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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

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

HDR Alaska, Inc.

February 2014 Draft

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APPENDICES

Appendix A: Detailed Ice Observations and Lower River HEC-RAS Modeling

Appendix B: 2013 Ice Field Measurements

LIST OF ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

Abbreviation	Definition
AEA	Alaska Energy Authority
anchor ice	Submerged ice attached or anchored to the bottom, irrespective of the nature of its formation. Often accumulates as frazil slush in open reaches.
APA	Alaska Power Authority
FERC	Federal Energy Regulatory Commission
frazil ice	Fine spicules, plates, or discoids of ice suspended in water. In rivers and lakes it is formed in supercooled, turbulent waters.
GIS	Geographic Information System
ILP	Integrated Licensing Process
ISR	Initial Study Report
LB	Left Bank
NEPA	National Environmental Policy Act
PAD	Pre-Application Document
PRM	Project River Mile
Project	Susitna-Watana Hydroelectric Project
RB	Right Bank
RM	River Mile(s) referencing those of the 1980s APA Project.
RSP	Revised Study Plan
USACE	United States. Army Corps of Engineers
USGS	United States Geological Survey

EXECUTIVE SUMMARY

Ice Processes 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 is currently in its second year of collecting freeze-up observations. Data collection will continue through ice break-up 2014. Numerical modeling of the Middle Susitna River has begun for existing conditions. A draft white paper reviewing other cold region hydroelectric projects and their effects on the ice regime has been produced.
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	As explained in the cover letter to this draft ISR, AEA’s plan for completing this study will be included in the final ISR filed with FERC on June 3, 2014.

Ice Processes Study 7.6	
Highlighted Results and Achievements	The Ice Processes in the Susitna River Study (Study 7.6) has documented two break-up seasons (2012 and 2013) and one freeze-up (2012) finding that the 2012 break-up was 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.

1. INTRODUCTION

On December 14, 2012, Alaska Energy Authority (AEA) filed with the Federal Energy Regulatory Commission (FERC or Commission) its Revised Study Plan (RSP), which included 58 individual study plans (AEA 2012). Included within the RSP was the Ice Processes in the Susitna River Study, Section 7.6. RSP Section 7.6 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.

On February 1, 2013, FERC staff issued its study determination (February 1 SPD) for 44 of the 58 studies, approving 31 studies as filed and 13 with modifications. On April 1, 2013, FERC issued its study determination (April 1 SPD) for the remaining 14 studies, approving 1 study as filed and 13 with modifications. RSP Section 7.6 was one of the 13 approved with modifications. In its April 1 SPD, FERC recommended the following:

Literature Review

- We *recommend* that AEA include relevant international and non-hydro sites in the literature review.

Open Water Lead Data Collection

- We recommend that AEA conduct one additional reconnaissance flight in January to document open leads at the same time as the field data collection to document freeze-up conditions.

Border Ice and Frazil Ice Assessment

- We recommend that AEA perform the analysis requested by NMFS, FWS and CSDA using updated versions of the proposed models (River1D and River2D) or a different model such as the CRISSP-2D model, if the proposed versions of the models are not capable of producing information to support border ice and frazil ice analyses. The one-dimensional model was not released to the public domain on January 1, 2013, as stated in the study plan; therefore, we cannot identify if there would be much additional effort or cost compared to what is proposed.

Operational Scenario Evaluation

- We recommend that the analysis include an evaluation of natural conditions, as well as a range of alternatives with the dam in place, including maximum load-following, run-of-river, base load, and any other reasonable operating scenarios, to assess project effects. Because the natural condition model would already exist, we expect that these costs would be minimal.

In accordance with the April 1 SPD, AEA has applied the FERC-requested modifications throughout the implementation of the Ice Processes in the Susitna River Study (Study 7.6).

Following the first study season, FERC's regulations for the Integrated Licensing Process (ILP) require AEA to "prepare and file with the Commission an initial study report describing its 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)). This Initial Study Report (ISR) on Ice Processes in the Susitna River Study (Study 7.6) has been prepared in accordance with FERC's ILP regulations and details AEA's status in implementing the study, as set forth in the FERC-approved RSP as modified by FERC's April 1 SPD (collectively referred to herein as the "Study Plan").

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]).

Study Goals and Objectives

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 IN 2013

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. Some of the information (aerial reconnaissance and transect data) is similar to information collected in the 1980s. Collecting the same observations over a period of years helped to define the year-to-year variability in the ice regime. Characterizing the existing ice regime and its variability provided a basis for evaluating the impacts of the project.

4.1. Aerial Reconnaissance

Aerial reconnaissance and global positioning system (GPS) mapping of ice features, including ice jams, ice bridges, frazil accumulations, and open leads during the break-up and freeze-up periods were performed from tidewater to the Oshetna River confluence (up to PRM 235.2 [RM 233.4]). The number of observations varied from year to year depending on ice process conditions, but it was anticipated that approximately 10 reconnaissance trips during spring break-up and 15 reconnaissance trips during winter freeze-up in 2012 and 2013 were necessary. The data collected included concentrations of frazil ice, locations of ice features and open leads, timing of ice-cover progression, geo-referenced photographs, and videos of ice processes. Ice processes field observation standards followed those of EM-1110-2-1612, Ice Engineering, developed by (USACE 2002) and (Michel 1971). Aerial reconnaissance included observations of the main Susitna River, and mouths of major tributaries including the Yentna, Chulitna, and Talkeetna rivers. Open leads were systematically mapped and classified as thermal or velocity in origin in March of each study year.

4.1.1. Variances from Study Plan

No variances from the methods described in this component of the Study Plan occurred in the 2013 study season.

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. Time-lapse cameras were set to take photos of the main channel or provide views of side sloughs at 1-hour intervals, with the results compiled into a video. Key information derived from the time-lapse videos included the timing of ice cover advance and decay past the camera location, the relative abundance of frazil ice visible in the channel during freeze-up, the growth of border ice from the shore during freeze-up, and the local interaction of ice with the floodplain. The selection of camera locations were refined if aerial observations indicated other more important locations (jamming locations). The locations of the time-lapse cameras for 2012 were as follows:

- PRM 13.9 (RM 9.5) – Alexander Slough
- PRM 29.7 (RM 25.6) – Susitna Station
- PRM 63.3 (RM 59) – Rustic Wilderness Side Channel
- PRM 91.7 (RM 88.2) – Birch Creek Slough
- PRM 102.7 (RM 99) – Slough 1 (2012 break-up only)
- PRM 105.4 (RM 101.5) –FA-104 (Whiskers Slough) (2012 freeze-up)
- PRM 106.8 (RM 103) – Talkeetna Station
- PRM 124.4 (RM 121) – Curry Slough
- PRM 132.4 (RM 129) – Slough 9
- PRM 144.4 (RM 141) – FA-144 (Slough 21)
- PRM 152.5 (RM 149) – FA-151 (Portage Creek)
- PRM 186.8 (RM 184) – FA-184 (Watana Dam)

Camera locations for 2013–2014 included the following:

- PRM 13.9 (RM 9.5) – Alexander Slough
- PRM 29.7 (RM 25.6) – Susitna Station
- PRM 64.2 (RM 60) – Rustic Wilderness Side Channel
- PRM 65.2 (RM 60.8) – Susitna Landing (2013 freeze-up)
- PRM 91.7 (RM 88.2) – Birch Creek
- PRM 104.9 (RM 101) – FA-104 (Whiskers Slough)
- PRM 113.2 (RM 109.6) – FA-115 (Slough 6A, Downstream) (2013 freeze-up)
- PRM 115.5 (RM 112) – FA-115 (Slough 6A, Upstream) (2013 freeze-up)
- PRM 127.9 (RM 124) – FA-128 (Slough 8A)
- PRM 132.4 (RM 129) – Slough 9
- PRM 138.3 (RM 135) – FA-138 (Gold Creek)
- PRM 141.4 (RM 138) – FA-141 (Indian River) (2013 freeze-up)
- PRM 144.4 (RM 141) – FA-144 (Slough 21)

Additional telemetered time-lapse cameras were located on the Susitna River and installed in 2012 by the Fish and Aquatics Instream Flow Study (Study 8.5). The network system includes a naming convention that serves to identify station locations and the primary purpose of the station. The convention is of the form: $EX_1X_2X_3$ where E represents Alaska **E**nergy Authority, X_1 indicates the river drainage (S = Susitna, C = Chulitna, T = Talkeetna), X_2 is the primary station purpose (B = base station; C = camera station; F = Pit tag array; G = groundwater station; M = meteorological station; R = repeater station; and S = surface water station), and X_3 = station sequence number, or specific Focus Area number and PRM (e.g., FA104). For example, station ESS80 represents Alaska Energy Authority station on the **S**usitna River for **S**urface water and is station 80. The Ice Processes in the Susitna River Study (Study 7.6) utilized the telemetered data and time-lapse images during both the 2012 and 2013 study period at the following sites:

- PRM 15.8 (RM 11) – Susitna River near Flathorn Lake (ESS10)
- PRM 17.7 (RM 13) – Susitna River near Dinglishna Hill (ESS15)
- PRM 30.1 (RM 26) – Susitna River at Susitna Station (ESS20)

- PRM 99.4 (RM 96) – Susitna River near Twister Creek (ESS30)
- PRM 101.8 (RM 98) – Susitna River near Chulitna River (ESS35)
- PRM 106.8 (RM 103) – Susitna River above Whiskers Creek (ESS40)
- PRM 116.7 (RM 113) – Susitna River below Lane Creek (ESS45)
- PRM 124.4 (RM 121) – Susitna River at Curry (ESS50)
- PRM 152.5 (RM 149) – Susitna River below Portage Creek (ESS55)
- PRM 168.3 (RM 165) – Susitna River near Devil Creek (ESS60)
- PRM 179.2 (RM 176.5) – Susitna River near Fog Creek (ESS65)
- PRM 186.8 (RM 184) – Susitna River below Deadman Creek (ESS70)
- PRM 224.8 (RM 223) – Susitna Gage near Cantwell (now ESS80)

And by the USGS at the following stations for both 2012 and 2013 study periods:

- PRM 184.7 (RM 182) – 15291700 (Susitna River Above Tsusena Creek)
- PRM 140.4 (RM 137) – 1529200 (Susitna River at Gold Creek)
- PRM 88 (RM 84) – 15292780 (Susitna River at Sunshine Station)
- 15292400 (Chulitna River near Talkeetna)
- 15292780 (Talkeetna River near Talkeetna)

In order to calibrate a border ice growth formulation for the River1D model, an additional time-lapse camera was placed in the Middle River during Fall 2013. The image was calibrated with an object of known length so that border ice width could be directly measured from the images. The camera was placed close to one of the Fish and Aquatics Instream Flow Study (Study 8.5) ESS stations so that ice growth measured in the image could be directly related to the air and water temperatures measured at the site. Surface velocity estimates at the location allowed calibration of the border ice formula used in River1D modeling.

