furthest downstream). The MIKE-Ice model was used to model the existing and proposed conditions for 25 winters. Following calibration to existing conditions data, it was found to produce reasonable predictions of the changes that would occur downstream of Romaine-1. For example, safe snowmobile access to the river is predicted to be delayed from one to three weeks and breakup is predicted to be about three weeks earlier.

7.4. Modeling on the Athabasca River

The Athabasca River in Northern Alberta is the only undammed major river in Alberta. Water use in this area is becoming an issue of increasing importance because of the expanding development of oil sands mining as well as increased population growth. Katopodis and Ghamry 2005 conducted a study to predict the hydraulics of the Athabasca River under conditions of partial or total ice cover. They utilized the River2D modeling software in a steady simulation to model the depths and velocities for three study reaches. They tested two different methods to calibrate the model for ice roughness; calibrating the bed roughness first to open water conditions and then adjusting the ice cover roughness to match ice-covered conditions, and by just using the ice-covered conditions to calibrate to a total roughness. They found that each of the two methods confirmed the capability of the River2D model to simulate the ice-covered hydraulics of the study reaches reasonably well, although the first method gave slightly better results.

Andrishak et al. 2008 conducted a study to gather extensive field data on freeze-up conditions in the Athabasca River for the purpose of calibrating the River1D model and then applying it to investigate the effects of future water withdrawals for oil sands development. The field observations focused on water temperature and ice concentrations throughout the freeze-up period. The River1D simulations showed that the water temperature results were in good agreement with the observed values. The ice concentration results showed the correct trend in ice concentration but absolute values were highly variable. There are sections of the modeled reach where numerous bars and islands are located and the side channels primarily freeze over thermally. This may explain the sensitivity of ice concentration in the model results and further analysis of inflow boundary ice concentration is needed.

Wojtowicz et al. 2009 documented their efforts to model the ice processes on the Athabasca River using CRISPP-2D and River2D. The focus of the study was the modeling of the development of border ice and hence its implications on the ice bridging phenomenon. Each model uses a different scheme for solving hydrodynamic conditions, and one goal was to compare the results of the two models. Since the ice module in River2D was still in development at the time of the study, it was used primarily for the initial hydrodynamic calibration, from which an equivalent model for CRISPP-2D was constructed. Preliminary border ice modeling results from CRISPP-2D were consistent with field observations in four of the six areas showing border ice growth in the modeled reach. The mixed results due to the complexity of the modeling, especially in longer modeling reaches and time periods, showed that there was still work to be done in developing an accurate model for border ice growth, bridging, and ice front progression. The paper outlines steps recommended to be taken to further develop the River2D thermal ice modeling software.

7.5. Modeling on the Hay River

Brayall and Hicks 2009 used the CRISSP-2D model to predict freeze-up and breakup conditions on the Hay River Delta where it enters Great Slave Lake at the Town of Hay River in the Northwest Territories. It showed good performance in simulating the freeze-up processes as the split of flows and frazil ice in the east and west channels of the delta matched observations well. The breakup proved more difficult and although the cover consolidation occurred at the anticipated location, the model was limited in the number of nodes and elements such that a coarse discretization had to be employed. As a result, the ice jam elevations were too low and the extent of the model did not match that of the observed jam. A future recommendation for the program would be modification to accept more nodes and elements.

8. CONCLUSION

This white paper has presented an overview of the existing ice processes on the Susitna River as well as key findings from prior studies on how ice processes affect fish spawning and rearing habitat. The effects of hydropower development on the ice regime in general and for the Susitna River in particular for the three periods of ice cover formation, ice cover, and break-up were presented. A review of hydropower developments in other cold regions of the world show that there are similarities in what to expect with development on the Susitna River but also point out operational scenarios that have been developed in other countries to minimize adverse effects. While hydropower development is the primary reason for alterations to an annual hydrograph, navigation and flood control are additional uses of flow control to alter the natural ice regime for economic benefit or to prevent loss and damages. Operational schemes developed for flow control often have the same objectives of reduced overall ice production, lower water levels, and controlled breakup.

Finally, it has been shown through model descriptions and examples of model applications on several cold regions rivers that it is not only possible but also prudent to use models to predict the changes to the ice regime from hydropower development. There exist very capable models in both 1-D and 2-D, steady and unsteady, proprietary or public domain which can be used to examine the impacts of changes to the hydrology and ice regime of a river.

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PART C - APPENDIX D: TECHNICAL MEMORANDUM: PROOF OF CONCEPT MODELING DEMONSTRATION

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Ice Processes in the Susitna River Study (7.6)

Initial Study Report

Part C - Appendix D
Technical Memorandum:
Proof of Concept Modeling Demonstration

Prepared for

Alaska Energy Authority

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

Prepared by

HDR

June 2014

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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) that will be conducted to characterize and evaluate these effects is described in a Study Plan that was reviewed by Stakeholders, 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/wp-content/uploads/. The Fish and Aquatics Instream Flow Study (8.5) produced a Technical Memorandum (ISR Study 8.5 Appendix N) which 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 processes 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 Ice Processes in the Susitna River Study produced this Technical Memorandum to describe the process followed in the demonstration of the ice modeling software. As stated above, the goal of the Proof of Concept was to show that the modeling process was CONCEPTUALLY sound and was able to provide the input data required by the Fish Habitat modeling effort in order to provide a matrix of information for the Decision Support System to transfer results to the rest of the Middle River System.

