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- Appendix A. Alternative visualizations of freeze-up progression and open leads.
- Appendix B. Technical memorandum: River1D model--initial open water calibration and validation.
- Appendix C. River2D open-water modeling report, Focus Area 128 (Slough 8A)

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Ice Processes in the Susitna River Study
Study Plan Section 7.6

2014-2015 Study Implementation Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

HDR

October 2015

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Appendix B: Technical Memorandum: River1D Model - Initial Open Water Calibration and Validation

Appendix C: Technical Memorandum: River2D Modeling Report of Focus Area 128 (Slough 8a)

LIST OF ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

Abbreviation	Definition
AEA	Alaska Energy Authority
ESS	Alaska **E**nergy Authority station on the **S**usitna River for **S**urface water
FA	Focus Area (Aquatic Habitat)
FERC	Federal Energy Regulatory Commission
GIS	Geographic Information System
HDR	HDR, Inc.
HEC-RAS	Hydrologic Engineering Centers River Analysis System
ILP	Integrated Licensing Process
ISR	Initial Study Report
PRM	Project River Mile
Project	Susitna-Watana Hydroelectric Project
R2	R2 Resource Consultants
RM	River Mile
RSP	Revised Study Plan
SPD	Study Plan Determination
USGS	U.S. Geological Survey

1. INTRODUCTION

This Ice Processes in the Susitna River Study, Section 7.6 of the Revised Study Plan (RSP) approved by the Federal Energy Regulatory Commission (FERC) for the Susitna-Watana Hydroelectric Project, FERC Project No. 14241, focuses on furthering the understanding of natural ice processes in the Susitna River and providing a method to model/predict pre-Project and post-Project ice processes in the Susitna River.

A summary of the development of this study, together with the Alaska Energy Authority's (AEA) implementation of it through the 2013 study season, appears in Part A, Section 1 of the Initial Study Report (ISR) filed with FERC in June 2014. As required under FERC's regulations for the Integrated Licensing Process (ILP), the ISR describes AEA's "overall progress in implementing the study plan and schedule and the data collected, including an explanation of any variance from the study plan and schedule." (18 CFR 5.15(c)(1)).

Since filing the ISR in June 2014, AEA has continued to implement the FERC-approved plan for the Ice Processes in the Susitna River Study. For example:

- The River1D ice processes model of the Middle River reach (PRM 100.7-187.2) and River2D models of the Focus Areas have continued to be developed and calibrated for open water conditions.
- A technical Memorandum describing detailed ice observations from October 2013-May 2014 was filed in September 2014.
- On October 17, 2014, AEA held an ISR meeting for the Ice Processes in the Susitna River Study.

In furtherance of the next round of ISR meetings and FERC's SPD expected in 2016, this report describes AEA's overall progress in implementing the Ice Processes in the Susitna River Study (Study 7.6) during calendar year 2014. Rather than a comprehensive reporting of all field work, data collection, and data analysis since the beginning of AEA's study program, this report is intended to supplement and update the information presented in Part A of the ISR for the Ice Processes in the Susitna River Study through the end of calendar year 2014. It describes the methods and results of the 2014 effort, and includes a discussion of the results achieved.

2. STUDY OBJECTIVES

The Ice Processes in the Susitna River Study (Study 7.6) will further the understanding of natural ice processes in the Susitna River and provide a method to model/predict pre-Project and post-Project ice processes in the Susitna River. The study will provide a basis for impact assessment, which will inform the development of any necessary protection, mitigation, and enhancement measures. The study also will provide ice processes input data for other resource studies with winter components (e.g., Fluvial Geomorphology Modeling below Watana Dam Study [Study 6.6], Instream Flow Studies [Studies 8.5-8.6], Instream Flow Riparian [ISR Study 8.6], and Groundwater Study [Study 7.5]).

The overall goals of the Ice Processes in the Susitna River Study (Study 7.6) are to understand existing ice processes in the Susitna River and to predict post-Project ice processes. The specific objectives are as follows:

- Document the timing, progression, and physical processes of freeze-up and break-up during 2012–2014 between tidewater and the Oshetna River confluence (PRM 235.2 [RM 233.4]), using historical data, aerial reconnaissance, stationary time-lapse cameras, and physical evidence.
- Determine the potential effect of various Project operational scenarios on ice processes downstream of Watana Dam using modeling and analytical methods.
  - Develop a modeling approach for quantitatively assessing ice processes in the Susitna River.
  - Calibrate the model based on existing conditions. Use the model to determine the extent of the open water reach downstream of Watana Dam during Project operations.
  - Use the model to determine the changes in timing and ice-cover progression and ice thickness and extent during Project operations.
- Develop detailed models and characterizations of ice processes at instream flow Focus Areas in order to provide physical data on winter habitat for the Fish and Aquatics Instream Flow Study (Study 8.5).
- Provide observational data of existing ice processes and modeling results of post-Project ice processes to the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6), Groundwater Study (7.5), Instream Flow Studies (Studies 8.5-8.6), Fish and Aquatics Study (Studies 9.12), Riparian Vegetation Study Downstream of the Proposed Susitna-Watana Dam (Study 11.6), Recreation and Aesthetics Studies (12.5-12.7), and Socioeconomic and Transportation Study (Study 15.7).
- Research and summarize large river ice processes relevant to the Susitna River, analytical methods that have been used to assess impacts of projects on ice-covered rivers, and the known effects of existing hydropower operations in cold climates.

Thermal and ice modeling for the reservoir and the general thermal modeling for the river during the 5 months when ice is not present will be accomplished under the Water Quality Modeling Study (Study 5.6). The output from that work will be used in this river ice processes study. Likewise, open water flow routing will be performed under the Fish and Aquatics Instream Flow Study (Study 8.5), while ice-affected flow routing will be performed by this study.

3. STUDY AREA

3.1. Observations

The ice processes observation study area includes the 234-mile segment of river between tidewater and the Oshetna River confluence (below PRM 235.2 [RM 233.4]). Observations of open leads, break-up progression, and freeze-up progression will be made in this area. In addition, ice thickness, top-of-ice elevations, and under-ice water stages will be surveyed in the Middle River to calibrate and verify a predictive ice model.

3.2. Middle River River1D Ice Processes Modeling

Predictive ice, hydrodynamic, and thermal modeling using River1D is planned for the Middle River between the Three Rivers Confluence near Talkeetna (PRM 103.8 [RM 100]) and the proposed dam (PRM 186.8 [RM 184]).

3.3. Middle River River2D Focus Area Ice Modeling

Several Focus Areas determined in conjunction with the Instream Flow Studies (Studies 8.5-8.6) in the Middle River will receive more detailed ice modeling and observation attention. Depending on the local channel geometry, either detailed River1D or River2D models will be developed, and observations of ice-cover progression, ice thickness, and open leads will be more detailed in order to calibrate these models. See the Instream Flow Study (RSP Section 8.5) for criteria and potential sites.

3.4. Lower River

There are currently no accepted models for predicting dynamic ice processes on complex braided channels such as those found in the Lower Susitna River downstream of Talkeetna; therefore, no hydrodynamic modeling is planned for the 100-mile reach between tidewater and the Talkeetna River (up to PRM 103.8 [RM 100]). However, there is a need to assess the potential for change to ice cover on the Lower River both for fish habitat studies and to understand the potential effects of the Project on winter transportation access and recreation, which depend on ice cover on the Lower Susitna River. Project effects to the Lower River will be based on the magnitude of change seen at the downstream boundary of the River1D model (approximately PRM 103.8 [RM 100]), the estimated contributions of frazil ice to the Lower River from the Middle River determined by observations and modeling, and with simpler steady flow models (HEC-RAS with ice cover) for short sections of interest in the Lower River (RSP Section 7.6.4.10).

4. METHODS AND VARIANCES

The observation and modeling efforts described below were used to characterize the Susitna River ice regime, identify spatial and temporal variations in ice processes, and provide information on the physical channel environment in the winter to other study disciplines. Characterizing the existing ice regime and its variability provided a basis for evaluating the impacts of the project.

4.1. Aerial Reconnaissance

Aerial reconnaissance of ice processes were performed from tidewater to the Oshetna River confluence (up to PRM 235.2 [RM 233.4]). The methods/variances are reported in Study Plan 7.6, ISR Part A, Section 4.1. No additional aerial reconnaissance work has been performed on this task since it was reported out in Study 7.6 Technical Memorandum: Detailed Ice observations October

2013- May 2014 filed in September 2014. Following the October 17, 2014 ISR meeting for the Ice Processes in the Susitna River Study, AEA requested that an alternate format be developed to graphically present the freeze-up progression and open lead survey data. These alternate visualizations are presented in Appendix A of this SIR. This task has been completed.