4.2.1. Variances from Study Plan

The camera at PRM 63.3 (RM 59), Rustic Wilderness Side Channel, was left in place for 2013-2014 combined with the new camera location at PRM 65 (RM 60.5), Susitna Landing; the cameras provided a nearly full coverage of the entire active Susitna River width important in assessing surface ice concentrations and ice cover progression.

The camera at PRM 91.4 (RM 88), Birch Creek Slough, was moved slightly downstream to provide an improved upstream view of the main flow channel and the mouth of Birch Creek Slough.

There were two cameras installed at FA-104 (Whiskers Slough), PRM 104.9 (RM 101); one on the left bank (LB) of the main channel and one on the right bank (RB) of the side channel. The RB side channel camera was relocated in October 2013 to a downstream island (PRM 104.2) to provide a view of a bridging and jamming location. The Groundwater Study (Study 7.5) installed time-lapse cameras at several locations in FA-104 in 2013 and these locations were coordinated with the Ice Processes in the Susitna River Study (Study 7.6) to maintain views previously covered by the camera that was relocated to PRM 104.2.

The cameras located at Slough 9 (PRM 132.4 [RM 129]) and FA-184 (Watana Dam), PRM 186.8 (RM 184), were destroyed during break-up ice jamming events in May 2013. A new camera was installed in October 2013 at Slough 9 slightly downstream on the LB to maintain visual coverage of this known ice jamming location. Lack of land access prevented proposed camera installations at the mouth of Portage Creek and at FA-184 (Watana Dam).

Following the 2012 freeze-up, all cameras were set to take photos at 15-minute intervals rather than the 1-hour interval stated above in order to provide a more accurate timing of ice cover front progression, changes in water level, and freeze-up and break-up jamming.

Rather than installing a single additional camera to track border ice growth, existing telemetered cameras at the Fish and Aquatics Instream Flow Study's (Study 8.5) ESS stations were utilized to more accurately assess shore ice growth. A calibrated scale was created and used at three of the ESS stations: ESS40 at PRM 106.8 (RM 103) above FA-104 (Whiskers Slough), ESS45 at PRM 116.5 (RM 113) near FA-115 (Slough 6A), and ESS50 at PRM 124.4 (RM 121) near Curry. This was accomplished by recording images at each site that included an object of known length at a measured distance from the camera.

4.3. Ice Measurement Data

Field data were collected in January and March 2013 at 9 of the 13 telemetered data network stations installed by the Fish and Aquatics Instream Flow Study (RSP Section 8.5) as listed above in Section 4.2. Data were collected at ESS20, and all stations between and including ESS35-ESS70. These transect data were used to calibrate the existing condition ice processes model. The following data were collected in conjunction with the Fish and Aquatics Instream Flow Study (RSP Section 8.5):

- Ice thickness, including total and submerged ice thicknesses and slush ice thickness (January and March) using drill or auger and plunge pole.
- Top-of-ice elevation (January and March) using standard survey techniques and established benchmarks.
- Air temperature (continuously).
- Water temperature (continuously where sensors survive freeze-up).
- Water stage (continuously where sensors survive freeze-up, January and March otherwise) using pressure transducers.
- Discharge (January and March) and under-ice velocity profiles using a current meter at ESS20, ESS40, and ESS55.
- Thickness of snow cover (January and March).

In addition to the ice measurement data collected at the telemetered data network stations listed above, a winter field data collection program was established at each Focus Area in consultation and coordination with the Fish and Aquatics Instream Flow (Study 8.5), Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6), Riparian Instream Flow Study (Study 8.6), and Groundwater Study (Study 7.5). Winter data will be collected at Focus Areas in 2014 including ice thicknesses, snow, ice, water, and bed elevations, water depths, and discharge measurements at flow splits sufficient to characterize the ice cover and calibrate a detailed model of the short reach. Freeze-up timing and processes, border ice encroachment, the presence of open leads, and historical ice jam processes will be characterized for each site in order to further understand how winter conditions affect fish habitat and geomorphology.

4.3.1. Variances from Study Plan

During the January and March 2013 field data collection efforts, two separate teams were utilized which resulted in slightly different techniques, equipment utilized for measurements, and figures of results. During the coordination of the Focus Area winter field data collection program for 2014, it was decided that the use of a single team for ice measurement data for 2014 would increase efficiency, guarantee uniformity of techniques and equipment, and provide for a uniform display of data and results.

4.4. Other Field Data

The Riparian Instream Flow Study (Study 8.6) collected field data on ice interactions with floodplains and vegetation, including tree scars and floodplain disturbance by ice. These data indicated locations where ice events have been significant. The results of the Riparian Instream Flow Study (Study 8.6) were used to delineate reaches of the river where ice processes, primarily break-up jams, have occurred in the past. The Riparian Instream Flow Study (Study 8.6) used these data to develop a model of riparian–floodplain interactions, while the Ice Processes Study used these data to supplement historical observations of ice jams and guide locations for specific observations.

4.4.1. Variances from Study Plan

No variances from the methods described in this component of the Study Plan occurred in the 2013 study season.

4.5. River1D Ice Processes Model Development for Existing Conditions

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 [RM 100]) and the proposed dam site (PRM 186.8 [RM184]). River1D 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 model has been developed by the University of Alberta River Ice Engineering Program (Hicks 2005; Andrishak and Hicks 2005a). Updated code was released to the public domain on January 1, 2013.

The River1D Ice Processes Model of the Middle Susitna River will be used to simulate time-variable flow routing, heat-flux processes, seasonal water temperature variation, frazil ice development, ice transport processes, border ice growth, and ice-cover progression and decay. 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. The model will also be used to provide boundary conditions to more detailed River2D Focus Area Ice Models embedded in the reach. Inputs to the existing condition model included the following:

- Surveyed river geometry as presented in the Open Water Flow Routing Model from the Fish and Aquatics Instream Flow Study (Study 8.5)
- Discharge as measured by gages along the modeled reach
- Air temperature and solar radiation from meteorological stations
- Water temperature along the river and tributaries from the Baseline Water Quality Study (Study 5.5)
- Boundary conditions for ice-cover progression (bridging locations and ice concentrations)
- Calibration data for border ice equations, including daily border ice width at a representative location.

The model will be verified using ice thickness and elevation measurements at Flow Routing Transects, and observed timing of ice-cover progression and decay. Data from the 1980s will also be used to verify the model for differing climate conditions. The existing conditions model will be updated with 2013 and 2014 data when new survey information is available in order to improve model accuracy.

4.5.1. Variances from Study Plan

The river geometry from the Fish and Aquatics Instream Flow Study (Study 8.5) Open Water Flow Routing Model included some modifications to match water elevations around islands. These modifications would result in changes in ice thickness for the River1D model at these cross sections and were deemed not appropriate for the ice modeling effort. Therefore, the Open Water Flow Routing Model cross sections were revised back to the original surveyed cross-section data.

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. Increased stage was modeled where transect data existed. Transect data exist at Susitna Station at PRM 30.1 (RM 26), PRM 44.2 (RM 40), PRM 53.1 (RM 48), PRM 64.2 (RM 60), (R&M 1985) and between PRM 79 (RM 75) and PRM 103.8 (RM 100) (from the Fish and Aquatics Instream Flow Study (Study 8.5))),. Projected maximum monthly discharge from the preliminary reservoir operations model was modeled with a range of ice thicknesses based on historical measurements. The potential for ice-cover delay in the Lower River was assessed based on the estimated contributions of frazil ice to the Lower River from the Middle River using observations and model output.

4.6.1. Variances from Study Plan

Since no River1D Ice Processes Model output (contribution of frazil ice from the Middle River) was available to assess ice-cover delay in the Lower River, this task focused on the changes in water surface elevation expected due to reservoir releases in excess of natural winter discharge. A delay of the ice cover formation in the Lower River would correspond to the seasonal drop in discharge over the freeze-up period, resulting in lower water levels at ice cover establishment.

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

Hydropower projects in northern countries, especially in Canada, have operated on ice-covered rivers for many decades (National Research Council of Canada 1990). Other river systems where ice modeling has been completed include:

- Peace River, Canada (Andrishak and Hicks 2005b; Andrishak and Hicks 2008; Hicks and Steffler 1992; She et al. 2012)
- Athabasca River, Canada (Katopodis and Ghamry 2005)
- Ohio River, USA (Shen et al. 1991)
- St. Clair River, USA (Kolerski and Shen 2010)
- Romaine River, Canada (Thériault et al. 2010)

The product of this portion of the study was a memorandum that summarized the following:

- Ice processes on the Susitna River as they relate to impacts of the Project on fish habitat and other resources.
- The impacts of hydropower or similar development projects on river ice processes in other northern countries.
- Methods of analysis and modeling used to assess impacts to ice processes and fish habitat in other systems, and a discussion of how these methods may be applicable to the Susitna River.

Relevant references were summarized and study authors contacted to obtain additional information relevant to the Susitna River.

4.7.1. Variances from Study Plan

No variances from the methods described in this component of the Study Plan occurred in the 2013 study season.

5. RESULTS

Results include all field and modeling efforts conducted from the March 2012 open lead mapping, through the October 2013 time-lapse camera maintenance and installation events. Observation and data collected are described below; data tables and narrations are included in Appendix A and Appendix B.

5.1. Break-up Observations

Break-up observations included aerial reconnaissance flights, time-lapse camera observations, and post-break-up ground reconnaissance at time-lapse camera locations.

5.1.1. 2012 Break-up Observations

Break-up 2012 was observed via 8 aerial reconnaissance flights and 14 time-lapse cameras along the study reaches. The reconnaissance flights occurred between April 19 and May 10.

The time-lapse cameras were installed prior to break-up on April 5 and 11, 2012, and pictures retrieved May 9, 2012, after break-up. The break-up summaries for each camera location are included in Appendix A.

Break-up on the Susitna River was slow and uneventful in 2012. Snowpack was 138% of normal in the Susitna Basin on April 1, but intermittent above-freezing temperatures in April and cool temperatures in May caused the snowpack to melt slowly. As a result, the river ice weakened and decayed in place before river discharges increased enough to mechanically break up the ice cover. When break-up did occur, the remaining ice was too weak to form large jams. Ice and water stayed within the channel except in a few places in the Middle River.

Lower River Observations

Between April 11 and April 19, open leads on the Lower River gradually widened. Ice began to break off the edges of open leads and accumulate against the solid ice cover on April 19 between PRM 58 (RM 53) and PRM 100 (RM 97). Leads continued to widen until ice runs began on April 25. Intermittent ice runs continued until May 6, when the Lower River was generally ice free.

The largest ice jam occurred near PRM 66 (RM 62) on April 30. Much of the main channel was jammed, forcing water overbank and into a short side channel on the left bank This was the largest instance of overbank flooding seen in the Lower River during the 2012 break-up.

Middle River Observations

Ice began moving and jamming in the Middle River between April 11 and April 19. On April 11, observers noted that open leads were widening and open water began appearing in Portage Creek (PRM 151.4 [RM 148]) and Fog Creek (PRM 165.3[RM 162]). On April 19, numerous small jams were observed from PRM 137.5 (RM 134) to PRM 162.7 (RM 159). Downstream of PRM 137.5 (RM 134), open leads remained narrow but lengthened. Upstream of PRM 162.7 (RM 159), the open leads had widened.