2. ICE PROCESSES MODELING

Many models have been developed or adapted to attempt to simulate the effects of ice on flow hydraulics. The first theoretical analysis efforts (Kennedy 1958) actually involved the estimation of forces on a boom by a pulpwood jam. Berdennikov 1964 extended this work to the forces on a boom from ice accumulations and additional research (Pariset and Hausser 1961, Pariset et al. 1966, and Uzuner and Kennedy 1976) added the components of jam weight, cohesion, refined formulations of the water shear on the underside of accumulations, and the frictional forces at the banks. Beltaos 1983 adapted the theoretical formulations and used many field observations to develop empirical relationships for many coefficients characterizing the forces on a static ice jam.

Ice processes models have advanced greatly over the past 35 years from the fairly simple 1-dimensional HEC-2 steady flow add-on routines such as ICETHK based on the theory described above for static equilibrium ice thickness of a jam. Advances include the addition of ice formation, transport, and decay as well as more detailed computational schemes and 2-dimensional models of ice processes. Most models are based on some combination of theory and field observations. While some aspects of ice processes theory are well understood, such as the frazil ice evolution and transport, others are not. Anchor ice deposition and release mechanisms, the effect of water velocity on shore ice growth, and ice cover bridging are not fully defined and thus empirical solutions based on field observations are often employed. It must be recognized that while models are based on theory, simplifications to the full equations and methods of discretization of those equations result in errors or integration/smoothing of results. The ice processes modeling software chosen for the Susitna Study are River1D and River2D, public domain software developed by the University of Alberta.

2.1. 1-D Ice Processes Modeling

River1D was developed to investigate the effects of ice covers and jams on the hydraulics of rivers (Hicks 2005; Andrishak and Hicks 2005a). It is a hydrodynamic flow routing and thermal model that also models frazil generation, ice-cover progression, and decay (Hicks and Steffler 1992; Andrishak and Hicks 2005a; Andrishak and Hicks 2005b; She and Hicks 2006; She et al. 2009; She et al. 2012). The model has the ability to route reservoir releases downstream at small time-steps (hourly or less) and was designed to be able to predict when fluctuating flows can destabilize a winter ice cover (She et al. 2012).

The River1D Ice Processes Modeling framework was originally developed using simple rectangular channel cross-sections without overbanks. Several modeling studies have demonstrated that this method is suitably accurate, particularly when resolving river channels with relatively large spacing between surveyed cross-sections. However, to maintain better consistency with the HEC-RAS 1D Open-water Flow Routing Model, River1D was modified for this project by the University of Alberta River Ice Engineering Group to include natural compound channels with detailed cross-section bathymetry and left and right overbanks. Additional project enhancements to the River1D modeling framework included:

- A HEC-RAS geometry-file convertor to automate creation of River1D geometry files
- Ability to define distributed, as well as discrete, lateral inflow hydrographs
- Ability to use either metric or English units.
- A routine to simulate border ice growth was recently added.

A River1D model was developed and is being modified and calibrated for ice processes and will be applied to the Susitna River between Talkeetna (PRM 103.8) and the proposed dam site (PRM 187.2). The first step was the development and calibration of an open-water model using known discharge events. The second step will be to simulate pre-Project ice processes to verify that the model is correctly working on the Susitna River. Since the River1D model was not fully calibrated for ice conditions prior to the Proof of Concept effort, the US Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HECRAS) modeling software was used to provide an appropriate simulant. HECRAS is a well known modeling system providing 1-dimensional hydraulic calculations for natural and constructed channels. HECRAS provides components for steady flow water surface profile computations; unsteady flow simulation; movable boundary sediment transport computations; and water quality analysis. A stationary ice cover can be modeled using both steady and unsteady simulations and a full ice jam force balance can be used to calculate jam thickness in a steady simulation. HECRAS is public domain software.

2.2. 2-D Focus Area Modeling

River2D is a 2-dimensional depth-averaged finite element hydrodynamic model for the analysis of river depth and velocity and includes options for a stationary ice cover, water temperature variations, and water quality simulations as well as a fish habitat module based on the PHABSIM weighted usable area approach. The model can be run in either steady or unsteady modes and has a pseudo-groundwater flow component that simplifies the wetting and drying of elements but also produces wetted areas for non-connected branches (providing an indication of where groundwater upwelling might occur). The software is public domain.

The River2D modeling software includes four separate programs. R2D_Bed allows the user to develop bed geometry based on surveyed data and assignment of breaklines to develop an appropriate bed elevation and roughness model. R2D_Ice is used to develop a similar representation of the thickness and roughness of a specified ice cover. R2D_Mesh is the easy to use computational mesh generation environment. River2D is the two-dimensional, depth averaged finite element computational with a variety of options for visualization and presentation of model results. Boundary conditions required include an inflow discharge at the upstream end of the model and either a rating curve or specified water surface elevations at the downstream end.

3. DEMONSTRATION OF THE MODELING CONCEPT

The Proof of Concept Modeling Demonstration was intended to show how all of the various models would interact to provide data to the fish habitat modeling efforts leading to defensible input to the Decision Support System. This was accomplished by having each of the modeling teams develop model input and output for the FA-128 (Slough 8A) Focus Area for existing conditions and for project operational scenario OS-1b. While most of the modeling teams used the output of the Open Water Flow Routing Model to define stage and discharge boundary conditions, the Ice Processes modeling required ice-effected stages as boundary conditions. As stated above, the River1D ice processes model was not fully calibrated at the time of the Proof of Concept and thus the HECRAS modeling software was used to provide ice-effected stages for the boundary conditions required by the River2D model.

