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Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Ice Processes in the Susitna River Study
Study Plan Section 7.6

Final Study Plan

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

July 2013

7.6. Ice Processes in the Susitna River Study

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.*

Additional Time-Lapse Camera Locations

- *We recommend that an additional camera be added at Susitna Landing.*

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.*

AEA provides this Final Study plan, which reflects all FERC requested modifications.

7.6.1. General Description of the Proposed Study

The Ice Processes in the Susitna River Study 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, instream flow, instream flow riparian, and groundwater).

Study Goals and Objectives

The overall goals of the ice processes study 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 the Oshetna River confluence (river mile [RM] 233.4) and tidewater (RM 0), 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 instream flow study.
- Provide observational data of existing ice processes and modeling results of post-Project ice processes to the fisheries, instream flow, instream flow riparian, fluvial geomorphology, groundwater, recreation, and socio-economic studies.
- 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 five months when ice is not present will be accomplished under the Water Quality Modeling Study (Section 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 (Section 8.5), while ice-affected flow routing will be performed by this study.

7.6.2. Existing Information and Need for Additional Information

7.6.2.1. Existing Information

Ice affects the Susitna River for approximately seven months of the year, between October and May. When air and water temperatures drop below freezing in September and October, border ice grows along the banks of the river, and frazil ice begins accumulating in the water column and flowing downstream. Flowing ice eventually clogs the channel in shallow or constricted reaches, or at tidewater, forming ice bridges. Frazil pans flowing downstream accumulate against ice bridges, causing the ice cover to progress upstream. By January, much of the river is under a stable ice cover, with the exception of persistent open leads corresponding with warm upwelling water or turbulent, high-velocity flows. Flows generally drop slowly throughout the winter until snowmelt commences in April. During April and May, river stages rise and the ice cover weakens, eventually breaking into pieces and flushing downstream (R&M 1982b). Ice jams are recurrent events in some reaches of the river. If severe, jams can flood upstream and adjacent areas, drive ice overbank onto gravel bars and into sloughs and side channels, shear-off or scar riparian vegetation, and threaten infrastructure such as the Alaska Railroad and riverbank property (R&M 1982b).

Ice processes were documented between the mouth of the Susitna River (RM 0) and the proposed dam site (RM 184) between 1980 and 1985 (R&M 1981, 1982a, 1983, 1984, 1985, 1986). Freeze-up and break-up progressions were monitored using aerial reconnaissance. Locations of ice bridges during freeze-up and ice jams during break-up were recorded each season. One winter, a time-lapse camera was installed in Devils Canyon to observe ice processes through the narrow, turbulent rapids. Additional ice data were collected to calibrate a model. These included ice thicknesses at selected river transects, top-of-ice elevations, air and water temperatures at meteorological stations and Gold Creek, slush ice porosity at selected transects in the Middle and Lower River, and frazil concentration and density at Gold Creek.

Winter observations have spanned a range of climatic conditions. The freeze-up period of 1985 was unusually cold, with about twice the accumulated freezing-degree days as the long-term average (R&M 1986), while the freeze-up period of 1984 was warm (R&M 1985). In the 1980s modeling studies, cold, average, and warm conditions were simulated using records from the winters of 1971–1972, 1976–1977, and 1981–1982, respectively (Harza-Ebasco 1984b). The winter of 1971–1972 still stands as one of the coldest on record at Talkeetna; however, according to the Western Regional Climate Data Center, the warmest winter on record occurred in 2002–2003.

Of particular interest was the influence of freeze-up and ice cover on salmon habitat areas. Water levels at certain sloughs in the Middle River and Lower River were monitored during the winter to determine whether staging during freeze-up and ice cover diverted water into side channels and sloughs (R&M 1984).

Other entities (National Weather Service, U.S. Geological Survey [USGS], and U.S. Army Corps of Engineers [USACE]) also have collected and compiled ice thickness, break-up, and freeze-up data for various locations on the river (Bilello 1980). Although these data were not collected for the purpose of understanding the potential effects of the Project, they are relevant for furthering our understanding of winter hydrology along the Susitna River.

