

# Susitna-Watana Hydroelectric Project Document

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July 1, 2013

Ms. Kimberly D. Bose  
Secretary  
Federal Energy Regulatory Commission  
888 First Street, NE  
Washington, DC 20426

**Re: Susitna-Watana Hydroelectric Project, FERC Project No. 14241-000;  
Fluvial Geomorphology Modeling Approach Technical Memorandum**

Dear Secretary Bose:

On April 1, 2013, the Federal Energy Regulatory Commission (Commission or FERC) issued its Study Plan Determination (April 1 SPD) for 14 of the 58 proposed individual studies in the Alaska Energy Authority's (AEA) Revised Study Plan (RSP) for the Susitna-Watana Hydroelectric Project, FERC Project No. 14241 (Project).

When approving the Study of Fluvial Geomorphology Modeling Below Watana Dam Study (RSP Section 6.6), the Commission recommended that AEA file a technical memorandum that provides additional information on the models and methods for addressing several aspects of the study plan. The recommendations were:

1. Modeling in Focus Areas

*We recommend that AEA file by June 30, 2013, the proposed technical memorandum related to the selection and application of the one- and two-dimensional models (proposed for development in the second quarter of 2013). We also recommend that the technical memorandum include the following information:*

1. *Specification of the one- and two-dimensional models to be used in the fluvial geomorphology modeling pursuant to this study as well as the aquatic habitat models pursuant to Study 8.5 (fish and aquatics instream flow);*
2. *Location and extent of one- and two-dimensional geomorphology and aquatic habitat modeling in project reaches, focus areas, and other study sites;*
3. *Rationale and criteria for model selection including an overview of model development;*
4. *For fluvial geomorphology modeling only, a detailed description of the processes and methods by which ice and large woody debris (LWD) would be incorporated into the modeling approach (as described in our*

*recommendations for incorporating large woody debris and ice processes into fluvial geomorphic modeling); and*

5. *Documentation of consultation with the Technical Work Group (TWG), including how the TWG's comments were addressed.*

2. Interaction of Geomorphic Processes in the Mainstem and Tributaries

*We recommend the study plan be modified to include a defined approach to evaluating geomorphic changes at the confluence of the Chulitna, Talkeetna, and Susitna rivers. The evaluation should extend from the mouth of both the Chulitna and Talkeetna rivers to the potentially affected upstream reaches of these tributaries. We recommend that AEA prepare a technical memorandum detailing a proposed approach for evaluating geomorphic changes in the three rivers confluence area, including explicitly stated objectives for evaluating geomorphic changes, an overview of the technical approach, additional data collection required, models and model components to be used, and additional analyses that would be conducted to address the stated objectives. We recommend that AEA file by June 30, 2013, this technical memorandum to include documentation and consultation with the TWG, including how the TWG's comments were addressed.*

3. Incorporating Large Woody Debris and Ice Processes into Fluvial Geomorphic Modeling

*As noted above in our analysis and recommendations for Modeling in Focus Areas, we are recommending that AEA file a technical memorandum with additional information on AEA's proposed model selection process. We recommend that an additional provision be added to the technical memorandum requiring that AEA describe in detail how ice and LWD would be incorporated into both one- and two-dimensional modeling approaches. The technical memorandum should explicitly state where and how each of the five scenarios for incorporating ice processes into one-dimensional and/or two-dimensional fluvial geomorphology modeling would be implemented, as well as details regarding where and how LWD pieces and/or accumulations would be incorporated into two-dimensional modeling.*

Consistent with the Commission's recommendations within the April 1 SPD, AEA is filing the attached Fluvial Geomorphology Modeling Approach Technical Memorandum (attached as Attachment A).

The draft version of this document was made available for review on May 3, 2013 and the material was presented at a Technical Workgroup Meeting on May 21, 2013. Attached as Attachment B is a comment response table that includes a description of how comments are incorporated into the final plan; and an explanation for why certain comments were not incorporated into the final plan.