3.1. Representative Years

The hydrographic record for selected USGS gages on the Susitna River and its tributaries is not complete (ranging in length from 4 to 57 years) but has been extended as described by Curran 2012 for the period of water years from 1950 through 2010. Coupled with meteorological records from the Talkeetna Airport, an assessment can be made as to the ability of any given year of the record to represent typical or extreme conditions of flow, temperature, or precipitation. The Ice Processes, Instream Flow, and Geomorphology modeling teams assessed the record to develop representative years for dry, wet, and average conditions as described in the Fluvial Geomorphology Modeling below Watana Dam Study (6.6) Appendix E. It was determined that dry and wet designations did not necessarily properly characterize the ice-covered periods of the year and that air temperature was a better indicator of severity (or lack thereof) of winter ice conditions and their effect on hydraulics. While the chosen wet year (1981) also corresponded to one of the warmest winters and the average year (1985) was average in terms of its winter temperatures, the chosen dry year of 1970 was actually slightly warmer than 1981 (the chosen warm year). A second alternative for the dry year was 1976 which was also one of the coldest winters on record. Therefore, three representative years were chosen to conduct detailed modeling; 1976 was dry and cold, 1981 was warm and wet, and 1985 was average. These three years will cover the range of conditions expected for both open water and ice-covered conditions.

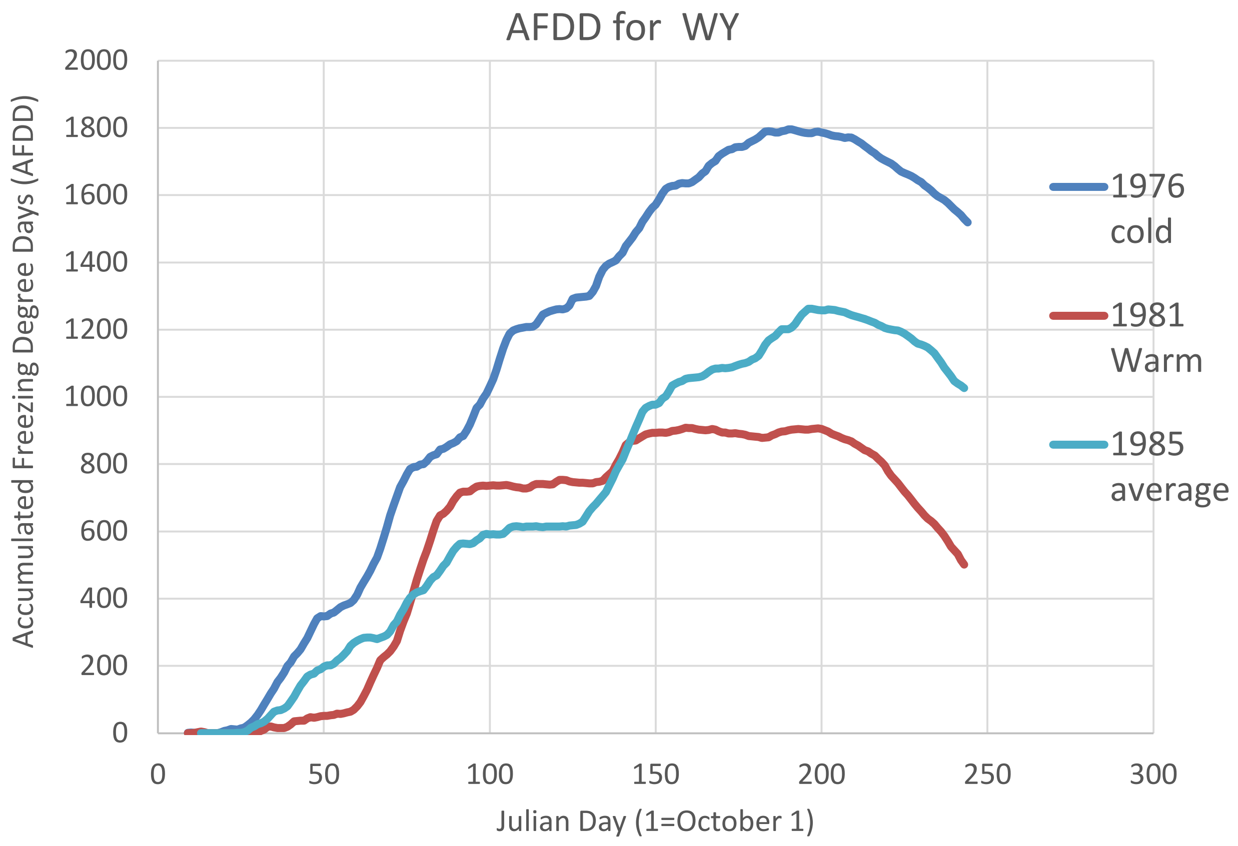

Figure 3-1. Accumulated Freezing Degree Days (AFDD) for Representative Years.

Figure 3.1-1 shows the accumulated freezing degree days (AFDD) for the three representative years, pointing out not only the differences in the total AFDD but also the differences in the freeze-up period. The freeze-up in 1976 (cold) and in 1981 (warm) were both fairly quick denoted by a steep curve but that the 1981 freeze-up occurred at a much later date (early December). The freeze-up in 1985 (average year) occurred over a longer time frame.