By April 23, snow had melted from the banks and bars, and open sections of river had increased. Small ice jams within open leads were observed between Slough 8 (PRM 130.6 [RM 127]) and the mouth of Devils Canyon (PRM 153.5 [RM 150]).

From April 27 to May 4, most of the ice jam activity occurred in the mainstem and side sloughs in the Middle River between PRM 124.4 (RM 121) and PRM 139.4 (RM 136). Below PRM 124.4 (RM 121), the river opened up gradually as open leads widened, but few jams were observed. By May 9, the Middle River was largely ice-free.

The largest jams with the greatest potential to affect vegetation, geomorphology, and fish habitat were near Sloughs 8, 9, and 11. Near PRM 137.5-139.4 (RM 134-136), a large ice jam occupied the main channel and right bank side channel from April 27 to May 2 (Figure 5.1.1-1). While the jam held, water was forced overbank into Slough 11 (PRM 138.7 [RM 135.3]). After the jam released, ice was observed overbank and in the riparian vegetation at PRM 139.2 (RM 135.8) on May 2, 2012. Neither scouring of the banks nor scarring of vegetation was observed following the jam release.

On May 2 a large jam was documented in the mainstem from PRM 130 (RM 126.4) to PRM 133.4 (RM 130.2), including Slough 8 and Slough 9. By May 4 the jam collapsed to span from PRM 131.6 (RM 128.2) to PRM 133.3 (RM 130.1). Following the release of this jam, ice floes were observed in the trees upstream of Slough 8A from PRM 130.2 (RM 126.6) to 131.2 (RM 127.8). The build-up and release of this jam is also documented on the Slough 9 time-lapse camera (PRM 132.4 [RM129]). Again, post-break-up reconnaissance did not document significant scour or vegetation scars resulting from this jam release.

Upper River Observations

Break-up commenced on the Upper River between April 11 and April 19. On April 19, two small ice jams were observed near PRM 222.9 (Figure 5.1.1-2). Ice jam activity had subsided by May 4, and the Upper River main channel was ice-free with stranded ice on the banks and bars by May 9. Especially large slabs of stranded ice were observed downstream of Vee Canyon at PRM 198.7 (RM 196), and at PRM 222.9 (RM 221) (Figure 5.1.1-3).

Despite the presence of ice jams, both ice and water generally remained below the vegetated bank throughout the break-up observation period. Exceptions to this were found just upstream of the dam site (PRM 186.8 [RM 184]), where water and ice flows severely undercut an island, uprooting several trees, and an ice slab bulldozed the elevated point of the island. There were no other observed ice-vegetation interactions or recent ice scouring.

5.1.2. 2013 Break-up Observations

Break-up 2013 was observed via 11 aerial reconnaissance flights and 14 time-lapse cameras along the study reaches. The break-up summaries for each camera location are included in Appendix A.

Break-up in 2013 was notable for being unusually late across Southcentral and Interior Alaska. Sustained record cold weather in April and May prevented substantial snowmelt or ice decay until late May, several weeks after break-up is typically over in the region. The April snowpack was 106% and 99% of normal in the Upper and Lower Susitna Basin, respectively, and in May these figures grew to 118% and 182% of normal. At the end of May, temperatures increased sharply to well above average, which initiated rapid snowmelt and decay of river ice. Break-up activity was concentrated between May 25 and May 29. The severity of break-up flooding and ice jams on the Middle and Lower River appeared to be similar to previously observed years, with several large jams and floods in the Middle River, and mild jamming in the Lower River with little apparent overbank flow. The longest and thickest ice jams formed in the Upper River in 2013. Significant ice jam locations in the Lower, Middle, and Upper Susitna River during breakup 2013 are shown in Figures 5.1.2-1, 5.1.2-2, and 5.1.2-3, respectively.

Lower River Observations

The Lower River showed signs of snowmelt and minor ice decay at tidewater until May 11, when many open leads showed definite signs of widening and major tributaries such as the

Chulitna and Talkeetna rivers were more than 50% open. The first signs of ice jams were observed on May 11. Downstream of PRM 50 [RM 45.9], the river saw few ice jams and subsequently little overbank flow. The Three Rivers confluence was the most dynamic with jams forming at the mouth of the Chulitna on May 23; observers noted large ice remnants pushed upwards of 200 feet onto the bank near the Chulitna-Susitna confluence on May 25. By May 29 the Lower River was clear of ice in the main channel, with only minor shorefast ice remaining.

Middle River Observations

Ice and snow cover in the Middle River gradually deteriorated in place until May 14th. On May 15th, observers noted ice jams present at Slough 6A (PRM 115.1 [RM 111.6]), Curry Station (PRM 124.2 [RM 120.7]), Slough 8A (PRM 129.5 [RM 125.9]), PRM 130.3 (RM 126.7), Gold Creek Bridge (PRM 139.9 [RM 136.5]), near Indian River (PRM 143.2 [RM 139.7]) and at the mouth of Devils Canyon (PRM 153.7 [RM 150.1]). By May 25 many ice jams were observed with the largest jams causing flooding in many sloughs including ice floes overtopping the bank at Whiskers Slough (PRM 105 [101.1]) (Figure 5.1.2-4) and Slough 9 (PRM 132.6 [RM 129.2]). Slough 8A, Slough 11 (PRM 136.6 [RM 133.2]), and Slough 21 (PRM 144.3 [RM 140.9]) had ice flowing into the side channels but remaining within the sloughs.

Upper River Observations

Little to no change was observed during the observation flights until May 23. At this time observers noted many tributaries beginning to open in addition to ice and snow cover decay on the main channel. By May 25, ice cover from the dam site upstream to Kosina Creek remained but was highly broken and jumbled with a large ice jam near Vee Canyon. Between May 26 and May 29, the main channel had mostly cleared all ice except for large ice shelves and stranded ice in side channels and along the shore.

5.2. Freeze-up

Freeze-up observations included aerial reconnaissance flights and time-lapse camera observations to capture ice front progression and freeze-up characteristics. The freeze-up summaries for each camera location are included in Appendix A.

5.2.1. 2012 Freeze-up

Freeze-up camera installation/preparation included the replacement of two cameras, one at Alexander Slough (PRM 13.9 [RM 9.5]) and one at FA-184 Watana Dam (PRM 186.8 [RM 184]) lost to bank erosion, probably during the September 2012 floods. One camera at Rustic Wilderness (PRM 63.3 [RM 59]) was moved to face the main channel, and one camera was removed from this location. Additional cameras were placed in FA-104 at PRM 106.8 (RM 103) on the left bank and at PRM 105 (RM 101.1) on the right bank; at FA-128 Slough 8A (PRM 129.6 [RM 126]); and at Slough 11 (PRM 136.6 [RM 133.2]). Other cameras were maintained by changing batteries and memory cards, and ensuring an unobstructed view.

Time-lapse cameras began recording prior to first frazil ice present in the river except for a few sites, noted below. Time-lapse photos were retrieved between January 13 and 18 after freeze-up was complete. Key observations from these cameras are summarized below. At some sites there were temperature and stage recorders and pertinent information from these instruments was also noted.

Freeze-up in 2012 was characterized by higher than average flows during early ice formation at the beginning of October, dropping to average winter flows by early November. Temperatures were average in November, and slightly warmer than average in December and January. Overall, freeze-up was characterized by ice progression from downstream to upstream with few significant events. General observations were as follows:

- Frazil flow began in the Upper Susitna River in early October.
- Based on visual observation, the greatest frazil contributors to the Lower Susitna River were the Upper Susitna and Yentna Rivers.
- The earliest ice bridges were short, thick frazil ice bridges in Devils Canyon, which did not progress upstream.
- Ice cover was initiated by bridging in the lowest 5 miles of the Susitna River.
- Ice cover progression advanced rapidly to the Yentna confluence, and slowed as it advanced upstream.

Freeze-up commenced in the study area around October 12. This was the date upon which frazil ice was first recorded at the ESS80 camera at PRM 224.8 (RM 223). By October 16, frazil ice was flowing past Talkeetna (Figure 5.2.1-1). Between October 17 and October 22, two long ice bridges formed in Devils Canyon, with one short bridge in between (Figure 5.2.1-2). A short ice bridge also formed just upstream of the dam site at PRM 189.2 (RM 186.5).

On October 23, two bridges formed near the mouth of the river and the ice cover began progressing upstream via juxtaposition (frazil pans flowed downstream, hit the upstream edge of the bridge, and froze into place). Observers at PRM 15.1 (RM 9.5) noted that ice was still flowing out to Cook Inlet in the afternoon, but had slowed greatly and ice pans were pushing against each other. The tide began rising after 5:30 p.m., and the bridges likely formed as accumulating frazil pans flowing into the mouth were halted by the rising tide. Late in the evening, the pressure transducer at ESS10 (PRM 14.9 [RM 10]) recorded a sharp increase in stage of about 2.5 feet, which was likely caused by the advancing ice front. Soon thereafter, the pressure transducer at ESS15 (PRM 19.6 [RM 15]) followed suit. By the October 26 reconnaissance flight, the ice cover had progressed up to PRM 36.8 (RM 33) at a rate of nearly 12 miles per day. The rapid progression was likely aided by contributions of frazil from the Yenta River, which supplied ice to the reach below PRM 31 (RM 27). By October 29, the ice cover had extended to PRM 58.6 (RM 54), a rate of 7 miles per day. By November 1, it had reached PRM 72.4 (RM 68), also about 7 miles per day. On November 7, ice cover reached PRM 93.3 (RM 90); the rate had slowed to about 4 miles per day.

The slowing of the ice cover progression between November 1 and November 7 did not appear to have been caused by either warmer weather or blockage of frazil upstream, but by factors related to the geometry of the river channel. Talkeetna weather indicated steady temperatures. Time-lapse photos from ESS30 (PRM 98.4 [RM 95]) show fairly steady frazil concentrations between November 1 and 7. The bridges in Devils Canyon did not appear to increase in size, although a few additional short bridges formed. The slowing of the ice front was most likely due to the increased gradient of the river, which increases the hydraulic thickening of the ice cover, and thus the volume of ice necessary to allow the ice cover to progress upstream.

Staging associated with ice cover advance through PRM 93.3 (RM 90) was indicated by progressive flooding of gravel bars and side channels. Figure 5.2.1-3 and Figure 5.2.1-4 show the Parks Highway Bridge area near PRM 88 (RM 84) before and after ice cover progression through this reach.

The ice front progression and bridge locations during the 2012 freeze-up in the Lower, Middle, and Upper Susitna River are shown in Figures 5.2.1-5, 5.2.1-6, and 5.2.1-7, respectively.