As always, AEA appreciates the participation and commitment to this licensing process demonstrated by Commission Staff, federal and state resource agencies, and other licensing participants. AEA looks forward to working with licensing participants and Commission Staff in implementing the approved studies, which AEA believes will comprehensively investigate and evaluate the full range of resource issues associated with the proposed Project and support AEA's license application, scheduled to be filed with the Commission in 2015.

If you have questions concerning this submission please contact me at [wdyok@aidea.org](mailto:wdyok@aidea.org) or (907) 771-3955.

Sincerely,

A handwritten signature in black ink that reads "Wayne M. Dyok". The signature is written in a cursive style with a horizontal line underneath the name.

Wayne Dyok  
Project Manager  
Alaska Energy Authority

Attachments

cc: Distribution List (w/o Attachments)

## **Attachment A**

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Fluvial Geomorphology Modeling Approach Technical Memorandum (June 2013)

# **Susitna-Watana Hydroelectric Project (FERC No. 14241)**

## **Fluvial Geomorphology Modeling Approach Technical Memorandum**

Prepared for

Alaska Energy Authority



**SUSITNA-WATANA HYDRO**

*Clean, reliable energy for the next 100 years.*

Prepared by

Tetra Tech

June 30, 2013

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## ACRONYMS AND ABBREVIATIONS

1-D	One dimensional
2-D	Two dimensional
ADCP	Acoustic Doppler Current Profiler
AEA	Alaska Energy Authority
AOW	additional open water
ASPRS	American Society of Photogrammetry and Remote Sensing
BEI	Bank Energy Index
BG	Background
cfs	cubic feet per second
D	Depth
DHI	Danish Hydraulic Institute
D/S	Downstream
FA(s)	Focus Area(s)
FaSTMECH	Flow and Sediment Transport with Morphologic Evolution of Channels
FERC	Federal Energy Regulatory Commission
FHWA	Federal Highway Administration
GIS	Geographic Information System
HEC-RAS	Hydrologic Engineering Centers River Analysis System
HSC	Habitat Suitability Criteria
iRIC	International River Interface Cooperative
LIDAR	Light detecting and ranging
LWD	Large woody debris
MBH	Mobile Boundary Hydraulic
MD_SWMS	Multi-Dimensional Surface-Water Modeling System
OS	Operational Scenario
PDO	Pacific Decadal Oscillation
PRM	Project River Mile
RoR	Run of River
RSP	Revised Study Plan
SPD	Study Plan Determination
SRH-1D (2D)	Sedimentation and River Hydraulics-One Dimension (Two Dimensions)
SToRM	System for Transport and River Modeling
TIN	Triangulated Irregular Network
TWG	Technical Work Group
U/S	Upstream
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
V	Velocity
WSE	Water-surface elevation

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## 1. INTRODUCTION

After submittal of the Fluvial Geomorphology Modeling Technical Memorandum (Tetra Tech 2012) and the Revised Study Plan (Alaska Energy Authority [AEA] 2012), the Federal Energy Regulatory Commission (FERC) issued a Study Plan Determination (SPD) on April 1, 2013, that included three recommendations to provide additional information on the models and methods for addressing several aspects of the study plan. The recommendations were:

### 1. Modeling in Focus Areas

*We recommend that AEA file by June 30, 2013, the proposed technical memorandum related to the selection and application of the one- and two-dimensional models (proposed for development in the second quarter of 2013). We also recommend that the technical memorandum include the following information:*

- 1. Specification of the one- and two-dimensional models to be used in the fluvial geomorphology modeling pursuant to this study as well as the aquatic habitat models pursuant to Study 8.5 (fish and aquatics instream flow);*
- 2. Location and extent of one- and two-dimensional geomorphology and aquatic habitat modeling in project reaches, focus areas, and other study sites;*
- 3. Rationale and criteria for model selection including an overview of model development;*
- 4. For fluvial geomorphology modeling only, a detailed description of the processes and methods by which ice and large woody debris (LWD) would be incorporated into the modeling approach (as described in our recommendations for incorporating large woody debris and ice processes into fluvial geomorphic modeling); and*
- 5. Documentation of consultation with the Technical Work Group (TWG), including how the TWG's comments were addressed.*