3.2. 1-D Modeling for Boundary Conditions

HECRAS was used to conduct 1-D modeling of the Susitna River under various ice conditions in order to develop boundary conditions for the detailed 2-D Focus Area modeling. The Ice Processes Study has gathered extensive field observations for the breakup in 2012 through the breakup in 2014 and these were used to characterize the ice conditions that would be modeled. Figures 3-2 through 3-4 depict the ice conditions at FA-128 (Slough 8A) during freeze-up of 2012. Figure 3-2 shows the river at the early stages of freeze-up at FA-128 (Slough 8A). While there is a considerable amount of frazil ice floating downstream, there is little shore ice that has developed and only the very minor channels have frozen over. Under these conditions, the effects of ice would be expected to be very little. Figure 3-3 shows the same location on November 20, 2012 and while there is still frazil moving down the main channel, shore ice growth has increased and the major side channel in the right hand side of the photo is frozen over by a thermally grown cover. These ice conditions would be expected to create some backwater effects. Finally, Figure 3-4 shows the same location on December 3, 2102 after the freeze-up front has progressed through this area. As the ice cover (freeze-up jam) is stopped, the flow resistance is greatly increased and the backwater effects of the cover will be large.

Figure 3-2. FA-128 (Slough 8A) on November 1, 2012, Q at Gold Creek ~6,000 cfs.

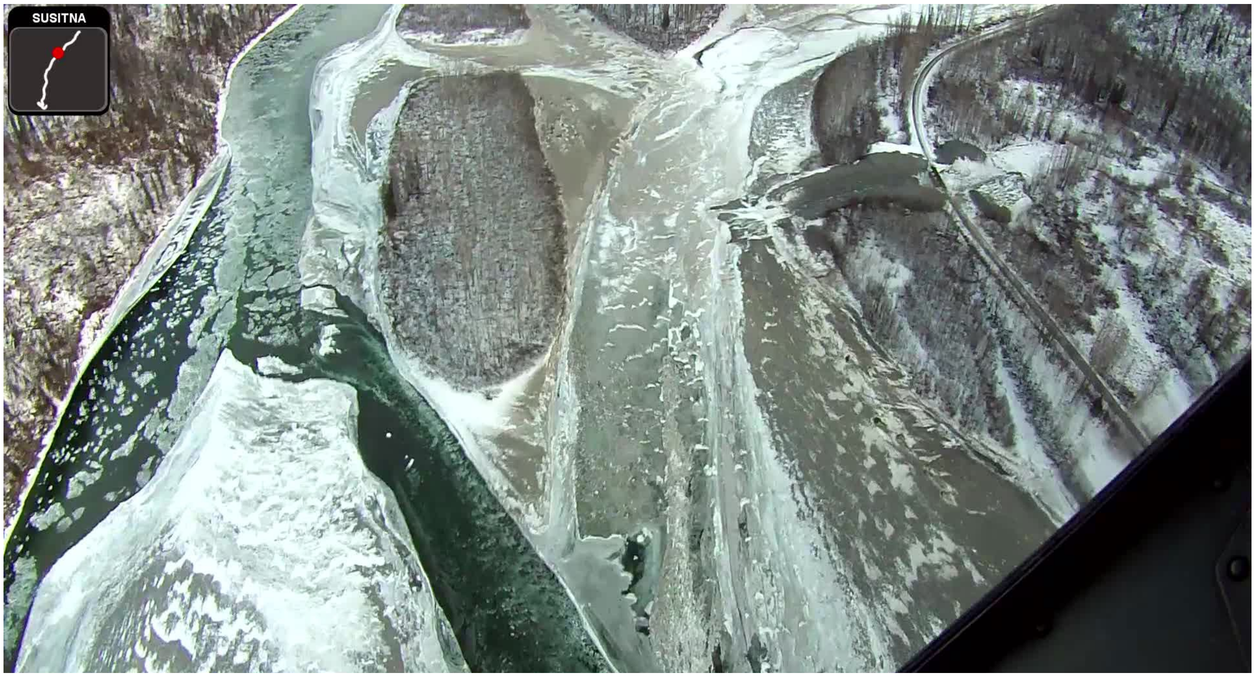

Figure 3-3. FA-128 (Slough 8A) on November 20, 2012, Q at Gold Creek <6,000 cfs.

Figure 3-4. FA-128 (Slough 8A) on December 3, 2012, Q at Gold Creek < 6,000 cfs.

The HECRAS modeling simulated this reach using various flows, ice thickness and roughness to mirror the conditions depicted in the figures. Conditions modeled and the results for the water surface elevations at the two bounding cross sections of FA-128 (Slough 8A) are given in Table 3-1.

Table 3-1. HECRAS Modeling Runs and Results

Discharge Gold Creek	Ice thick channel	Ice rough channel	Ice thick OB	Ice rough OB	wsl at PRM 128.1	wsl at PRM 129.7
6000 cfs	0	0	0	0	562.56 ft	574.60 ft
6000 cfs	0	0	1 ft	0.040	562.64 ft	574.66 ft
6000 cfs	3.28 ft	0.045	1 ft	0.040	566.35 ft	579.22 ft
6000 cfs	jam (7.5 ft)	jam	1 ft	0.040	569.04 ft	581.87 ft
2000 cfs	jam (5.5 ft)	jam	1 ft	0.040	565.61 ft	578.08 ft
10,000 cfs	jam (8.5 ft)	jam	1 ft	0.040	570.92 ft	583.81 ft

The entries with a discharge at Gold Creek of 6,000 cfs represent the changing conditions depicted in Figures 3-2 through 3-4, while the 2,000 cfs discharge would represent the low or minimum flow condition during the middle of the winter. The 10,000 cfs entry represents the peak flow rate during the winter under Operational Scenario OS-1b. The table clearly shows that for increasing discharge, the water levels increase and for jamming conditions, increased discharge results in increased ice thickness (and thus water levels).