5.2.2. 2013 Freeze-up

In preparation for freeze-up 2013, maintenance was performed on time-lapse cameras remaining in the field from breakup 2013 and new cameras that were installed following FERC recommendations. Cameras were located at:

- PRM 13.9 (RM 9.5) – Alexander Slough
- PRM 29.7 (RM 25.6) – Susitna Station
- PRM 64.2 (RM 60) – Rustic Wilderness
- PRM 65.2 (RM 60.8) – Susitna Landing
- PRM 91.7 (RM 88.2) – Birch Creek
- PRM 104.3 (RM 100.2) – FA-104 (Whiskers Slough)
- PRM 105.2 (RM 101.3) – Wood House
- PRM 113.2 (RM 109.6) – FA-113 (Slough 6A)
- PRM 115.4 (RM 111.9) – FA-115 (Slough 6A)
- PRM 129.6 (RM 126) – FA-128 (Slough 8A)
- PRM 132.2 (RM 142.2) – FA-144 (Slough 21)

Cameras were installed 10 to 15 feet above the ground in trees near the river to capture images of freeze-up. Cameras were mounted to trees with nylon webbing and were programmed to capture images every 15 minutes between 8:00 a.m. and 7:00 p.m.

5.3. Open Lead Mapping

Open leads were documented throughout the 234 miles of the Susitna River study area before temperatures rose above freezing. Observers classified the leads as thermal, velocity, or unknown. Leads classified as thermal in origin were generally shallow, located in areas typical of groundwater inflow (sloughs, side channels, or bank toes), and did not appear from the air to have strong current. Velocity leads were located in the main channel or substantial side channels and had visible current. Velocity leads often had broken or jumbled ice along the margins or accumulated at the downstream end. It is likely that many leads in the main channel exist because of a combination of thermal input and rapid current. R&M mapped open leads on March 2, 1983, between PRM 88.8 (RM85) and PRM 154.7 (RM 151). R&M recorded river mile at upstream end, length, width, location (main channel, side channel, or slough), and type (thermal or velocity). Detailed descriptions of the open lead mapping observations can be found in Appendix A.

5.3.1. 2012 Open Lead Mapping

Open lead mapping followed the classifications described above. Open leads up to PRM164 (RM160.6) were mapped on March 21 and March 22; PRM 162-220 (RM 158.4-217.9) was mapped on April 4.

Lower River Open Leads

Most of the open leads documented in the Lower River appeared to be thermal leads associated with upwelling through gravel bar complexes and bank toes. They were small compared with the width of the channel (less than 5%), and were shallow trickles emerging from gravel bars. Some open leads had a distinct rust color, suggesting that they drained peat or other tannic material. There were approximately the same concentration of open leads in side channels and sloughs as there were in the main channel. The longest main channel open leads occurred near the town of Talkeetna, around PRM 100.3 (RM 97).

Middle River Open Leads

Open leads were more frequent in the Middle River than in the Lower River, both in the main channel and in sloughs. In 2012, velocity leads continued up to the confluence of Devil Creek at PRM 166.1 (RM 163) in 2012. Upstream of this confluence, the river gradient decreases, and the open leads were a mix of thermal and velocity-derived. Thermal leads occurred more often in side channels and along gravel bar complexes, while velocity leads occurred near bedrock outcrops and sharp bends.

Upper River Open Leads

The Upper River had fewer open leads in general than the Middle and Lower rivers. Short thermal leads were documented in side channels and gravel bar complexes, and velocity leads were documented between Vee Canyon (PRM 222.9 [RM 221]) and the Oshetna River (PRM 235.5 [RM 234]). Open leads were also documented at tributary mouths, including the mouths of Watana Creek, Kosina Creek, Jay Creek, and the Oshetna River.

5.3.2. 2013 Open Lead Mapping

The 2013 open lead mapping followed the same classifications as in 2012. Open leads up to PRM 235.2 (RM 236.7) were mapped on March 12.

Lower River Open Leads

Few open leads existed between the mouth of the Susitna River and the Yentna River confluence (PRM 0-31 [RM 0-27]), with the exception of the Alexander Slough area (PRM 15.1 [RM 9.5]), which had numerous thermal leads. There were a few short velocity leads in the main channel that had persisted since ice cover formed in October, and a few short thermal leads associated with the bank toe or side channels. The number of open leads increased around the Yentna River confluence, with several velocity leads in the main channel along the confluence area. Upstream of the confluence, through the Delta Islands reach, the left (east) main braid had numerous small thermal leads, while the right (west) main braid had numerous velocity leads and a few thermal leads at the margins of gravel bars. A long side channel on left side of the braidplain from Little Willow Creek to 197½ Mile Creek (PRM 54-64 [RM 49-59.8]) had numerous thermal leads, while the main channel braid along the right (west) bank had numerous short velocity leads. A larger velocity lead with broken ice at the downstream end occupied the main channel thalweg at PRM 81.5 (RM 77.7) near Montana Creek. Long thermal leads occurred in the Sunshine Slough complex, Birch Creek Slough complex, and Trapper Creek confluence area. The Three Rivers confluence had the greatest concentration of velocity leads in the Lower River. These were also the widest velocity leads. These leads formed shortly after freeze-up had progressed upstream of Talkeetna and slowly decreased in length over the course of the winter as frazil and anchor ice accumulated in them and temperatures remained below freezing.

Middle River Open Leads

Between the Chulitna River confluence and Devils Canyon, most thermal leads were concentrated in side sloughs and upland sloughs. FA-104 (Whiskers Slough) and Whiskers Creek confluence had extensive thermal leads present (PRM 104 [RM 100.1]), along with FA-115 (Slough 6A, PRM 115.5 [RM 112]), FA-128 (Slough 8A, PRM 127.9 [RM 124]) (Figure 5.3.2-1), Slough 9 (PRM 132.4 [RM 129]), FA-138 (Gold Creek, PRM 138.3 [RM 135]), and FA-144 (Slough 21, PRM 144.4 [RM 141]). Several tributary mouths were associated with open thermal leads downstream of the confluence, including Lane Creek (PRM 116 [RM 112.5]), Indian River, and Portage Creek. Intermittent velocity leads were present throughout the main channel downstream of Devils Canyon (Figure 5.3.2-2), and long stretches of open water over the rapids in Devils Canyon. Upstream of Devils Canyon there were a few velocity leads and thermal leads associated with the Fog Creek and Tsusena Creek confluences. Overall in the Middle River, more open leads existed downstream of Devils Canyon than upstream from the canyon.

Upper River Open Leads

The Upper River had fewer open leads than the middle or lower segments. Multiple velocity leads were present just downstream of Deadman Creek (PRM 189 [RM 186.2]), in Vee Canyon (PRM 226 [RM 224.5]), and around the Oshetna River confluence (PRM 235 [RM 233.4]). Thermal leads were mainly associated with creek confluences, as it is likely that leads in these areas originated both from turbulent flow and thermal input associated with tributary deltas. Seeps along the river were apparent, but instead of thermal leads, they appeared as large icings just above river level.

5.4. Ice Measurement Data

Ice thickness, top-of-ice elevations, and thickness of snow cover data were collected in January and March 2013 by Ice Processes in the Susitna River Study (Study 7.6) field teams at nine transects: ESS20, ESS35, ESS40, ESS45, ESS50, ESS55, ESS60, ESS65, and ESS70. Discharge measurements were collected at ESS20, ESS40, and ESS50 in March 2013.

Measurement transects for the ice thickness and elevation surveys varied widely in character from wide, shallow channels on the Lower River and certain portions of the Middle River, to deeper channels constrained by canyon walls. Consequently, the ice thickness and its topography varied as well. ESS20 and ESS55 had a relatively flat ice surface and a water surface elevation near, or above, the ice elevation. ESS45 and ESS50 also had relatively smooth topography but showed some slumping in the surface ice over sections of the channel with the most flow. At the other transects pressure ridges and cracks along the ice surface indicate some movement within the cover. A summary of ice thickness measurements conducted in 2013 is provided in Appendix B.

In January 2013, the field team attempted to measure discharge at ESS20, Susitna Station (PRM 30.1 [RM 26]) using a Sontek M9 Acoustic Doppler Current Profiler due to depths greater than 30 feet during summer measurements at the station. They were unable to complete the measurement due to equipment malfunctions caused by temperatures around 10 degrees Fahrenheit and layers of frazil ice more than 8 feet thick beneath much of the cross-section. During the March field event the field team conducted discharge measurements at ESS20, ESS40, and ESS55 in conjunction with ice thickness and elevation measurements performed during March 2013. The field team used an extendable ice rod and found the average frazil ice thickness to be over 10 feet and as much as 27 feet in places at ESS20. Field teams from the Fish and Aquatics Instream Flow Study (Study 8.5) collected discharge measurements from April 2 through April 6. Instantaneous winter discharge measurements are summarized in Appendix B.

5.5. Modeling

5.5.1. Enhancements to the River1D Ice Processes Modeling Framework

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 framework, 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 comprehensive series of numerical tests were performed in 2013 to ensure that these enhanced features were functioning correctly, and an updated River1D User's Manual is currently being developed.

5.5.2. River1D Ice Processes Model Development for Existing Conditions

In 2013, a Susitna River River1D Ice Processes Model was developed for preliminary 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.

In 2013, validated survey data were available for 88 Middle River channel cross-sections (excluding overbanks) within the model domain. These surveyed cross-sections were supplemented with spatially interpolated cross-sections separated by 0.2-mile increments.

Manning's *n* roughness was adopted from the Open-Water Instream Flow Routing (RSP Section 8.5) HEC-RAS Model. These initial values are likely to be modified during final model calibration, which will commence when validated survey data for 60 additional Middle River cross-sections become available.

An unsteady inflow hydrograph was extracted from USGS gage 15291700 (Susitna River above Tsusena Creek, PRM 184.9 [RM 182.2]) for the Existing-Condition Open-Water Calibration interval that ran August 11–17, 2012. This was the same calibration interval selected previously for the Open-Water Instream Flow-Routing HEC-RAS Model, so results from the two modeling frameworks (i.e., River1D and HEC-RAS) could be compared directly. Unsteady lateral inflow hydrographs were developed via superposition and subtraction of hydrographs from the following five USGS gages:

- USGS gage 15291700 (Susitna River above Tsusena Creek, PRM 184.9 [RM 182.2]
- USGS gage 15292000 (Susitna River at Gold Creek, PRM 140.1 [RM 136.7])
- USGS gage 15292400 (Chulitna River near Talkeetna)
- USGS gage 15292700 (Talkeetna River near Talkeetna)
- USGS gage 15292780 (Susitna River at Sunshine, PRM 88 [RM 84])

Upstream USGS hydrographs were advanced or lagged as needed (at 15-min increments) to provide best fit to measured hydrographs at the Susitna River Gold Creek and Sunshine gages.

River1D computed open-water discharge hydrographs compared favorably with results from the initial HEC-RAS open-water model calibration. A more detailed assessment of model results is not warranted at this juncture, given limited survey data for only 88 main channel cross-sections along the 107-mile section of river comprising the model domain.

5.5.3. River2D Focus Areas Ice Models

Preliminary survey data were obtained for FA-104 (Whiskers Slough) and River2D test grids and model runs were conducted as an initial look at Focus Area modeling. The preliminary survey data lacked upland elevations for islands and overbanks, necessitating manual specification of numerous upland nodes to better constrain channel extents. Nevertheless, the principal purpose of this exercise was still achieved, which was to provide an initial assessment of grid resolution required to effectively model Focus Area back channels.