Freeze-up and melt-out processes in the Middle River (between Gold Creek and Talkeetna) were modeled using ICECAL, a numerical model developed by the USACE Cold Regions Research and Engineering Laboratory (CRREL) (Harza-Ebasco 1984). The model utilized the outputs from a temperature model developed for the river (SNTEMP) and empirical data on frazil production and ice-cover progression derived from observations. Both the Watana-only and Watana-Devils Canyon operations, as proposed in the 1980s, were modeled for a range of meteorological conditions that had been encountered, including a cold winter (1971–1972), a very warm winter (1976–1977), a warm winter (1982–1983), and an average winter (1981–1982). The results of the model included predictions of the extent of ice cover, the timing of ice-cover progression, ice surface elevations, and the inundated area beneath the ice cover for selected cross-sections. The elevation of water flowing beneath the ice was compared to the elevation necessary to overtop slough berms at selected fish habitat study areas in the Middle River in order to assess the impacts of Project operation on winter flow in these sloughs. Empirical data on frazil production and ice-cover progression was used to estimate changes in ice-cover progression between tidewater and Talkeetna. Reservoir ice was simulated using a DYRESM model and calibrated to conditions at Eklutna Lake (Harza-Ebasco 1986).

Key findings of the 1980s modeling effort included the following (for the Watana-only scenarios):

- The open water reach would likely extend 44–57 miles downstream of the dam site.
- Ice thicknesses were generally similar under project conditions, where ice was predicted to occur.
- Winter water surface elevations under ice would be 2–7 feet higher under project conditions, and would result in the flooding of some sloughs with mainstem water in the Middle River without mitigation.
- Freeze-up would be delayed by 2–5 weeks in the fall, and ice-out would occur 5–7 weeks earlier in the spring.
- Ice jams during break-up would be reduced in severity post-project because of the regulation of spring snowmelt flows.

R&M undertook a survey of ice-affected hydropower projects in other northern regions (Harza-Ebasco 1985). The results of the survey indicated that other hydroelectric projects generally relied on observations and operator experience to limit adverse effects of flow regulation on winter conditions. Ice jamming during the freeze-up and subsequent flooding of infrastructure and communities were the primary concerns.

7.6.2.2. Additional Information Needs

The need for additional information beyond what was gathered and analyzed during the 1980s is driven by four factors: (1) the new proposed configuration of the Project and Project operational scenarios; (2) advances in predictive models of winter flow regimes beyond what was available in the 1980s; (3) the need to capture any changes (due to channel or climate changes) since the 1980s; and (4) the need to supply ice-related hydraulic data in greater detail for Focus Areas selected for the instream flow study.

The 1980s Su-Hydro project was envisioned as a two-dam project, with an upper dam, reservoir, and powerhouse near river mile (RM) 184 (Watana Dam). It was envisioned that the upper development would be operated in load-following mode to meet power demands. A lower dam, reservoir, and powerhouse (Devils Canyon Dam) would provide additional power generation, but would also re-regulate flow releases from the upper development. Downstream flow releases from the Devils Canyon Dam would not have the daily flow fluctuations associated with load-following operations of the upper development.

The Pre-Application Document (PAD) describes an operational scenario that would release more water in the winter, with a potential for day-to-day fluctuations. The ICECAL model was a steady flow model, and thus could not simulate flow fluctuations or route winter flows. A dynamic model will be able to simultaneously predict flow and temperature fluctuations downstream of the dam, as well as ice-cover progression. Finally, the ICECAL model was only calibrated to flows between Talkeetna and Gold Creek. There are several important fish habitat areas upstream of Gold Creek where knowledge of winter conditions is necessary to predict post-Project habitat changes.

Despite changes in channel form, which are likely to have the greatest effect at the Chulitna confluence near Talkeetna, most of the detailed data collected in the 1980s can be used in the current effort, including verifying the model. Freeze-up progression upstream from tidewater was catalogued each year of the study, including the rate of ice front advance, ice bridging locations, daily frazil discharges at Gold Creek and weekly discharges for the Yentna, Chulitna, Talkeetna, and Middle Susitna. Daily meteorological observations were recorded in Talkeetna and near the dam site. Staging observations were made in the Lower and Middle Rivers, which described the rise in water level immediately upstream from the progressing ice front. Ice thicknesses and elevations were collected in the Lower and Middle Rivers each year of the study, and the shape of the ice cover across transects was characterized, since thicknesses varied between the bank and the thalweg. Open leads were mapped in the late winter for several years, including open sloughs and side channels. Break-up progression was monitored each spring of the study, and ice jam locations were mapped. All of these observations are relevant to the current study. Detailed observations were also made if frazil density, in order to determine the source of frazil, and effects of snowfall, low and high discharges, and variable temperatures on ice cover development. It is especially important to have detailed observations for a range of climatic conditions so that the role of meteorological factors in influencing ice cover formation can be better understood.