3.3. 2-D Focus Area Modeling Demonstration

The 2-D modeling was conducted to demonstrate that River2D could provide the types of model outputs that would be required by the habitat modeling teams and provided in a format and discretization that would be useful to their analysis. Figure 3-5 and 3-6 depict the River2D bed elevation model (clipped at an elevation 610 ft) and the River2D computational mesh, respectively. The main flow channel and primary side channels can easily be seen in Figure 3-5 while sloughs and minor drainages are also evident. Figure 3-6 indicates how the mesh is developed to provide adequate discretization in the smaller sloughs and side channels by decreasing the mesh size in those channels.

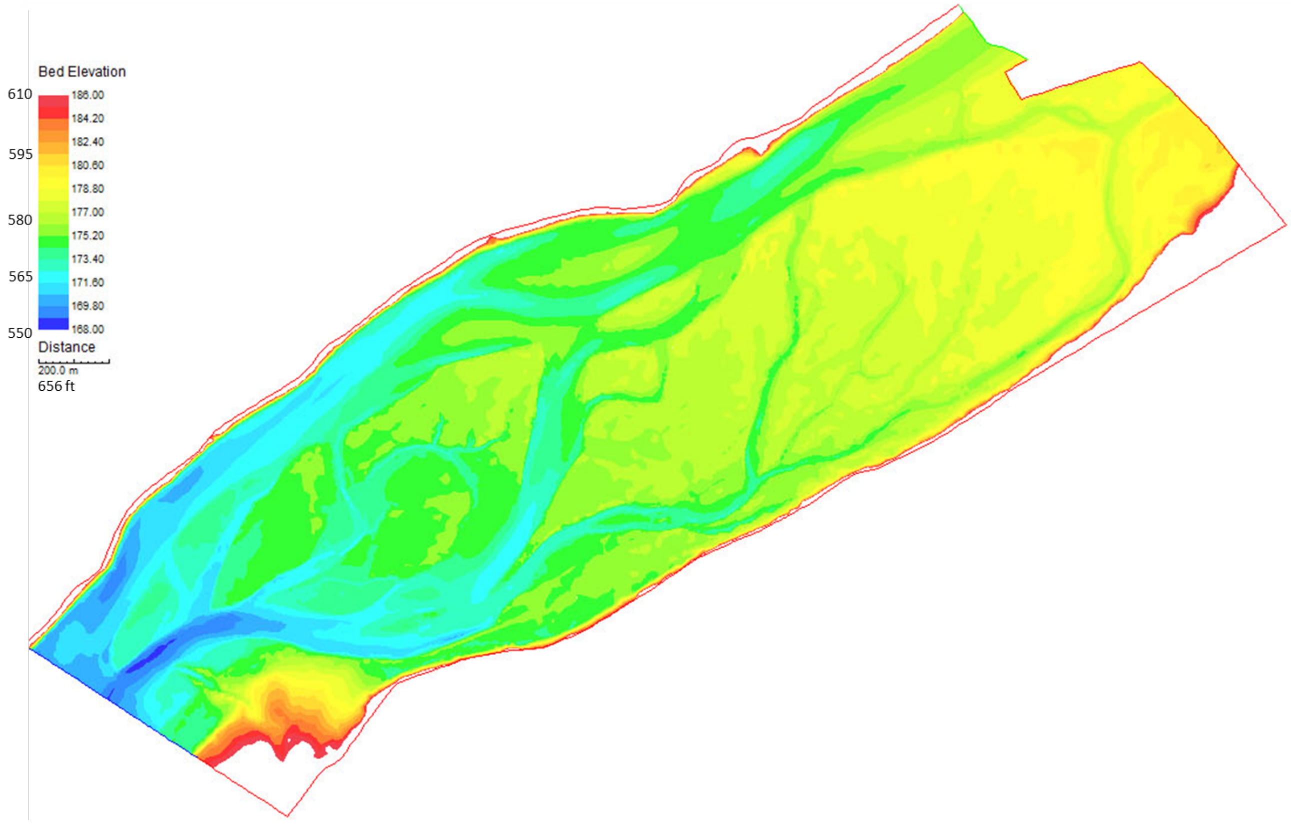

Figure 3-5. River2D bed elevation model (clipped at 610 ft elevation).