The items in this recommendation are addressed in the following sections of this Technical Memorandum:

- Selection of 1- and 2-D models is included in Section 3. "Selection of Hydraulic and Bed Evolution Models."
- Application of 1- and 2-D models is included in Section 4. "Model Application."
- Specification of the 1-D model is Section 3.1.4 "Selection of 1-D Model."
- Specification of the 2-D model is Section 3.2.4 "Selection of 2-D Model."
- The selected 1- and 2-D models will be used for hydraulic input to the aquatic habitat analyses and modeling as described in Section 4.3.1.2 "Hydraulic Modeling for Habitat Analysis."
- Location and extent of 1- and 2-D models is included in Section 4.1 "Models and Survey Extent." Project reaches are described in Section 4.1.1 "Reach-Scale Model," Focus Areas are described in Section 4.1.2 "Local-Scale Focus Area Models," and other study sites (tributaries) are described in Section 4.1.3 "Other Tributary Models."

- Rationale and criteria for model selection are included in Sections 3.1.2 “Selection Criteria for 1-D models” and 3.2.2 “Selection Criteria 2-D Models.”
- Overviews of model development are Sections 3.1.1 “Overview of 1-D Model Development” and 3.2.1 “Overview of 2-D Model Development.”
- See recommendation 3, below, for items related to LWD and Ice modeling.
- Documentation of consultation is Section 5. “Consultation Documentation.”

## 2. Interaction of Geomorphic Processes in the Mainstem and Tributaries

*We recommend the study plan be modified to include a defined approach to evaluating geomorphic changes at the confluence of the Chulitna, Talkeetna, and Susitna rivers. The evaluation should extend from the mouth of both the Chulitna and Talkeetna rivers to the potentially affected upstream reaches of these tributaries. We recommend that AEA prepare a technical memorandum detailing a proposed approach for evaluating geomorphic changes in the three rivers confluence area, including explicitly stated objectives for evaluating geomorphic changes, an overview of the technical approach, additional data collection required, models and model components to be used, and additional analyses that would be conducted to address the stated objectives. We recommend that AEA file by June 30, 2013, this technical memorandum to include documentation and consultation with the TWG, including how the TWG’s comments were addressed.*

The items in this recommendation are addressed in the following sections of this Technical Memorandum:

- The defined modeling approach is included as Section 2.2 “Comprehensive Modeling Approach.”
- The evaluation of the Chulitna and Talkeetna Rivers, including the approach and objectives is part of Section 1.2 “Objectives.”

## 3. Incorporating Large Woody Debris and Ice Processes into Fluvial Geomorphic Modeling

*As noted above in our analysis and recommendations for Modeling in Focus Areas, we are recommending that AEA file a technical memorandum with additional information on AEA’s proposed model selection process. We recommend that an additional provision be added to the technical memorandum requiring that AEA describe in detail how ice and LWD would be incorporated into both one- and two-dimensional modeling approaches. The technical memorandum should explicitly state where and how each of the five scenarios for incorporating ice processes into one-dimensional and/or two-dimensional fluvial geomorphology modeling would be implemented, as well as details regarding where and how LWD pieces and/or accumulations would be incorporated into two-dimensional modeling.*

The items in this recommendation are addressed in the following sections of this Technical Memorandum:

- LWD processes and modeling methods are described in Sections 4.2.2.2 “Large Woody Debris Modeling” for 1-D modeling and 4.3.2 “Large Woody Debris Effects” for 2-D modeling.
- The five scenarios for ice modeling are described for 1-D modeling in Section 4.2.3 “Ice Effects” and for 2-D modeling in Section 4.3.3 “Ice Effects.”