Freeze-up and break-up processes depend on a complex suite of variables, some of which currently are outside the realm of predictive modeling, usually because the process depends on very local conditions, or sequence of events. Ice bridging locations are an example of a process that cannot currently be predicted by a model; thus, analytical methods to predict ice-cover progression depend on multiple years of observations. The presence of open thermal leads is another phenomenon that is not captured by ice processes models because it depends on local hyporheic flow conditions or groundwater contributions. Additional documentation is needed to determine whether locations of these features and timing of ice-cover progression are similar to conditions observed in the 1980s. In addition, in the 1980s, the location of frazil production early in the freeze-up period varied significantly between study years. An assessment is needed to determine the importance of the Susitna River upstream and downstream of the proposed dam in frazil production for a range of meteorological conditions.

7.6.3. Study Area

7.6.3.1. Observations

The ice processes observation study area includes the 234-mile segment of river between tidewater and the Oshetna River confluence (from RM 0 to 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.

7.6.3.2. Middle River River1D Modeling

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

7.6.3.3. Middle River Detailed Modeling (Focus Areas)

Several Focus Areas determined in conjunction with the instream flow habitat and riparian studies 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 Fish and Aquatics Instream Flow Study (Section 8.5) for criteria and potential sites.

7.6.3.4. 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 (from RM 0 to 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 determined based on the magnitude of change seen at the downstream boundary of the River1D model (approximately RM 100), the estimated contributions of frazil ice to the Lower River from the Middle River from observations and modeling, and with simpler steady flow models (HEC-RAS with ice cover) for short sections of interest in the Lower River (Section 7.6.4.10).

7.6.4. Study Methods

The observation and modeling efforts described below will be 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 will help define the year-to-year variability in the ice regime. Characterizing the existing ice regime and its variability will provide a basis for evaluating the impacts of the project.

7.6.4.1. 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 will be performed from tidewater to the Oshetna River confluence (from RM 0 to RM 233.4). The number of observations will vary depending on ice process conditions, but it is anticipated that approximately 10 reconnaissance trips per spring will occur during break-up and 15 reconnaissance trips per winter will occur during freeze-up in 2012, 2013, and 2014. The data collected will include 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 follow those of EM-1110-2-1612, Ice Engineering, developed by USACE (2002) and Michel (1972). Aerial reconnaissance will include observations of the main Susitna River, and mouths of major tributaries including the Yentna, Chulitna, and Talkeetna rivers. Open leads will be systematically mapped and classified as thermal or velocity in origin in January and March of each study year.

7.6.4.2. Time-Lapse Camera Monitoring

Time-lapse cameras will monitor break-up and freeze-up at locations corresponding to flow routing model instrumentation, key ice processes, and fish habitat locations. Time-lapse cameras are set to take photos of the main channel or a side slough at one-hour intervals, and the results are compiled into a video. Key information to be derived from time-lapse videos includes 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 during freeze-up from the shore, and the local interaction of ice with the floodplain. The selection of camera locations may be refined if aerial observations indicate other more important locations. The locations of the time-lapse cameras for 2012 are as follows:

- RM 9.5 – Near Upper Tidal Influence
- RM 25.6 – Susitna Station
- RM 59 – Rustic Wilderness Side Channel
- RM 88 – Birch Creek Slough
- RM 99 – Slough 1 (2012 break-up only)
- RM 101.5 – Whiskers Slough (2012 freeze-up)
- RM 103 – Talkeetna Station
- RM 121 – Curry Slough
- RM 129 – Slough 9
- RM 141 – Slough 21
- RM 149 – Mouth of Portage Creek
- RM 184 – Dam Site

Planned camera locations for 2013–2014 include the following:

- RM 9.5 – Near Upper Tidal Influence
- RM 25.6 – Susitna Station
- RM 60.5 – Susitna Landing
- RM 101 – Whiskers Slough

- RM 112 – Slough 6A
- RM 124 – Slough 8A
- RM 135 – Slough 11
- RM 138 – Indian River
- RM 141 – Slough 21
- RM 149 – Mouth of Portage Creek
- RM 171 – MR2-wide
- RM 184 – Dam Site

Additional telemetered time-lapse cameras are located at the following sites by the flow transect study:

- RM 11 – Susitna River near Flathorn Lake (ESS10)
- RM 13 – Susitna River near Dinglishna Hill (ESS15)
- RM 26 – Susitna River at Susitna Station (ESS20)
- RM 96 – Susitna River near Twister Creek (ESS30)
- RM 98 – Susitna River near Chulitna River (ESS35)
- RM 103 – Susitna River above Whiskers Creek (ESS40)
- RM 113 – Susitna River below Lane Creek (ESS45)
- RM 121 – Susitna River at Curry (ESS50)
- RM 149 – Susitna River below Portage Creek (ESS55)
- RM 165 – Susitna River near Devil Creek (ESS60)
- RM 176.5 – Susitna River near Fog Creek (ESS65)
- RM 184 – Susitna River below Deadman Creek (ESS70)
- RM 223 – Susitna Gage near Cantwell (now ESS80)