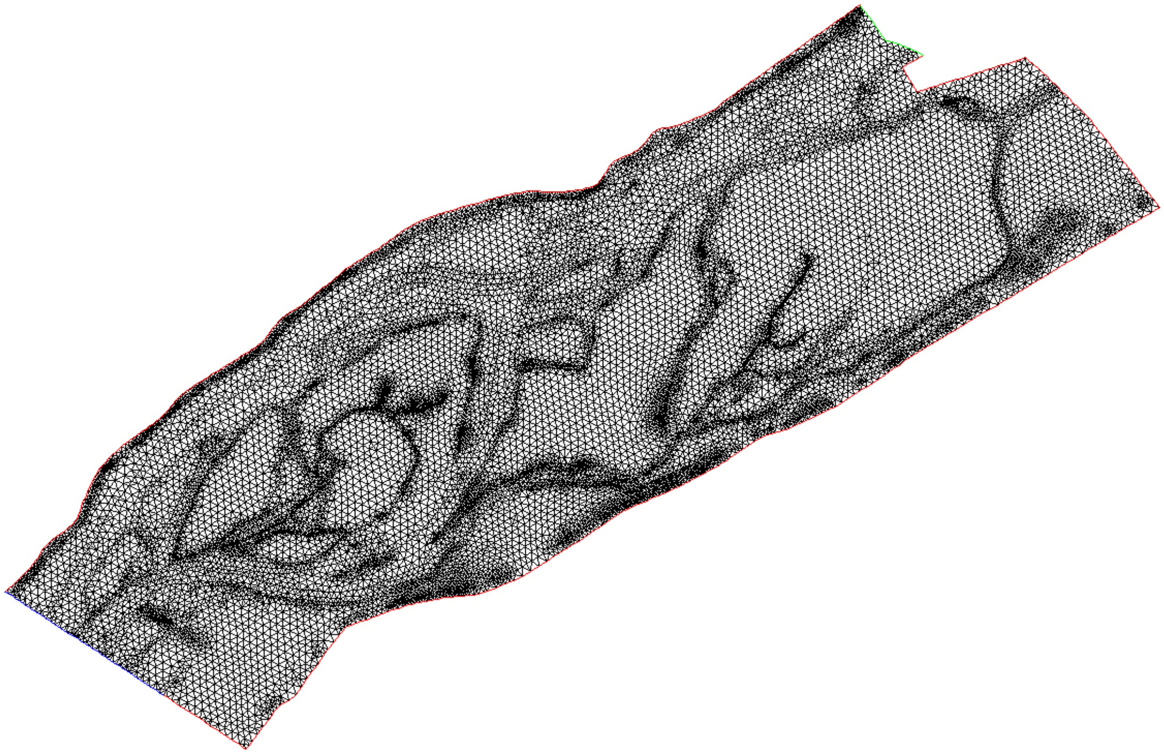

Figure 3-6. River2D computational mesh.

For the Proof of Concept Modeling Demonstration, River2D was used to simulate the conditions of freeze-up depicted in Figures 3-2 to 3-4 and also to investigate the effects of high winter flows (operational scenario OS-1b) on ice and water levels at FA-128 (Slough 8A). As an example of the results that can be achieved using River2D, Figure 3-7 shows the velocity vectors and depths (color scale) for the conditions depicted in Figure 3-2 associated with generally open water conditions but with some shore ice and floating frazil in the main and side channels. Figure 3-8 shows the results for the conditions after the passage of the freeze-up front (as depicted in Figure 3-4) when the main channel has a freeze-up accumulation cover (jam) and the side channels have a smooth ice cover. The two scenarios were modeled with the same flow of 6,000 cfs at Gold Creek and show the effects of the addition of the ice cover. Depths increased noticeably in the side channels and minor connecting channels.

As an example of the potential changes that might occur with an operational scenario such as OS-1b, the River2D model was run at the existing typical mid-winter low flow condition of 2,000 cfs (measured at Gold Creek) and also to simulate load following with a peak daily flow near 10,000 cfs. For both of these runs, a single ice thickness of 1 m (3.28 ft) was stipulated on the main channel and major side channel with a roughness similar to what would be expected for conditions of a freeze-up accumulation cover. Figure 3-9 shows the lower velocities under existing conditions (2000 cfs) while Figure 3-10 shows a significant increase in velocity and increased depths with many of the side channels and connecting channels flooded for the OS-1b scenario (10,000 cfs). It is likely that the ice thicknesses would be greater for OS-1b which would result in higher water levels (greater depths) and ice elevations.