5.5.4. Lower River Assessment

Two sections of the Lower River were modeled under steady state conditions using the US Army Corps of Engineers HEC-RAS model (Hydrological Engineering Center – River Analysis System) near Sunshine (PRM 80-86.3 [RM 76.1-82.1]) and at Susitna Station (PRM 30.1 [RM 26]). The model was used to provide a comparison of water elevations under existing conditions and what might occur under increased flow conditions in the winter associated with proposed Project operations. The major increase in water elevation during the winter occurs with the establishment and progression of an ice cover (static ice cover) through a reach. The establishment of the static ice cover in the Lower River (from the mouth up to PRM 100) occurs over a period that ranges from approximately 3 weeks to 2 months in the fall/early winter beginning when the average daily air temperature falls below freezing. Daily air temperature records for the Talkeetna Airport were used to determine the beginning of the freeze-up period for each year. Based on historic ice cover observations in 1980–1985, 2012, and 2013, the river ice cover reaches Talkeetna (freezes over at Talkeetna) after the accumulation of approximately 175 freezing degree days (degrees F) following the onset of subfreezing air temperatures. The beginning of freezing can occur as early as October 5th or as late as December 11th each year, resulting in a wide range of discharge in the Susitna River during the freeze-up period. A report by Curran (2012) provided for a reconstruction of daily streamflow records for gages at Gold Creek, Sunshine, and Susitna Station, AK, for the period of 1950–2010. Using this information on freeze-up dates and the reconstructed records, the discharge range over the freeze-up period was determined for the gages at Gold Creek (USGS gage 15292000), Sunshine (USGS gage 15292780), and Susitna Station (USGS gage 15294350). Detailed explanations of the discharge range during freeze-up for this reconstructed period of 1950–2010 can be found in Appendix A.

At the beginning of the freeze-up period, the river at Sunshine is flowing open with some minor amounts of frazil ice flowing unimpeded downstream. The natural discharge under these conditions (based on the reconstructed data for 1950–2010) ranges from 5,000 to 28,000 cfs. By the time the freeze-up is completed at Sunshine, the river is covered with a static ice surface formed of accumulated frazil pans and slush. The side channels are fairly smooth and freeze over first while the main channel is slightly rougher, considered to be more of a freeze-up jam accumulation. The discharge recedes during the freeze-up process and when the ice cover reaches Talkeetna, the discharge naturally ranges from 3,000 to 8,000 cfs at Sunshine. Therefore, to simulate the impacts of both ice cover formation as well as the proposed increase in winter discharge levels associated with project operation, a range of flows were modeled. The current natural conditions at the beginning of freeze-up were simulated as open water at a range of discharge from 5,000 to 28,000 cfs. The range of natural ice conditions at the completion of the freeze-up period was simulated as ice jammed conditions at a range of discharge from 3,000 to 8,000 cfs. Finally, additional ice jammed conditions were modeled to simulate the effects of increased winter project flows at discharges of 10,000 and 12,000 cfs (all discharge levels at Sunshine). Plots of the HEC-RAS output are included in Appendix A. The results indicate a stage (for a representative cross-section about midway through the modeled Sunshine reach) of 243.8 to 250.2 ft. at the beginning of freeze-up, corresponding to a discharge of 5,000 to 28,000 cfs at Sunshine. Following freeze-up and establishment of an ice cover, the results indicate a stage of 246.2 to 249.1 ft., corresponding to a discharge of 3,000 to 8,000 cfs at Sunshine with an ice cover thickness ranging from 2.7 to 3.7 ft. thick. Increasing the modeled discharge to 10,000 and 12,000 cfs results in a stage of 249.8 and 250.4 ft. with ice cover thicknesses of 4.0 and 4.2 ft., respectively. Elevations are feet above mean sea level (NAVD88).

A similar effort was conducted to simulate conditions at Susitna Station at PRM 30 (RM 25.9). At the beginning of the freeze-up period at Susitna Station, the river is flowing open with some minor amounts of frazil ice with natural discharge ranging (based on the reconstructed data for 1950–2010) from 11,000 to 58,000 cfs. By the time the freeze-up is completed at Susitna Station, the river is also covered with a static ice surface formed of accumulated frazil pans and slush, typical of a smooth freeze-up jam accumulation. The discharge recedes during the freeze-up process and when the ice cover reaches Talkeetna, naturally ranges from 6,950 to 25,000 cfs. The current natural conditions at the beginning of freeze-up were simulated as open water at a range of discharge from 11,000 to 58,000 cfs. The range of natural ice conditions at the completion of the freeze-up period was simulated as ice jammed conditions at a range of discharge from 7,000 to 25,000 cfs. Finally, additional ice jammed conditions were modeled to simulate the effects of increased winter project flows at discharges of 30,000 and 35,000 cfs (all discharge levels at Susitna Station). Plots of the HEC-RAS output are included in the Appendix A. The USGS gage at Susitna Station also corresponds to the location of ESS20; both stage recording stations provided direct observations of the stage increase due to the progression of the ice cover through this reach. The model results indicate a stage (at the USGS gage site) of 32.7 to 39.0 ft. at the beginning of freeze-up, corresponding to a discharge of 11,000 to 58,000 cfs at Susitna Station. Following freeze-up and establishment of an ice cover, the results indicate a stage of 31.4 to 38.7 ft., corresponding to a discharge of 7,000 to 25,000 cfs at Susitna Station with an ice cover. Increasing the modeled discharge to 30,000 and 35,000 cfs results in a stage of 40.0 and 41.1 ft., respectively. Elevations are feet above mean sea level (NAVD88). The USGS gage at Susitna Station reports a stage reading referenced to a vertical datum that is approximately 28.2 ft above mean sea level (NAVD88).

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

The study team compiled a summary annotated bibliography of historic Alaska Power Authority documentation of Susitna River ice processes and modeling completed in the 1980s. The annotated bibliography summarized research, analysis, and modeling related to the effects of hydropower projects on ice processes of the Peace, Romaine, and Athabasca rivers in Canada. These documents, along with the observations completed during the 2012 and 2013 ice seasons, provided an excellent description of ice processes on the Susitna River. A discussion of the effects of river ice processes on fish habitat was also included. Additional hydropower projects in Norway, Iceland, and Canada in addition to those listed above were included in the development of a white paper that expands on the bibliography. The draft document includes the following:

- Ice processes on the Susitna River as they relate to impacts of the Project on fish habitat and other resources.
- The impacts of hydropower or similar development projects on river ice processes in other northern countries.
- Methods of analysis and modeling used to assess impacts to ice processes and fish habitat in other systems, and a discussion of how these methods may be applicable to the Susitna River.

The various modeling techniques described include River1D, River2D, RIVICE, ICEJAM, HEC-RAS, Mike-Ice, and CRISSP2D.

6. DISCUSSION

6.1. Break-up

Compared to earlier reports, break-up in 2012 was exceptionally mild, with few large jams and little observed flooding. It is likely the mildest break-up that has been systematically observed. In contrast to 2012, the 2013 break-up was unusually late, a result of sustained record cold weather in April and May. The majority of break-up activity was concentrated between May 25 and May 29 in 2013, several weeks later than in 2012 when the river was largely ice free by May 9.

The Lower River was subject to relatively uneventful break-ups in the 1980s, 2012, and 2013 and does not appear to frequently cause extensive damage as it does in the Middle River. The 1981 break-up study observed an ice jam at the Deshka River (PRM 44.6 [RM 40.5]) and Montana Creek (PRM 81 [RM 77]) confluences. In 1982, two large ice jams at PRM 90 (RM 85.5) and PRM 92.4 (RM 89) released with a high enough stage to entrain logs stranded from summertime flooding (R&M 1981) (R&M 1983). During the 1985 break-up, jams were observed at PRM 81.7 (RM 78) and PRM 90.1 (RM 86) (R&M 1986). In 2012 there were some large jams, but no overbank ice jam events. The 2013 breakup was also mild; some jams occurred from PRM 50-70 (RM 45.9-62.2) but flooding was limited to islands in the main channel.

The Middle River experienced severe ice jams during break-up in 2013, the 1980s, and earlier; however, the 2012 break-up did little or no damage. Ice floes accumulated in the same general reaches as those reported previously in the Middle River. The majority of ice jam observations in the Middle River during the 1981–1985 break-up studies were within the same 15-mile section of the river from PRM 124.4 (RM 121) to PRM 139.4 (RM 136) as in the 2012 and 2013 break-up observations, although ice jams were more frequent, extensive, and severe in 1981–1985. The following locations were subject to ice jam activity and flooding in the 1980s, 2012, and 2013:

- Slough 11 (PRM 137.5-139.4 [RM 134-136]): Major ice jams and ice jam flooding were documented near Slough 11 (PRM 139.4 [RM 136]) in 1983 and 1985 (LaBelle 1984; R&M 1985). Previous observers documented that Slough 11 was in fact created by an extensive ice jam breakout in May of 1976 (R&M 1983).

- Slough 8 and Slough 9 (PRM 130-133.4 [RM 126.4-130.2]): Historically, PRM 132.4 (RM 129) (Slough 9 area) was a very active break-up location with many observations of ice jams and side channel and slough ice-induced flooding (LaBelle 1984) (R&M 1983). In 1985, a break-up jam released from the same location and caused ice to flow through and possibly scour Slough 8A (R&M 1986).

- PRM 124.4-126.8 (RM 121-123): In May of 1983 and 1985, a 1-mile long major ice jam was observed at PRM 125.6 (RM 122) (R&M 1983). A smaller jam was documented here in 2012.

Break-up was not systematically documented in the Upper River prior to 2012, with the exception of FA-184 (Watana Dam), where jams were reported in May of 1983. Large stranded chunks and damaged vegetation observed in 2012 indicated that more recent jams had inundated the floodplain. In 2013, the majority of break-up occurred in the same time frame as that in the Middle and Lower rivers.

6.2. Freeze-up

Freeze-up 2012 is the only freeze-up event observed by the study at the time of this report. While the aerial reconnaissance flights have been completed for freeze-up 2013, the photo and video coverage from those flights have not yet been analyzed. Images of the 2013 freeze-up from the time lapse cameras have also not been retrieved at the time of this report. However, 2012 provided an opportunity to observe freeze-up during relatively high flows (discharges at Gold Creek were about 15,000 on October 12, compared to a mean of 7,600 cfs, and at Sunshine were about 42,000 on October 12, compared to a mean of 19,600 cfs). The high flows prevented intermediate bridges and ice cover from forming between tidewater and Devils Canyon, and likely somewhat delayed the initial ice bridge formation at tidewater, although the timing of ice bridge formation was similar to previous reports. The following aspects of freeze-up 2012 were consistent with R&M's observations between 1980 and 1985:

- Frazil flow begins in the Upper Susitna in October.
- The greatest frazil concentrations are in the Susitna and Yentna rivers, with minor frazil contribution from the Chulitna or Talkeetna rivers to the Lower Susitna River.
- Earliest ice bridges are short, thick frazil ice bridges in Devils Canyon, which do not progress upstream.
- Ice cover is initiated by bridging in the lowest 5 miles of the Susitna River.
- Ice cover advances rapidly to the Yentna confluence, and gradually slows as it advances upstream.
- Staging associated with ice cover advance in the Lower River is between 1 and 3 feet.