And by the USGS at the following stations:

- RM 182 – Susitna River Above Tsusena Creek
- RM 137 – Susitna River at Gold Creek
- RM 84 – Susitna River at Sunshine Station
- Chulitna River near the Susitna confluence

In order to calibrate a border ice growth formulation for the River1D model, an additional time-lapse camera will be placed in the fall of 2013 in the Middle River. The image will be calibrated with an object of known length so that border ice width can be directly measured from the images. Ideally the camera will be placed close to one of the pressure transducer locations so that ice growth measured in the image can be directly related to temperature at the site. Surface velocity will be estimated at intervals at the location to calibrate the border ice formula.

7.6.4.3. Transect Data

Winter field data will be collected at the 9 of the 13 transects identified above for the flow routing model study (ESS70-ESS30). These transect data will be used to calibrate the existing condition ice processes model. The following data will be collected in conjunction with the flow routing study:

- 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 current meter and/or ADCP, except ESS30.
- Thickness of snow cover (January and March).

Additional transect data will be collected at Focus Areas in the Middle River in 2014, including ice thickness and elevation data and discharge data. These data will also be used to calibrate the River1D model.

7.6.4.4. Focus Area Field Data Collection

A winter field data collection program will be established at each Focus Area in consultation with the instream flow, geomorphology, riparian, and groundwater studies. Winter data collected at Focus Areas will include ice thicknesses, 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 understanding of how winter conditions affect fish habitat and geomorphology.

Field conditions during winter data collection are likely to occasionally be challenging, owing to hazardous weather, limited daylight, and river ice conditions. Where large open leads or questionable ice stability preclude measurements at established transects, measurements may need to be relocated upstream or downstream of the transect. Likewise, equipment such as pressure transducers, temperature probes, and cameras will likely fail from time to time. The field data collection program may be revised where needed to overcome these challenges.

7.6.4.5. Other Field Data

The Riparian Instream Flow Study (Section 8.6) will be collecting field data on ice interactions with floodplains and vegetation, including tree scars and floodplain disturbance by ice. These data indicate locations where ice events have been significant. The results of the Riparian Instream Flow Study will be used to delineate reaches of the river where ice processes, primarily break-up jams, have occurred in the past. The Riparian Instream Flow Study will use these data to develop a model of riparian–floodplain interactions, while the ice study will use these data to supplement historical observations of ice jams.

7.6.4.6. River Ice Processes Model Development for Existing Conditions

A River1D model will be developed and applied to the Susitna River between the proposed dam site and Talkeetna. 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 and 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 is due to be released to the public domain on January 1, 2013.

The Susitna River Ice Processes Model 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 is to calibrate an open-water model using known discharge events. The second step is 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 Focus Area models embedded in the reach. Inputs to the existing condition model include the following:

- River geometry from the instream flow routing study
- 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 Water Quality Study (Section 5.0)
- 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 be used to verify the model for differing climate conditions. The existing conditions model may be updated with 2013 or 2014 data if new information is gained that will improve model accuracy.

7.6.4.7. River Ice Processes Model Projections for Proposed Conditions

For the Middle River, the calibrated River1D model will be used to model the proposed Project operational scenarios. The model will predict water temperature, frazil ice production, ice cover formation, elevation and extent of ice cover, and flow hydrograph (winter flow routing and water levels) between the proposed dam site and Talkeetna. The model will also predict ice cover stability, including potential for jamming, under load-following fluctuations. For the spring melt period, the model will predict ice-cover decay, including the potential for break-up jams. Proposed operational scenarios will include, at a minimum, the load-following scenario described in the PAD, a base load scenario, and a run of river scenario. Up to two additional operational scenarios will be added to evaluate a reasonable range of alternatives.

Additional inputs to the proposed conditions model include the following:

- Flow releases from Watana Dam provided by the Reservoir Operations Model
- Temperature of released flow provided by the Water Quality Model

- Range of meteorological conditions (warm, cold, wet, and dry winters) as developed in coordination with the Water Quality Study (Section 5.0)

An empirical formulation will be added to River1D to compute border ice growth. The formula will be calibrated by field data collected during freeze-up of 2013.

The River1D model will model temperature between freeze-up and break-up on the Susitna River, while the EFDC Water Quality Model (Section 5.6) will model temperature during the open water season and the HEC-RAS model (Section 8.5) will model flow routing during open water conditions. Both temperature models will use the same meteorological and water temperature baseline data outlined in Section 5. The models will overlap during early freeze-up, usually mid-September to October, and late break-up, usually late April to mid-May. This will provide an independent check of model accuracy. When the models predict that river temperatures will reach freezing (32^{o}F) for a portion of the mainstem, the Ice Processes Model results will take precedence for temperature and hydraulic routing.