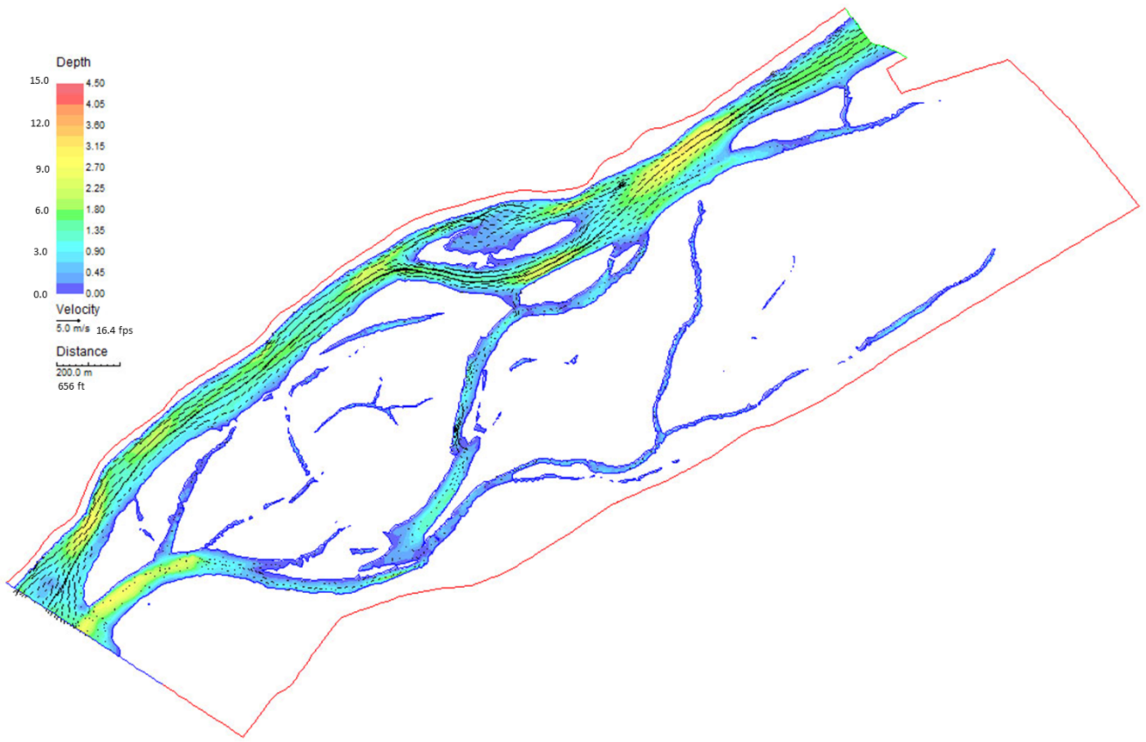

Figure 3-7. FA-128 (Slough 8A) Early freeze-up conditions, Q at Gold Creek ~ 6,000 cfs.

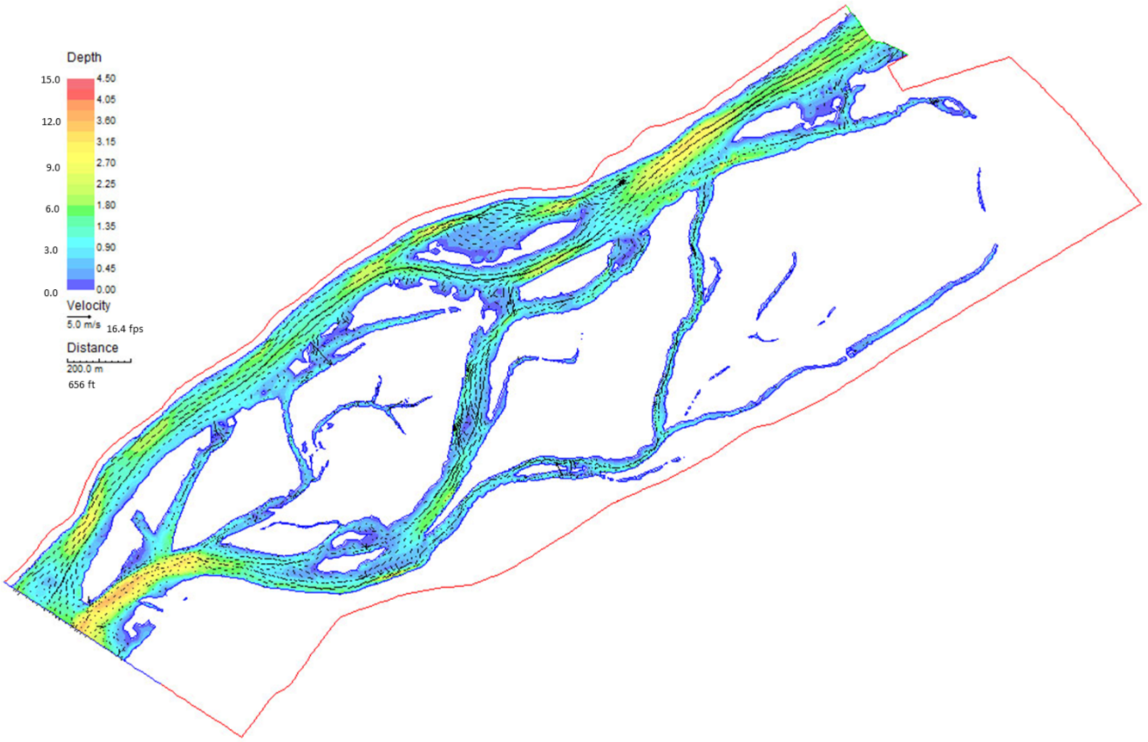

Figure 3-8. FA-128 (Slough 8A) After passage of freeze-up front.