An ice cover had not formed on the Middle River by early November in 2012. Shore ice was gradually widening, and frazil ice was thick enough to clog constrictions in the main channel, giving the appearance of imminent bridging. Observations similar to these were documented in 1981 and 1982 in the Middle River. The early appearance of anchor ice in shallow riffles upstream of Devils Canyon is also consistent between study years.

An ice cover had not yet formed on the Upper River by November 7, 2012. Although ice observations did not extend to the Upper River in the 1980s, it was speculated that reductions in frazil concentrations at Gold Creek were associated with an ice cover forming upstream of Devils Canyon. The formation of the intermittent Devils Canyon ice cover on October 22 did not have a noticeable effect on frazil concentrations at Portage Creek in a review of telemetered camera images. Detailed timing of the ice bridge formation in Devils Canyon between October 17 and October 22 is unknown. None of these bridges were captured on cameras, and they were far enough removed from pressure transducers that any staging associated with their formation was not recorded. Frazil concentrations did not appear to drop at ESS70 (PRM 186.9 [RM 184.1]) or ESS55 (PRM 151.4 [RM 148]) during this period, which would have indicated the timing of the upper river ice bridge formation, or Devils Canyon ice bridge formations, respectively. This indicates that the total volume of frazil removed from the river by these bridges was negligible compared to the volume generated between the bridges and flowing downstream underneath them.

The November 15 reconnaissance flight observed a significant reduction in frazil ice concentration in the Middle River. This reduction in frazil was attributed to a 23-mile-long ice cover that formed upstream from Watana Creek between PRM 195 and 218 (RM 192.3-215.9). Very little frazil ice was observed flowing downstream of this ice cover when compared to the November 7 flight when this ice cover was not present.

6.3. Open Lead Mapping

Open leads followed the same general pattern in 2012 and 2013 as in 1983, despite using different criteria for establishing the origin of the lead. Side channels and sloughs in the Middle River were mapped as open or partially open during all surveys, while velocity leads were more common in the steep reach upstream of Indian River in all surveys. Lower River open leads were difficult to compare because the main channel appears to have shifted eastward since 1983. After watching open leads form and evolve over the 2012 freeze-up season, observers developed additional criteria for determining whether a lead is derived from thermal input or velocity. Observers appeared to use different criteria in 1983 than field teams did in 2012 and 2013 for establishing the origin of the lead as thermal or velocity, because the majority of the 1983 leads were classified as velocity leads, including sloughs. The criteria used in 1983 were not documented in the study report from R&M.

6.3.1. Lower River

Observations in 1983 of open leads covered the section of the Lower River upstream of PRM 88 (RM 84). Main channel open leads were generally not comparable because the channel has shifted eastward since 1983 in this reach. However, the Birch Creek Slough complex at PRM 90.5 (RM 87) was documented as open in 1983, 2012, and 2013. In 1983, 2012, and 2013 persistent velocity leads were documented near the town of Talkeetna between PRM 99.4 (RM 96) and PRM 100.3 (RM 97).

6.3.2. Middle River

In 2012 and 2013 thermal leads were concentrated around sloughs, including Slough 1 (PRM 102.7 [RM 99]), FA-104 Whiskers Slough (PRM 106.8 [RM 103]), FA-115 Slough 6A (PRM 115.5 [RM 112]), FA-128 Slough 8A (PRM 130.6 [RM 127]), Slough 9 (PRM 132.4 [RM 129]), FA-138 Gold Creek (PRM 139.4 [RM 136]), and FA-141 Slough 21 (PRM 145.5 [RM 142]). All of these except for Whiskers Slough and Slough 1 were also documented in 1983, although open lead classifications differed slightly from later mapping events. Downstream of PRM 133.2 (RM 130), the 2012 and 2013 mainstem open leads were generally classified as thermal, while the 1983 mainstem open leads were classified as velocity. Upstream of PRM 133.2 (RM 130), most mainstem open leads were classified as velocity leads during all survey years, corresponding to an increase in river gradient. Numerous velocity leads were documented in all three studies near the Portage Creek confluence and throughout the Devils Canyon reach, although the exact locations of the leads differed from year to year. The 1983 survey ended at PRM 154.7 (RM 151) while the 2012 and 2013 studies continued upstream of Devils Canyon.

6.3.3. Upper River

In the 2012 and 2013 open lead surveys there were fewer velocity leads on the Upper River than on the Middle and Lower rivers, which is probably related to the decrease in hydraulic gradient above Devils Canyon. Few thermal leads were observed and those present tended to be associated with creek confluences and likely a result of turbulent flow and thermal input from tributary deltas.

6.4. Ice Measurement Data

The most consistent aspect between stations was the presence of frazil ice beneath the ice surface. The thickness of the frazil ice layer differed drastically between stations as well as across each measurement transect, but it was present in large enough amounts at each site to have an effect on the under-ice hydrology and hydraulics. At many of the sites visited the flow beneath the ice surface was separated into two channels by frazil ice. At ESS35 and ESS60 there were isolated side channels that seemed to be controlled by substrate topography as well as surface and frazil ice. Only ESS40 and ESS50 were flowing entirely in one channel beneath the ice, and even these sites were constrained by frazil ice.

The March measurements appear to have captured the late winter low flow period. Unit runoff values (computed by dividing discharge by the total drainage area above the measurement transects) decreased an average of about 27.5% from January to the March field event. During both field events the unit runoff values generally increased when moving downstream.

6.5. Modeling

6.5.1. Lower River Assessment

The Lower River HEC-RAS modeling provided estimates of what the “normal” range of stage would be at the beginning of and following the establishment of an ice cover at both the Sunshine reach (PRM 80 to 86.3) and at Susitna Station (PRM 30). At Sunshine, at the beginning of freeze-up, the discharge ranges from 5,000 to 28,000 cfs with corresponding representative stage (within the Sunshine modeled reach) of 243.8 to 250.2 ft., respectively. Following the establishment of an ice cover in this reach, the discharge ranges from 3,000 to 8,000 cfs with a corresponding stage of 246.2 to 249.1 ft., respectively. Increases in discharge to 10,000 and 12,000 cfs result in stages (with an ice cover) of 249.8 to 250.4 ft., respectively. The modeling indicates that even if proposed operational scenarios increase the discharge (during freeze-up and throughout the winter), the resulting stages would only be increased by a maximum of about 1 ft. over the naturally occurring stage range just prior to freeze-up. During freeze-up 2013, the Sunshine gage recorded an increase in stage of approximately 5 ft. with the progression of the ice cover through the gage location. While the USGS estimates of discharge during this period are not yet available, at the beginning of freeze-up the discharge at the Sunshine gage was approximately 21,000 cfs, within the “normal” range.

Similarly, at Susitna Station at the beginning of freeze-up, the discharge ranges from 11,000 to 58,000 cfs with a corresponding stage at the Susitna Station gage of 32.7 to 39.0 ft., respectively. Following the establishment of an ice cover in this reach, the discharge ranges from 7,000 to 25,000 cfs with a corresponding stage of 31.4 to 38.7 ft., respectively. Increases in discharge to 30,000 and 35,000 cfs result in stages (with an ice cover) of 40.0 to 41.1 ft., respectively. During freeze-up 2012, ESS20 and the Susitna Station gage provided a direct record of the stage increase of approximately 4.8 ft. to a stage of 41.1 ft. with the progression of the ice cover through the gage location. This occurred when the discharge at the Susitna Station gage was 33,000 cfs, higher than the freeze-up discharges of 1950–2010. The stage and discharge recorded during the 2012 freeze-up match very well to the modeled stage at 35,000 cfs at the

Susitna Station location. An annotated stage hydrograph of the 2012 freeze-up at Susitna Station is presented in Appendix A.

7. COMPLETING THE STUDY

[As explained in the cover letter to this draft ISR, AEA's plan for completing this study will be included in the final ISR filed with FERC on June 3, 2014.]

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9. FIGURES

Figure 5.1.1-1. Ice jam near PRM 139.4 (RM 136) on April 27, 2012. Slough 11 is in the upper left side of the photo. Photo is looking downstream.

Figure 5.1.1-2. Ice jam in Vee Canyon, April 27, 2012. PRM 223.4 (RM 221.5).

Figure 5.1.1-3. Remnant ice slabs downstream of Vee Canyon at PRM 222.9 (RM 221), May 2, 2012.