7.6.4.8. Focus Areas Ice Processes Model

The River1D model will be at the same scale as the Mainstem Open-water Flow Routing Model (Section 8.5.4.3), and will be using the same river channel geometry. Focus Areas selected by the ISF study (Section 8.5.4.2) will be subject to more detailed geometric surveys and modeling in order to evaluate Project effects to smaller scale habitat. In some of the proposed Focus Areas near the dam site, the river may not be predicted to freeze over post-Project. For these sites, year-round conditions will be modeled using the open-water model. If ice cover is predicted by the River1D model to occur at these sites post-Project, winter hydraulic conditions at these sites will be modeled using either more detailed River1D models or River2D models, depending on channel geometry and the influence of two-dimensional hydraulics. In some cases, the River1D model may be applied to split flow or bend reaches if the advantages of computational simplicity appear to outweigh the potential reduction in accuracy of not simulating cross-channel flow. The extent of the detailed models may be modified from the instream flow Focus Area boundaries to accommodate appropriate boundary conditions for ice processes.

Boundary conditions for the Focus Area models will be derived from the River1D flow routing model, and geometric input will include more detailed ice cover characterization based on 2013-2014 winter measurements. Location-specific details such as open leads, channel blockage by ice, or ice jam flood releases may be modeled. These processes will be simulated if needed by other studies and if sufficient calibration data (open lead locations, ice-scars, ice jam dimensions, etc.) can be determined or estimated from observations. The hydraulic data to be derived from the Focus Area ice models will be determined on a case-by-case basis by the needs of instream flow, geomorphology, and other studies, but will include at a minimum extent of inundation, flow stages and velocities for post-Project winter conditions under load-following and base-load scenarios.

7.6.4.9. Model Accuracy and Error Analysis

The limitations of the ice model fall under three basic categories: 1) simplifying assumptions in the governing equations, 2) interpolation between measured points, and 3) error in measuring input data. The error introduced to the model for each of these categories will be analyzed as part of the ice processes model development.

All hydraulic and ice-processes models rely on simplifying assumptions in order to render the governing equations solvable. For instance, frictional resistance to flow in a channel is a complex phenomenon influenced by channel geometry, bed material, turbulence, and the texture of the underside of the ice cover, if present. However, most hydraulic models simplify all frictional resistance into a single value known as Manning's n. Estimating Manning's n for different flow conditions introduces error to the model. This error can be evaluated by varying Manning's n and determining the difference in results that would occur if the input value were 50% greater or smaller than the chosen value.

Models are generally limited in application to hydraulic conditions that best match the assumptions of the simplifying equations. River1D is a hydrodynamic and thermal model designed to route rapidly varying flows (such as reservoir releases) and calculate heat transfer between the atmosphere and the river. As a 1-D model, it assumes flow vectors are parallel across the channel and that water surface elevations are constant across a transect. Where flow is split into multiple channels or makes sharp curves, River1D would still assume all flow is parallel, even though in reality flow is diverging and converging. For most of the Middle River, this assumption should still allow reasonably accurate predictions of the effects of project operations on ice processes and winter flow routing. For smaller scale investigations into hydraulic conditions at specific side slough habitats, for instance, more accurate determination of flow around an island or bend may be needed. Thus, River2D may be applied to portions of some of the Focus Areas. The primary limitations of River2D are input data needs (detailed geometry and calibration data) and computational complexity. These limitations currently preclude the application of River2D to long reaches.

Models also rely on interpolation between measured input values, such as surveyed transects and meteorological data. Modeled values at surveyed cross-sections will be more accurate than those derived from the model between surveyed cross-sections. Surveyed sections were thus chosen carefully to coincide with changes in channel geometry. Air temperature and solar radiation varies along the river in between measurement points. Data collected in the 1980s in different locations and in 2012-2013 at ESS10-ESS80 will allow us to analyze the variability and estimate the likely error at unmeasured locations.

An assessment of model accuracy and sources of error will be included in the discussion of model results. The main sources of error to be analyzed include the following:

- Error associated with measuring input data (air temperature, solar radiation, water temperature, and ice concentration). This will be estimated by performing a sensitivity analysis to variance in each of these parameters.
- Error associated with estimating Manning's n under ice. This will be estimated by performing a sensitivity analysis using different values of Manning's n.
- Error associated with interpolating measured values over distances (river channel geometry between measured cross-sections, air temperature and solar radiation between meteorological stations). In some cases, this will be evaluated using a sensitivity analysis (for instance, to assess the impact of temperature variations between stations). To reduce the error associated with geometric interpolation, only results at measured cross-sections will be reported.