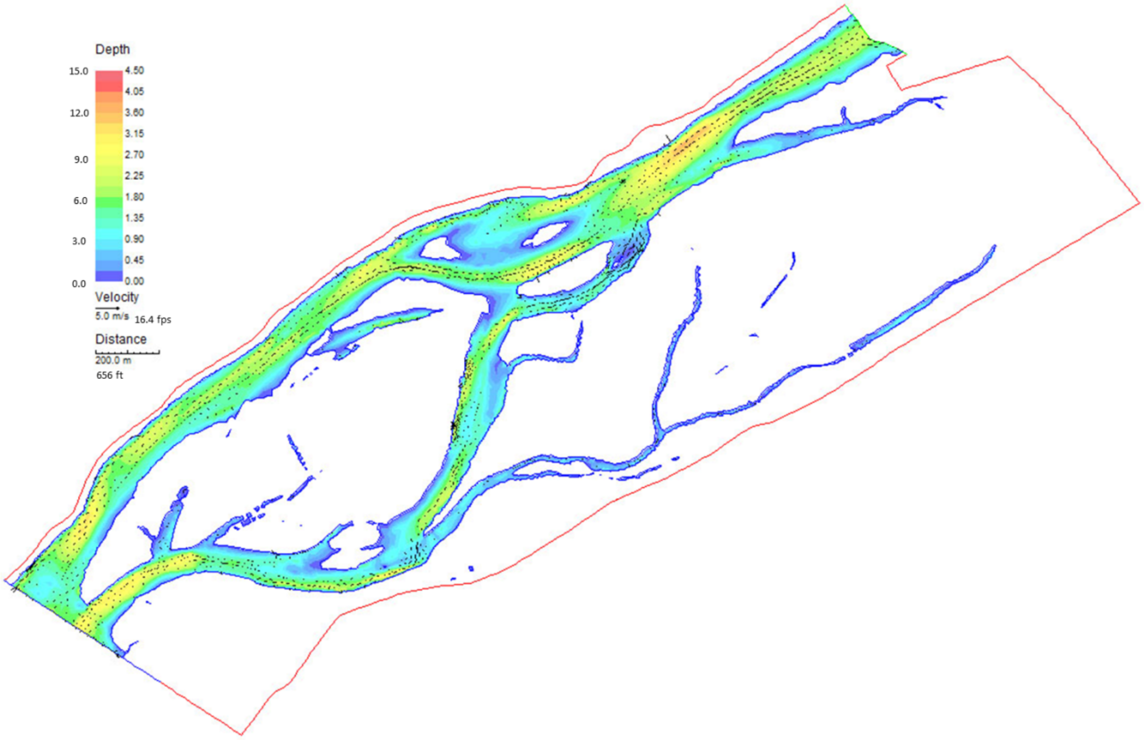

Figure 3-9. FA-128 (Slough 8A), ice covered, Q at Gold Creek 2,000 cfs

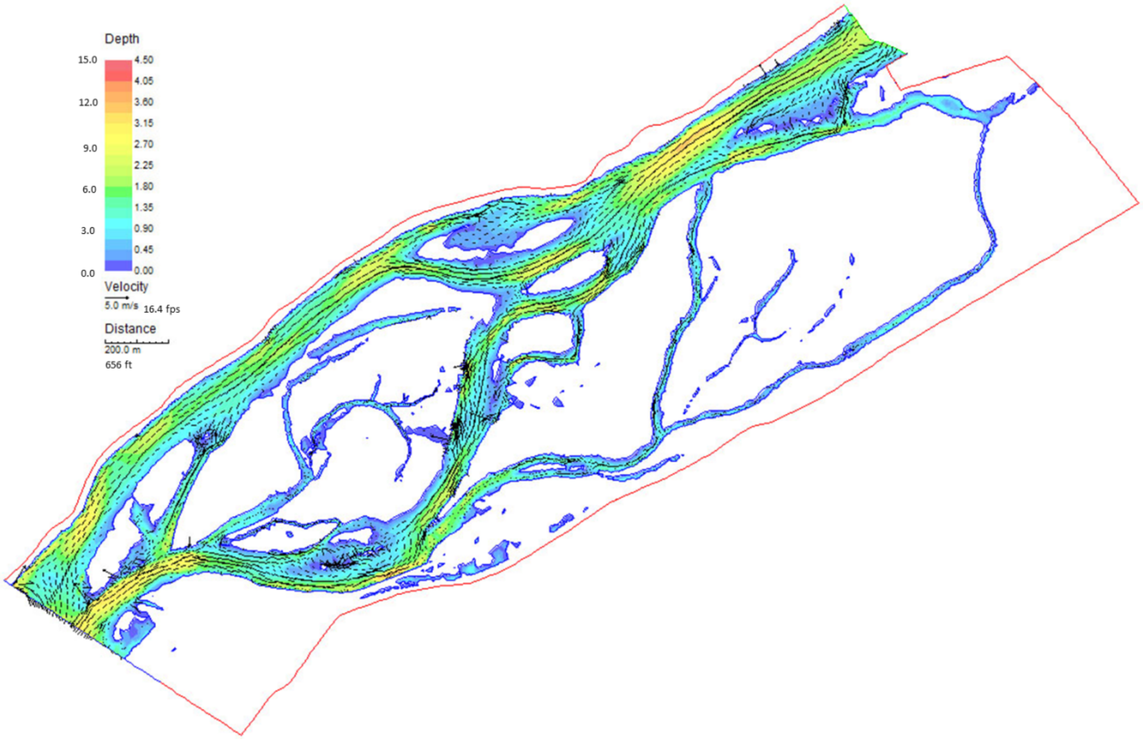

Figure 3-10. FA-128 (Slough 8A), ice covered, Q at Gold Creek 10,000 cfs.

4. SUMMARY

The Proof of Concept Modeling Demonstration was intended to show how all of the various models would interact to provide data to the fish habitat modeling efforts leading to defensible input to the Decision Support System. As stated above, the River1D ice processes model was not fully calibrated at the time of the Proof of Concept and thus the HECRAS modeling software was used to provide ice-effected stages for the boundary conditions required by the River2D model. The results of the HECRAS (for 1D) and River2D (for 2D) modeling efforts were able to provide reasonable results for the modeling of ice conditions at FA-128 (Slough 8A) for the Proof of Concept tests comparing existing conditions to what might be expected under Operational Scenario OS-1b. The output of the models provided suitable data density to serve as input to the fish habitat modeling.

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