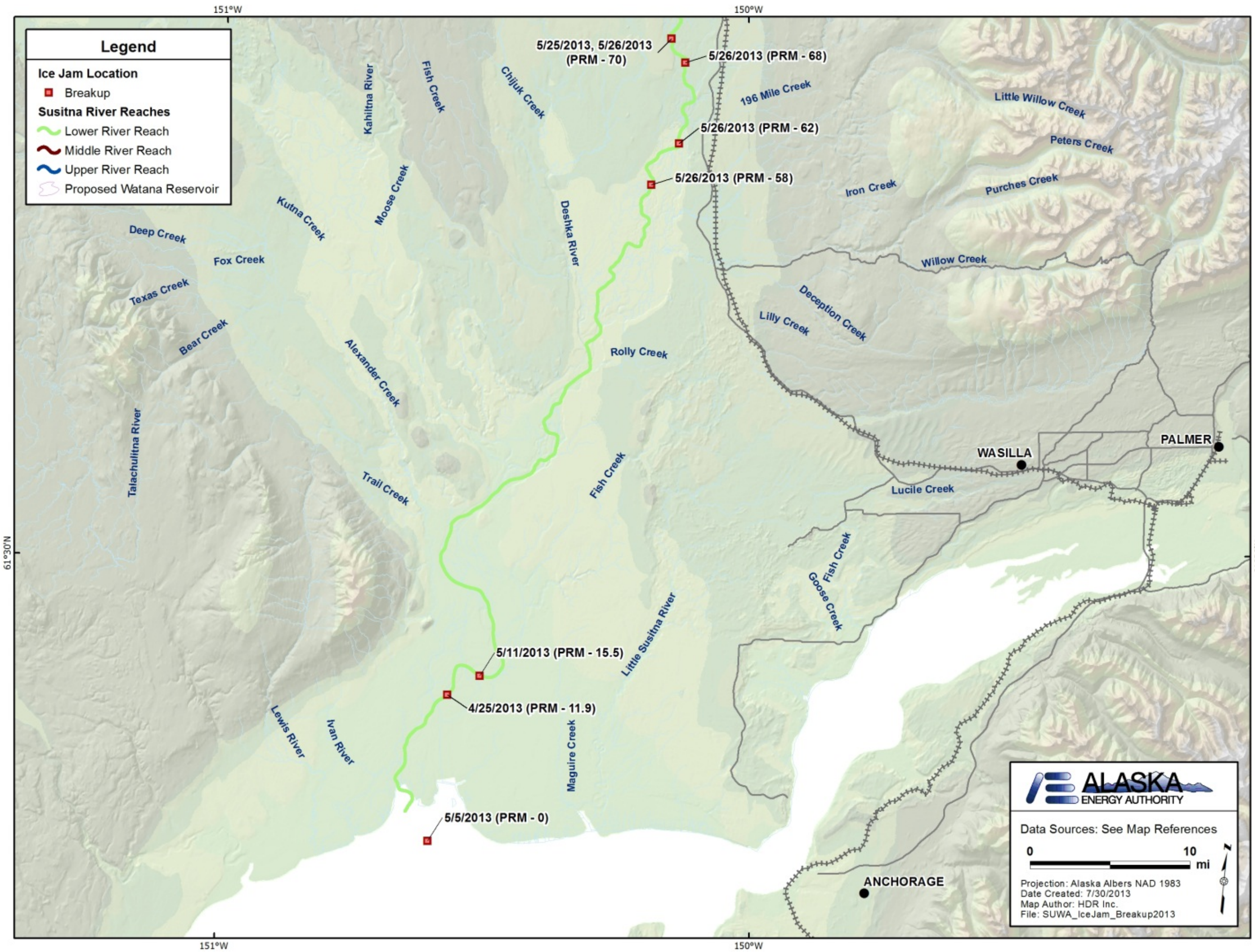

Figure 5.1.2-1. 2013 Significant Ice Jam Locations–Lower Susitna River

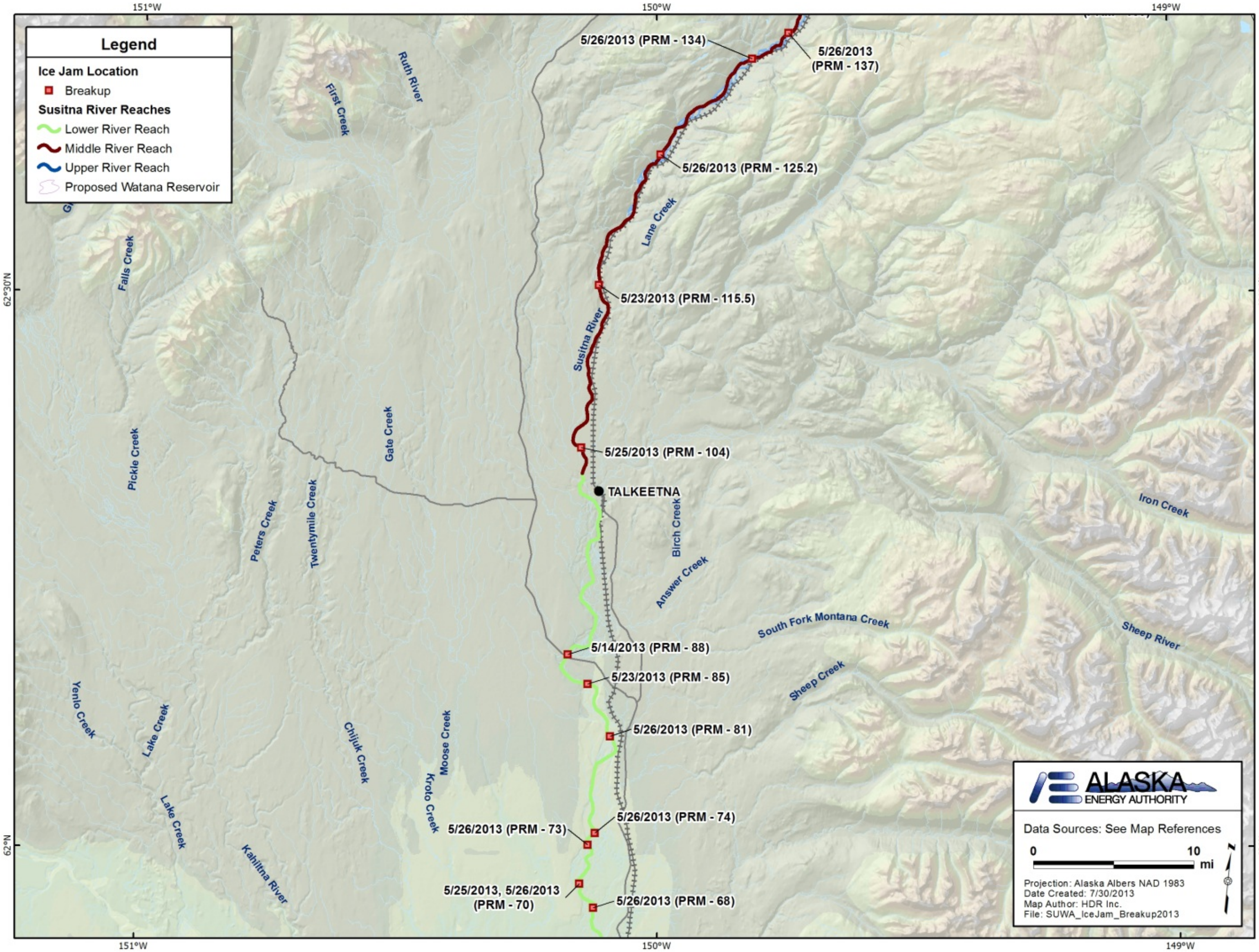

Figure 5.1.2-2. 2013 Significant Ice Jam Locations–Middle Susitna River

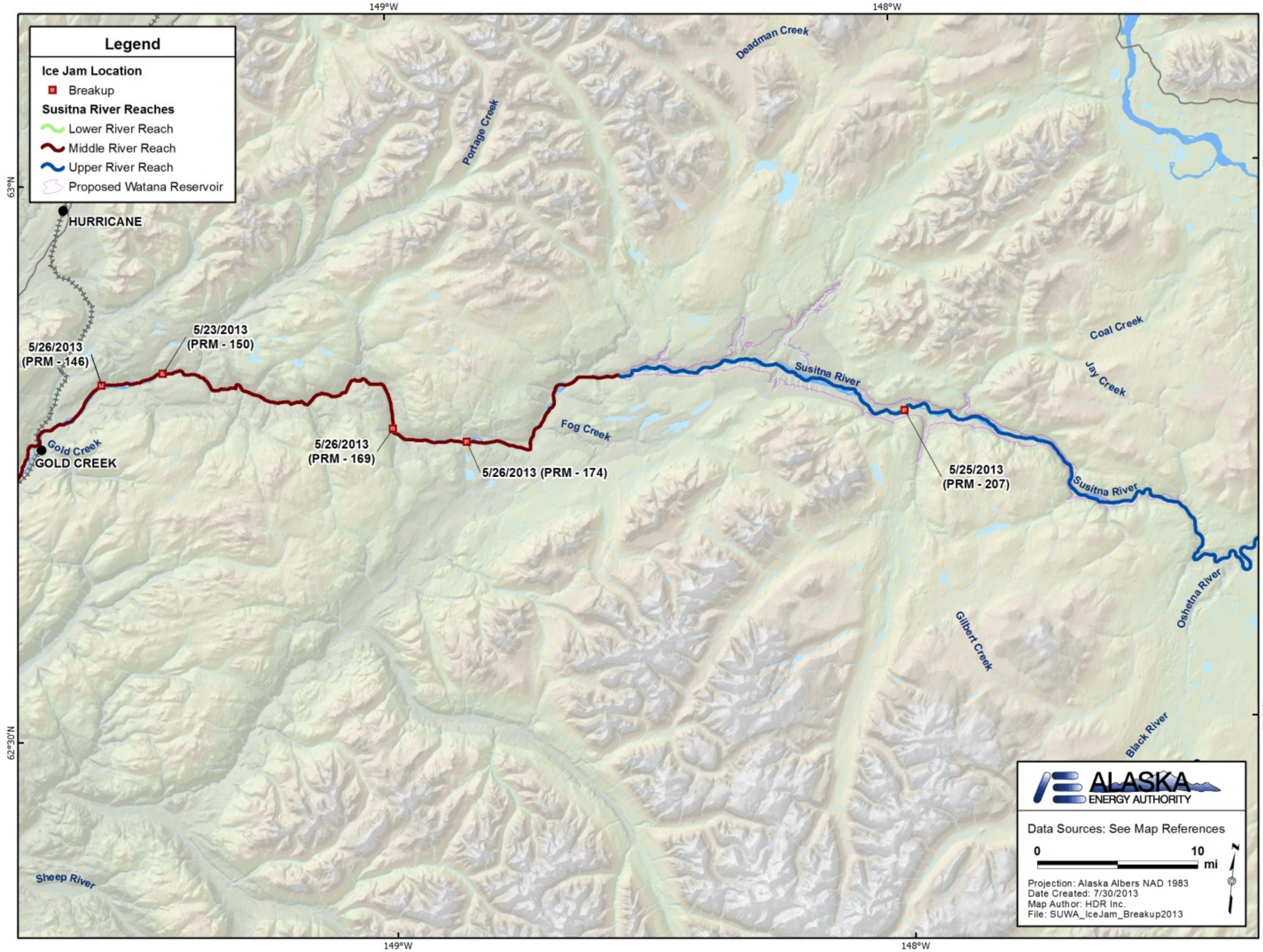

Figure 5.1.2-3. 2013 Significant Ice Jam Locations–Upper Susitna River

Figure 5.1.2-4. Ice jams at Whiskers Slough (PRM 105.4 [RM 101.5]) May 25, 2013.

Figure 5.2.1-1. Frazil ice pans flowing past PRM 103.8 (RM 100), October 16, 2012.

Figure 5.2.1-2. Ice bridge in Devil Canyon, PRM 154.7 (RM 151). Flow is from bottom to top. October 22, 2012.

Figure 5.2.1-3. Parks Highway bridge at PRM 88 (RM 84) on November 1, 2012 prior to ice cover progression through the reach.

Figure 5.2.1-4. Parks Highway Bridge at PRM 88 (RM 84) on November 7, 2012 after ice cover progression through the reach. Note flooded gravel bars on both sides of the river.