The limitations of applying a simplified model to complex conditions, such as applying River1D to sections of river with two-dimensional flow, will be assessed by comparing the results of the existing condition model to observed conditions (i.e., model calibration). The methods for calibration are described in Sections 7.6.4.1 through 7.6.4.4.

7.6.4.10. 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 will be modeled where transect data exist. Transect data exist between RM 75 and RM 100 (from the 2012 hydrology study), at Susitna Station at RM 26, and at RM 40, RM 48, and RM 60 (R&M 1985). Projected maximum monthly discharge from the preliminary reservoir operations model will be modeled with a range of ice thicknesses based on historical measurements. The potential for ice-cover delay in the Lower River will be assessed based on the estimated contributions of frazil ice to the Lower River from the Middle River using observations and model output.

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

Hydropower projects in northern North America, especially in Canada, and in other northern countries 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 the following:

- 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 will be a memorandum that will summarize 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 (including relevant international and non-hydro sites) 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 will be summarized and study authors contacted to obtain additional information that may be relevant to the Susitna River.

7.6.5. Consistency with Generally Accepted Scientific Practice

This study's methodologies for data collection, analysis, modeling, field schedules, and study durations are consistent with generally accepted practice in the scientific community. Field study methods follow those of the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) Engineering Manual (USACE 2002) and Michel (1972). The study plans were developed with the input of technical experts including the University of Alberta Ice Engineering Group. The River1D model is a state-of-the-art numerical model designed to evaluate freeze-up and break-up processes on large rivers, including the effects of hydropower regulation, and it will be applied under the guidance of the model developers.

7.6.6. Schedule

Field data will be collected as follows (freeze-up and break-up dates will vary depending on meteorological conditions, but are expected to fall within the range specified below):

- Continuous time-lapse camera data will be collected during the break-up and freeze-up periods 2012–2014.
- Freeze-up reconnaissance observations will be conducted between October 1 and January 15, 2012, 2013, and 2014.
- Ice thickness and elevation data along transects will be collected in conjunction with winter discharges collected by the instream flow routing study in January and March of 2013, and again in January and March of 2014.
- Open lead locations will be documented between March 1 and April 1 of 2012 and 2013, and 2014, and also once between January 1 and February 1 of 2014.
- Break-up reconnaissance observations will be conducted between April 1 and May 15, 2012, 2013, and 2014.

Model development and calibration will occur continuously during 2013 and 2014 (see Table 7.6-1). Preliminary modeling runs for existing conditions will be calibrated to 2012 and 2013 conditions by the end of 2013, and proposed operations scenarios will be run primarily in 2014. AEA will issue Initial and Updated Study Reports documenting actions taken to date within one and two years, respectively, of FERC's Study Plan Determination (i.e., February 1, 2013).

7.6.7. Relationship with Other Studies

The interdependency of the ice study with other studies is illustrated in Figures 7.6-1 and 7.6-2. Field observations of ice-scars and ice-related floodplain impacts from the Riparian Instream Flow Study (Section 8.6) will contribute to the Ice Processes in the Susitna River Study. The instream flow habitat and geomorphology studies will help define where Focus Areas should be for detailed winter data collection and modeling. The instream flow routing study will contribute winter stage and discharge measurements at transect locations. The Ice Processes in the Susitna River Study will contribute observations of open lead locations to the groundwater study, and observations of ice thickness and extent at Focus Areas and transect locations to the instream flow habitat, instream flow riparian, and geomorphology studies. General observations about break-up and freeze-up processes, especially where these processes impact the floodplain and riparian vegetation, will contribute to the instream flow riparian and geomorphology studies. These data will be provided in the form of aerial photographs and videos, GIS map layers, tabular data, and field reports.

The ice modeling study requires input data primarily from the water quality and instream flow routing studies. The water quality study will contribute baseline water temperature and meteorological data for the existing conditions model and predicted outflow temperatures for the proposed condition model. The instream flow routing study will contribute river channel geometry, rating curves, and predicted outflow hydrographs to the Ice Processes Model. Output from the model includes under-ice flow routing, temperature, ice thickness and elevation, and extent and timing of freeze-up and break-up. These data will be used by a number of studies including geomorphology, riparian, transportation, recreation, and instream flow. These data will be provided in tabular form and map form, where applicable.