4.2. Time-Lapse Camera Monitoring

Time-lapse cameras were used to monitor break-up and freeze-up at locations corresponding to flow routing model instrumentation, key ice processes, and fish habitat locations. The methods/variances are reported in Study Plan 7.6, ISR Part A, Section 4.2. No work has been performed on this task since it was reported out in Study 7.6 Technical Memorandum: Detailed Ice observations October 2013 - May 2014 filed in September 2014. This task has been completed.

4.3. Ice Measurement Data

Field data were collected at several telemetered data network stations in accordance to the methods/variances reported in Study Plan 7.6, ISR Part A, Section 4.3. No work has been performed on this task since it was reported out in Study 7.6 Technical Memorandum: Detailed Ice observations October 2013 - May 2014 filed in September 2014. A modification of this task since the filing of the Study Plan 7.6, ISR in June 2014 is the continuation of this task to provide ice and snow thickness and water elevation measurements at specific locations within FA-128 for further calibration of the ice modeling efforts.

4.4. Other Field Data

The Riparian Instream Flow Study, Study Plan 8.6, ISR Part A, Section 4.4 describes the methods/variances reported in the collection of ice scar data on trees along the Middle River reach. Work continues to finalize this task of Study 8.6 and coordinate with Study 7.6 and will be reported in future TM's.

4.5. Modeling of River Ice Processes

A one dimensional model of river ice processes (River1D) and two dimensional models of select Focus Areas (River2D) continue to be developed and calibrated for the Middle River reach of the Susitna River. The methods/variances are reported in the RSP Section 7.6.4.6 through 7.6.4.9 and in Study Plan 7.6, ISR Part A, Section 4.5. Appendix B of this SIR presents the initial open water calibration of the River1D model. Appendix C of this SIR presents the open water calibration of the River2D model of FA-128 (Slough 8A). As a modification of this task, the River1D modeling of the Middle River reach will continue. River2D modeling of specific Focus Areas will also continue.

4.6. Lower River Assessment

The primary impact of Project operations on the Lower River in the winter is likely to be increased stage owing to reservoir releases in excess of natural winter discharge. An assessment of winter stages on the Lower River was conducted in accordance with the methods/variances reported in Study Plan 7.6, ISR Part A, Section 4.6. No work has been performed on this task since it was reported out in Study 7.6 ISR Part A, Section 5.5.4 and Appendix A. This task has been completed.

4.7. Review and Compilation of Existing Cold Regions Hydropower Project Operations and Effects

A review of literature describing hydropower projects in northern countries was conducted to develop a white paper describing possible effects of project operations. The methods/variances are presented in Study Plan 7.6, ISR Part A Section 4.7. This white paper was reported out as Study Plan 7.6, ISR Part C – Appendix C. This task has been completed.

5. RESULTS

Results reported out in this SIR include the alternate visualizations of the freeze-up progression maps and open lead survey information. The formulation and open water calibration of the River1D model of the Middle River and the River2D model of Focus Area 128 (Slough 8A) are also presented.

5.1. Alternate Visualizations of Freeze-up Progression and Open Lead Survey Information

Following the October 17, 2014 ISR meeting for the Ice Processes in the Susitna River Study, AEA requested that an alternate format be developed to graphically present the freeze-up progression and open lead survey data. Stakeholders requested that the information be placed in more of a map-based format rather than a graphical indication by river mile. Data from the aerial surveys and other ground-based observations were used to develop geographic information system (GIS) representations of a simplified Susitna River Corridor on a single page. Data were plotted on these base maps for the 2012 and 2013 freeze-up, as well as the open lead survey information of March 2013, February 2014, and April 2014. The maps show where the river was ice-covered, open, or open with flowing frazil ice on given observation dates. Up to three dates are provided on each map to visualize the progression of the growing cover. Location of open leads, identified as thermal leads or velocity leads were also plotted on base maps for the dates of the open lead surveys. Also, to provide a comparison to the 1980's study data, freeze-up progression maps were developed for 1980-1985 and open lead survey information from 1982-83. In addition to the series of freeze-up progression maps for each year, a figure has been produced which includes the discharge hydrograph at the USGS Gold Creek gage and air temperature record at Talkeetna for the period of October 1 through December 31 for each year. These figures include a symbol on the discharge hydrograph to designate the dates of the observations and demonstrate the changes that occur in the discharge over the freeze-up period. While the discharges and temperatures have varied over the years, it has been observed that the freeze-up progression and locations of open leads during the winter period are similar in manner and location. The locations of breakup jams and accumulations of ice in the overbank areas also follow similar patterns. The combination of the 1980's data and the field observations and data collected during the spring 2012 through spring 2014 period has provided a very complete data set for a variety of freeze-up, winter, and breakup conditions. The alternate visualizations demonstrate these similarities and ranges of natural conditions and are presented in Appendix A of this SIR.