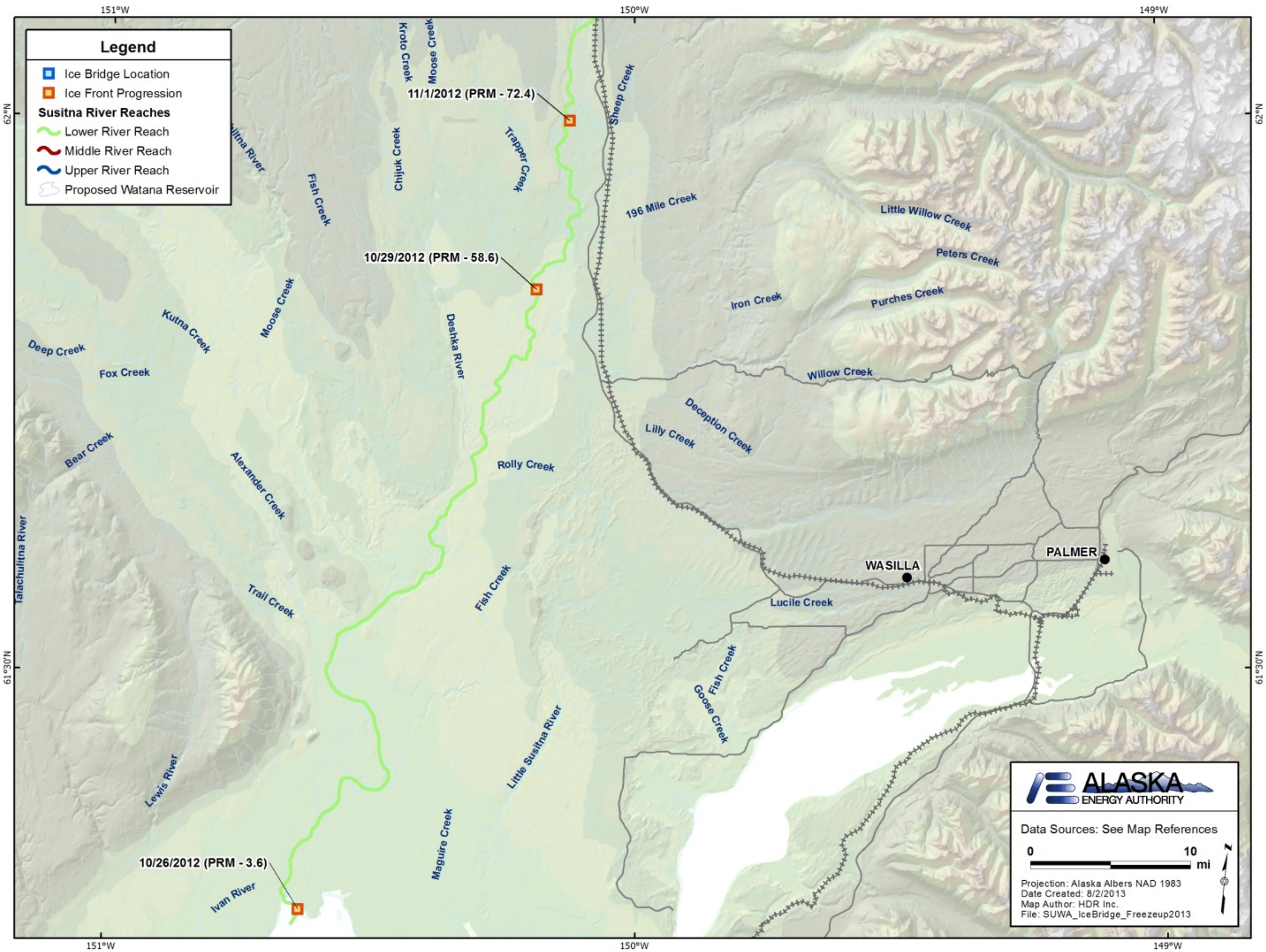

Figure 5.2.1-5. 2012 Ice Front Progression and Ice Bridge Locations–Lower Susitna River

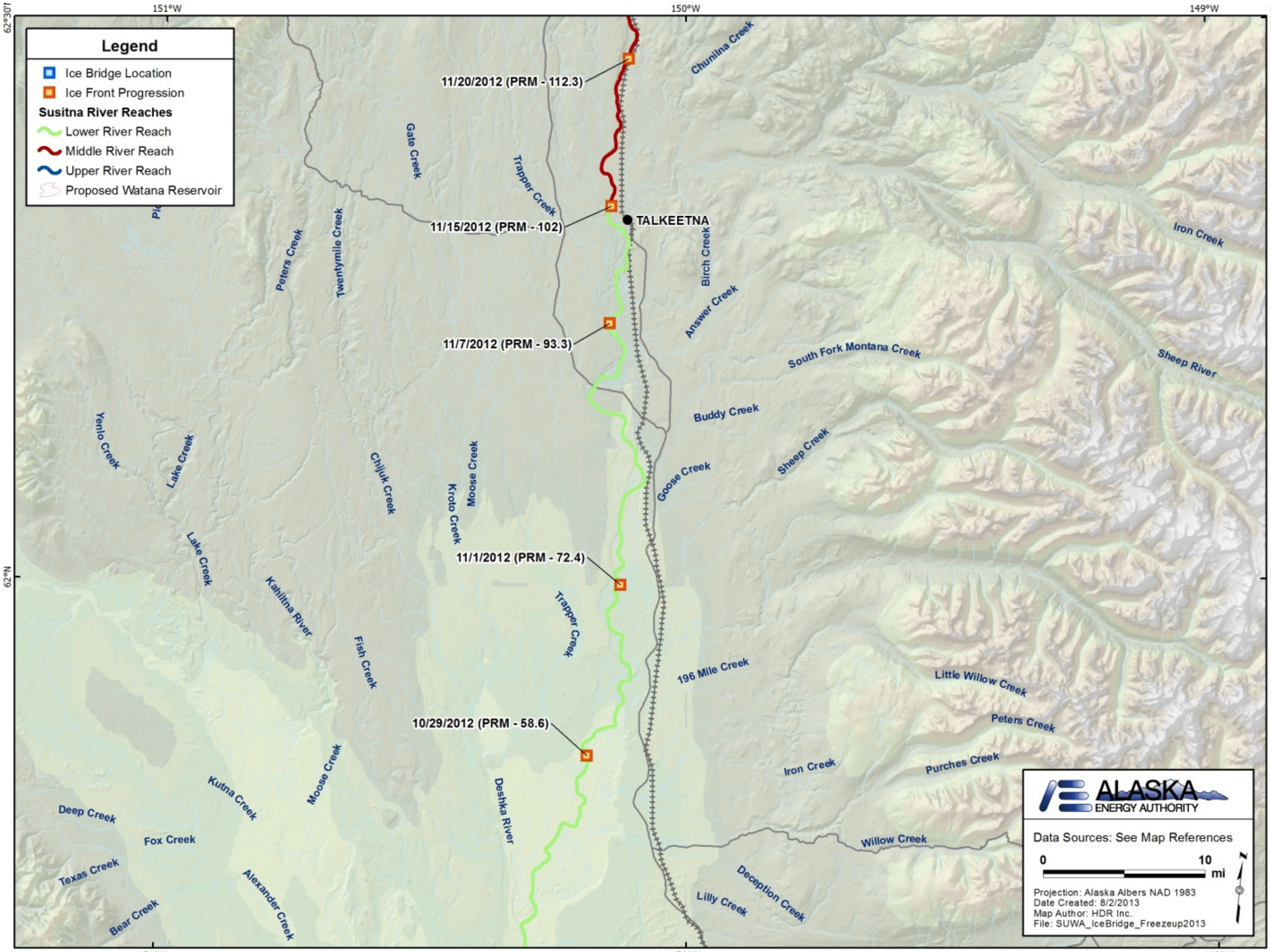

Figure 5.2.1-6. 2012 Ice Front Progression and Ice Bridge Locations–Middle Susitna River

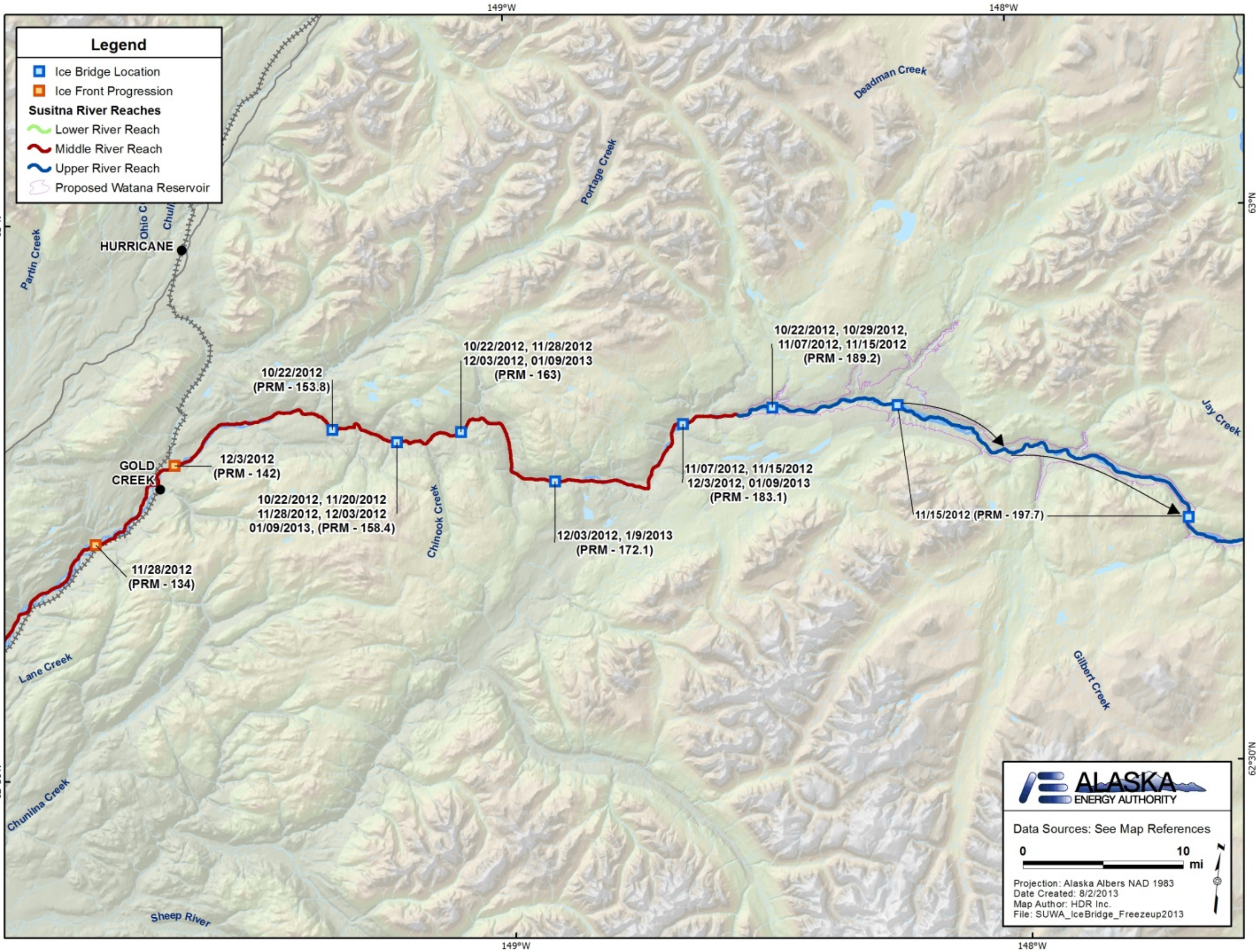

Figure 5.2.1-7. 2012 Ice Front Progression and Ice Bridge Locations–Upper Susitna River

Figure 5.3.2-1. Thermal lead at FA-128 (Slough 8A), PRM 128.3 (RM 124.5). March 12, 2013.

Figure 5.3.2-2. A long velocity lead at PRM 146 (RM 142.5). March 12, 2013.

APPENDIX A: DETAILED ICE OBSERVATIONS AND LOWER RIVER HEC-RAS MODELING

[See separate file for Appendix.]

APPENDIX B: 2013 ICE FIELD MEASUREMENTS

[See separate file for Appendix.]