The ice modeling study will perform detailed 1-D and 2-D modeling at Focus Areas defined by the instream flow study. The results of these models may include hydraulic properties of ice jam flood releases in reaches where ice jams have been observed. These results will be used by the geomorphology and instream flow riparian studies to estimate the effects of ice jam floods on sediment transport and riparian vegetation. Details of how these models will be applied will be worked out when the Focus Areas have been agreed upon, and the applicability of ice jam floods to local floodplain processes is assessed.

Several hydraulic and temperature models will be developed for the Middle River and Focus Areas. The Ice Processes River1D Model will provide flow routing and temperature results for the Middle River for the ice-affected period. The ice-affected period begins when a portion of the river cools to 32 degrees and ice begins to form in the fall, and continues until ice has flushed out of the river in the spring and ice is no longer affecting water temperature or river hydraulics. As discussed above, the Water Quality Temperature Model and the Open-Water Hydraulic Routing Model will provide flow routing and temperature results for the Middle River for the ice-free period. The detailed River2D and River1D models developed for instream flow Focus Areas will provide hydraulic data for the ice-affected period for these Focus Areas.

7.6.8. Level of Effort and Cost

Below is an estimate of costs associated with field documentation and model development in 2013–2014, which are the major components of the ice study.

Costs of Field Observation Effort

The 2013–2014 field components include the following, and are anticipated to roughly total about $1.5M (including helicopter hours):

- Ice thickness, elevation, and discharge measurements
- Open lead reconnaissance, mapping, and video processing
- Break-up reconnaissance, mapping, and video processing
- Time-lapse camera setup, maintenance, and processing
- Freeze-up reconnaissance, mapping, and video processing

The 2013–2014 modeling components include the following, and are anticipated to roughly total about $850,000:

- Geometric and meteorological data compilation and input
- Open water flow routing model development and calibration
- Existing condition ice-covered model development and calibration
- Focus Area geometry input
- Existing condition Focus Area model development
- Proposed condition hydrologic and meteorological data compilation and input
- Project alternative River1D model development
- Project alternative Focus Area model development
- Lower River HEC-RAS assessment

7.6.9. Literature Cited

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7.6.10. Tables

Table 7.6-1. Schedule for implementation of the Ice Processes in the Susitna River Study.

Activity	2012				2013				2014				2015
	1 Q	2 Q	3 Q	4 Q	1 Q	2 Q	3 Q	4 Q	1 Q	2 Q	3 Q	4 Q	1Q
Open Lead Surveys, ice thickness and elevation	—				—				—				
Break-up Reconnaissance		—				—				—			
Freeze-up Reconnaissance				—	—			—	—				
Initial Study Report								—	Δ				
Existing Condition 1-D Model Development					—	—	—	—	·····	·····	·····	·····	
Proposed Condition 1-D Model Development								—	—	—	—	—	·····
Intensive Site Models									—	—	—	—	·····
Updated Study Report											—	—	▲

Legend:

—— Planned Activity
----- Follow-up activity (as needed)
Δ Initial Study Report
▲ Updated Study Report