5.2. River1D Middle River Model Development and Initial Open Water Calibration

The Middle River Reach River1D Ice Processes Model was developed for initial open-water calibration and for comparison with results from the Open-water Flow Routing Model (RSP Section 8.5). The River1D model domain included the Susitna River mainstem from the proposed dam site (PRM 187.2 [RM 184.4]) to a downstream boundary (PRM 80.0 [RM 76.1]) located approximately 20 miles downstream of the Talkeetna River confluence. Discharge and stage data for four calibration events were compiled during time periods in 2012 and 2013. These events covered a range of discharge at Gold Creek (PRM 140) from 6700 to almost 73,000 cfs, discharges that represent everything from late fall just prior to freeze-up through discharges that would result in side channel slough and lower terrace flooding. A validation event was also run for a time period during the summer of 2013. The initial open water calibration events showed the model mean relative discharge errors for the USGS gage at Gold Creek to be 0.5 to 0.9 %. The mean absolute error in water surface elevation at the various calibration points (ESS Stations) ranged from 0.1 to 1.0 feet for the calibration events. Some of the error in water surface elevation was attributed to the measuring stations (ESS and USGS gage stations) being different than the reported output for specific River1D cross sections. The River1D model development, background, and initial open water calibration are presented in Appendix B of the SIR.

5.3. River2D Model Development and Open Water Calibration for Focus Area 128 (Slough 8A)

River2D is a two-dimensional model used to determine water velocities, depths, and the effects of a laterally stationary but vertically varying ice cover. The model can be run in either steady or unsteady flow conditions. A River2D model was developed for Focus Area 128 (Slough 8A), an important spawning and rearing area in the Susitna River. The model was calibrated to open water conditions based on field data of water velocities, discharge, and water elevation collected during June and July 2013. The FA-128 (Slough 8A) River2D model was shown to perform very well with three goodness of fit parameters describing the model performance. The RMSE (Root-Mean-Square Error) ranged from 0.2 - 0.5 feet for all calibration runs. The theory and basis of the River2D modeling, development of the FA-128 model and calibration to open water conditions are presented in Appendix C of the SIR.

6. DISCUSSION

The overall goal of the Ice Processes in the Susitna River Study (Study 7.6) is to understand existing ice processes in the Susitna River and to develop tools in order to predict post-Project ice processes. Data collection and observations of the ice processes during freeze-up, mid-winter, and breakup from spring 2012 through May 2014 have provided insights into the mechanisms of frazil and anchor ice production, ice transport, shore ice growth, water elevation changes as the ice cover progresses through an area, discharge variations and their effects during winter, and the breakup process. Observations of the ice processes include aerial surveys, ground-based time-lapse camera images, georeferenced photo and video images, measurements of ice thickness, and discharge. In addition to the wealth of data that can be found at http://gis.suhydro.org/SIR/07-Hydrology/7.6-

Ice/ several of the other studies also collected data that supported the ice studies. This included the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6), Groundwater Study (7.5), Instream Flow Studies (Studies 8.5-8.6), Fish and Aquatics Study (Studies 9.12), and the Riparian Vegetation Study Downstream of the Proposed Susitna-Watana Dam (Study 11.6). The remote camera images and data recorded by the Susitna-Watana Hydroelectric Data Network system (Instream Flow Studies) were particularly useful in determining ice conditions between aerial surveys and for water level changes due to the presence or movement of the ice cover.

Another source of data on ice processes is the wealth of information compiled during the 1980's studies of the project area. Freeze-up cover progression for those years is presented alongside the 2012 and 2013 freeze-up progression in Appendix A of this report. The two sets of data are complimentary with similar bridging locations, timing of the cover formation, and the occurrence and location of open leads (both thermal and velocity). While there are variations from year to year due to changes in discharge, air temperatures, and the severity and duration of cold spells, the processes are fairly uniform. This compilation of data on ice processes has allowed an assessment of the baseline conditions in the Susitna River and how year to year variations impact water levels, extent and duration of the ice cover and the wide range of conditions during the breakup period. This understanding of the effects of variations will guide the River1D ice modeling efforts in both reproducing the existing conditions (present and historic) as well as predicting the effects of post-Project operations. The following general statements can be made concerning the existing ice processes on the Susitna River:

- Floating frazil ice first appears in the Middle and Lower Susitna River about the time that the average daily air temperature reaches freezing at Talkeetna.
- The discharge at the USGS Gold Creek gage drops to 5,000 cfs or below by late October or early November each year. A short time later, the ice cover bridges at the mouth of the Susitna River and begins to progress upstream.
- The ice cover progresses steadily upstream and reaches Talkeetna in early to late November, though it has reached Talkeetna as early as late October in very cold years and as late as January in warmer years.
- The discharge continues to fall throughout the freeze-up period, reaching 1,500-2,500 cfs by the end of December.
- As the ice cover progresses through an area, the stage (water elevation) increases by 3-8 feet due to the resistance to flow by the newly formed cover.
- The ice cover continues to progress upstream, reaching Gold Creek (PRM 140) by early to mid-December.
- Additional cover bridging points exist within Devils Canyon (PRM 153-164) and near the Dam site (PRM187.2).
- During mid to late winter, the discharge is at its lowest and the ice cover elevation and water level are noticeably decreased.
- Both velocity and thermal open leads persist at many locations throughout the winter.

- Breakup can occur as early as late April and as late as the end of May and varies widely from year to year in terms of severity. Even in mild breakup years, there can be limited areas that experience jamming and overbank flooding. Severe years can experience massive jams, extensive flooding and damage to riparian vegetation as well as the ARRC tracks between Talkeetna and Gold Creek.

The River1D modeling to date has shown that the model is capable of reproducing the stage and discharge for a wide range of unsteady events during open water conditions. As presented in Appendix B of this report, the open water calibration and validation shows that the model provides results well within the 1 foot tolerance for an unsteady one dimensional model. The preliminary water temperature modeling has shown that the River1D model is very capable at predicting water temperature cool down. The River2D model has been used to predict water elevations and velocities in two dimensions. The development of a model for Focus Area 128 (Slough 8A) and its open water calibration is presented in Appendix C. Both of these models will be used to assess the impacts of changes in winter discharge rates on the ice processes in the Middle River and to provide important winter conditions data to many other studies.

7. CONCLUSION

As presented in the various filings, the Ice Processes in the Susitna River Study has completed many of the tasks established in Section 7.6 of the Revised Study Plan (RSP). Specifically:

- Documentation of the timing, progression, and physical processes of freeze-up and break-up during 2012–2014 between tidewater and the Oshetna River confluence (PRM 235.2 [RM 233.4]), using historical data, aerial reconnaissance, stationary time-lapse cameras, and physical evidence has been completed and reported out in Study Plan 7.6, ISR filed in June 2014, the Study 7.6 Technical Memorandum: Detailed Ice observations October 2013 - May 2014 filed in September 2014, and this SIR.
- A white paper that investigated large river ice processes relevant to the Susitna River, analytical methods that have been used to assess impacts of projects on ice-covered rivers, and the known effects of existing hydropower operations in cold climates was completed and reported out in the ISR.
- An assessment of the Lower River was conducted using HEC-RAS to evaluate the effects of changes in winter discharge on the water surface elevation as reported out in the ISR.
- Observational data of existing ice processes were provided to several studies (Study 6.6, 7.5, 8.5-8.6, 9.12, 11.6, 12.5-12.7, and 15.7).
- A River1D model of the Middle River reach was developed and calibrated for open water conditions as reported out in this SIR.
- A River2D model of Focus Area 128 (Slough 8A) was developed and calibrated for open water conditions as reported out in the SIR.

Tasks that remain to be completed in order to meet the study objectives include:

- Calibration of the River1D model of the Middle River reach for ice-covered conditions. The calibrated model will be used to develop pre-project and with-project conditions (ILF-1) of ice cover extent, water levels and velocities throughout the Middle River reach specifically for 1976 (cold year), 1981 (warm year), and 1985 (average year). Additional historic and/or operational scenarios will be modeled as needed.
- Using the results of the River1D modeling, develop ice-covered models of Focus Area 128 (Slough 8A) and other focus areas as required. Field measurements of ice thickness, snow depth, and water surface elevation will be collected at Focus Area 128 to facilitate model calibration.
- Conduct a model accuracy and error analysis arising from 1) simplifying assumptions in the governing equations, 2) interpolation between measured points, and 3) error in measuring input data.
- Provide modeling results to be used as input to various other Studies modeling efforts as required.

8. LITERATURE CITED

AEA (Alaska Energy Authority). 2012. Revised Study Plan (RSP): Susitna-Watana Hydroelectric Project FERC Project No. 14241. Prepared for the Federal Energy Regulatory Commission by the Alaska Energy Authority, Anchorage. December 2012.