This technical memorandum was developed to provide responses to the SPD recommendations. The intent is to identify the models and methods for addressing the specific comments and recommendations, recognizing that adjustments to the approaches may occur as additional information is acquired. The draft technical memorandum was included as a topic at the May 21, 2013, TWG meeting. This document will be updated in Q1 2014 as methods are refined based on field data collection, further coordination between this and other study components, and initial model development.

The selection of the one-dimensional (1-D) and two-dimensional (2-D) models, as well as the modeling approaches, has been coordinated with the other pertinent studies and the licensing participants. As part of the coordination process, an early draft of this technical memorandum, titled Fluvial Geomorphology Modeling (Tetra Tech 2012), was posted on the AEA website in May 2012.

The fluvial geomorphology modeling team will continue to develop the modeling approaches and coordinate with other studies on modeling needs. Site reconnaissance, data collection, and field observations in the summer of 2013 will also result in additional detail and possible adjustments to the modeling approaches. The length of modeling for the tributaries will be identified in the field, and hydraulic and sediment-transport modeling domains for the Focus Areas may be extended slightly, on the order of a channel width or less, to improve boundary conditions, but no adjustments will be made to the actual Focus Area limits. A revised modeling approach technical memorandum will be submitted in the first quarter of 2014. The revised memo will incorporate further understanding of the system gained from the summer 2013 field data collection and observations as well as the experience of performing the initial 1-D and 2-D model runs.

## 1.1 Background

The purpose of the fluvial geomorphology studies is to assess the potential effects of the Susitna-Watana Hydroelectric Project on the dynamic behavior of the river downstream of the proposed dam, with particular focus on potential changes in instream and riparian habitat. The Project will alter flow rates and sediment supply downstream of the dam, and the channel form is expected to respond to the changes. Whether the existing channel morphology will remain the same or at least be in “dynamic equilibrium” under post-project conditions is a significant question in any instream flow study. In other words, is the channel morphology in a state of dynamic equilibrium such that the distribution of habitat conditions will be reflected by existing channel morphology or will changes in morphology occur that will influence the relative distribution or characteristics of aquatic habitat over the term of the license (Bovee 1982)? This key issue prompts four overall questions that must be addressed by the geomorphology study:

- Is the system currently in a state of dynamic equilibrium?
- If the system is not currently in a state of dynamic equilibrium, what is the expected evolution over the term of the license?
- Will the Project affect the morphologic evolution of the Susitna River compared to pre-project conditions?
- If the Project will alter the morphology of the river, what are the expected changes over the term of the license?

The methods and results from the geomorphology study and the fluvial geomorphology modeling study will address these questions. These studies will be coordinated to:

- determine how the river system functions under existing conditions;
- determine how the current conditions form and maintain a range of aquatic and channel margin habitats; and
- identify the magnitudes of changes in the controlling variables and how these will affect existing channel morphology;

The fluvial geomorphology modeling will include a range of analyses for Existing and with-Project scenarios. These analyses will be used to:

- develop calibrated models to predict the magnitudes and trends of geomorphic response to the Project;
- apply the models to estimate potential for channel change for with-Project operations compared to existing conditions;
- support coordination with the geomorphic and other studies to integrate model results with understanding of geomorphic processes and controls to identify potential Project effects; and
- support the evaluation of potential Project effects by other studies that relate to channel and hydraulic results throughout the river corridor over the license period

To develop the modeling approach, specific issues that need to be addressed have been identified. These issues have been further differentiated into reach-scale and local-scale issues since the scale influences the proposed approach. The reach-scale modeling of the Susitna River will be performed using 1-D models, as they are well suited for long term simulations over long river reaches. Reach-scale results will address channel morphologic change on the order of  $10^1$  to  $10^0$  x the Susitna River width and subdivide the flow between channel, left floodplain, and right floodplain. The 1-D models will be used to assess reach-scale sediment-transport conditions, potential changes in bed and water-surface elevations, changes in channel profile, and potential changes in bed material gradation. The 1-D models will also provide boundary conditions for the local-scale modeling (i.e., the Focus Areas) that will be performed for relatively short reaches of the Middle Susitna River Segment using 2-D models.