7.6.11. Figures

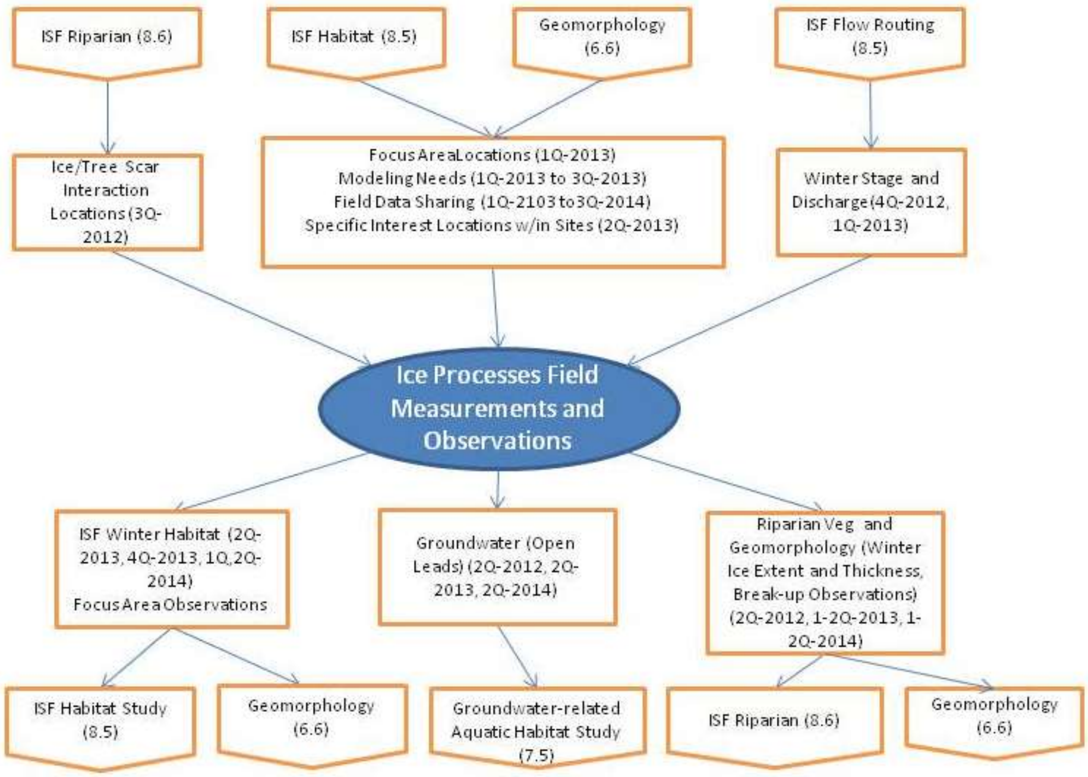

Figure 7.6-1. Relationship of ice observations to other studies.

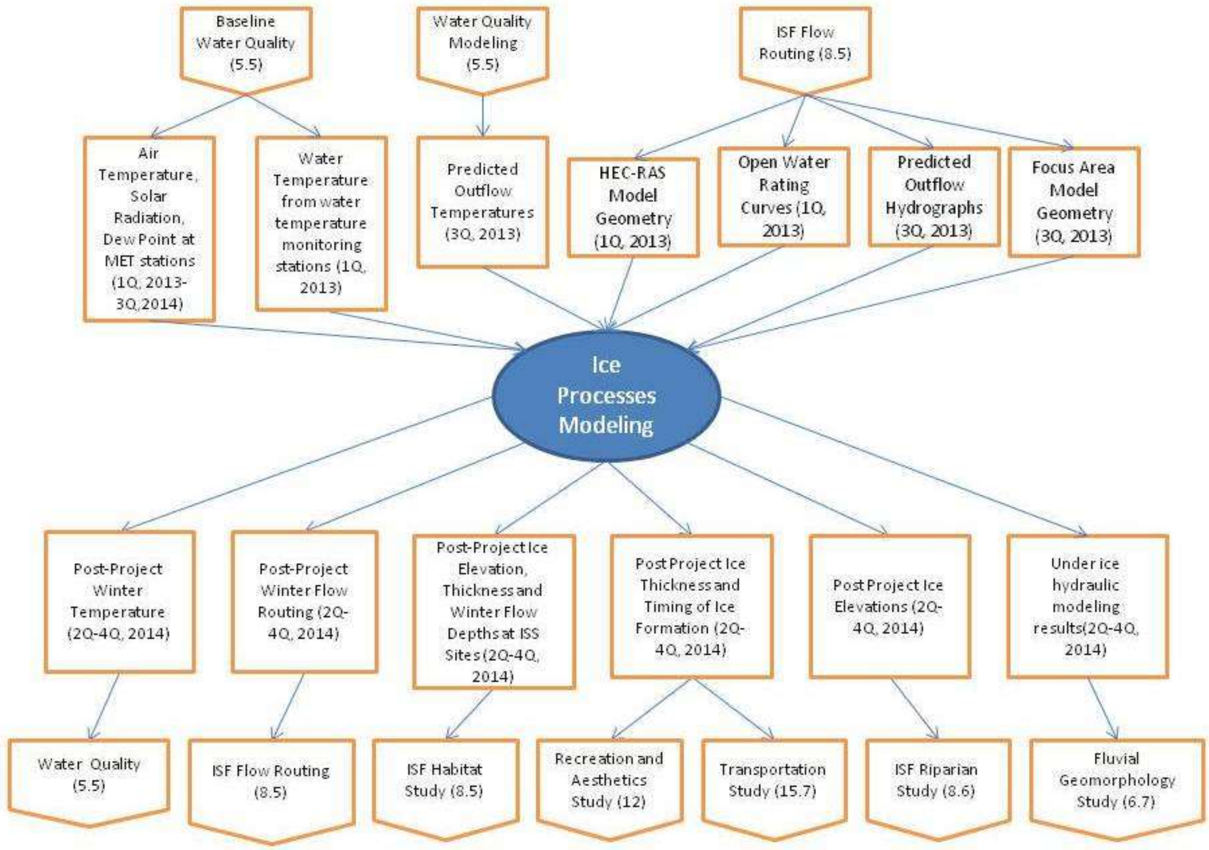

Figure 7.6-2. Relationship of ice modeling to other studies.