The detailed results of the 2-D models will provide more localized information on changes in hydraulic and bed conditions over a range of flows for existing and with-project conditions. The local-scale results within Focus Areas will provide results over a range of scales. For the main channel the element size will be on the order of  $10^{-1}$  x the Susitna River width, but results can be integrated to obtain channel average results ( $10^0$  x width). Model refinement must be greater in areas of appreciable geometric change or where velocity magnitude and direction change rapidly. In these areas model refinement will be between  $10^{-1}$  and  $10^{-2}$  x Susitna River width. A high

level of refinement is required for detailed habitat analysis in the lateral features. These areas will be analyzed at the  $10^{-2}$  x Susitna River width. Floodplain and island areas tend to have higher flow resistance and the shallow, low velocity conditions do not require as detailed of a resolution in the models. These areas will be modeled at scales ranging from  $10^0$  to  $10^{-1}$  x Susitna River width.

- The fluvial geomorphology modeling will include evaluation of existing conditions compared to four operational scenarios over the 50-year term of the license. The four operational scenarios include maximum load following, base load, intermediate load following, and Run of River (RoR). These scenarios are described as: Max Load Following OS-1: The Maximum Load Following OS-1 scenario is based on the assumption that the entire load fluctuation of the Railbelt would be provided by the Susitna-Watana Project, and that all other sources of electrical power in the Railbelt would be running at base load. This assumed condition is not realistic for an entire year, and the results of this condition should be conservative with respect to assessing downstream impacts of load following.
- Base Load: This scenario assumes that the Project is operated to support the Railbelt base load and does not operate in a load following mode.
- Intermediate Load Following: This scenario represents an intermediate condition between the Maximum Load Following OS-1 and the Base Load scenarios in which the Susitna – Watana Project provides a portion of the load fluctuation of the Railbelt (the portion of the load fluctuation that the Project would supply has not been determined).
- Run of River: In this scenario the Project is operated to match outflow from the reservoir with inflow to the reservoir. The exception would be during the initial filling of the reservoir when inflow would exceed outflow. The major difference between this scenario and the pre-Project condition would be the trapping of the vast majority of the sediment load in the reservoir under the Run of River scenario.

### 1.1.1 Reach-Scale Issues

Reach-scale issues refer to aspects of the system that involve the overall behavior and general characteristics of the Susitna River over many miles. Each reach represents a spatial extent of the Susitna River that has a consistent set of fluvial geomorphic characteristics. Reach-scale issues include:

- Historical changes in the system and the existing status with respect to dynamic equilibrium (i.e., the overall sediment-transport balance).
- Changes in both the bed material (sand and coarser sizes) and wash (fine sediment) load sediment supply to the system due to trapping in Watana Reservoir.
- Long-term balance between sediment supply and transport capacity and the resulting aggradation/degradation response of the system for pre- and post-Project conditions.
- Changes in bed material mobility in terms of size and frequency of substrate mobilized due to alteration of the magnitude and duration of peak flows and sediment supply by the project.
- Project-induced changes in supply and transport of finer sediments that influence turbidity.

- Potential for changes in channel dimensions (i.e., width and depth) and channel pattern (i.e., braiding versus single-thread or multiple-thread with static islands) due to the Project and the magnitude of the potential change.
- Project-induced changes in river stage due to reach-scale changes in hydrology, bed profile, channel dimensions, and potentially hydraulic roughness.
- Characterization of the types, amounts, and features of LWD both in terms of supply and the overall effects of LWD on sediment transport.
- Changes in ice cover effects on sediment mobilization.

### 1.1.2 Local-Scale Issues

Local-scale issues refer to aspects of the system that involve the specific behavior and characteristics of the Susitna River at a scale associated with site-specific geomorphic and habitat features. Local-scale issues are addressed using a more detailed assessment over a smaller spatial area; however, these analyses must draw from and build upon the understanding and characterization of the system behavior determined at the reach scale. Local-scale issues include:

Processes responsible for formation and maintenance of the individual geomorphic features and associated habitat types. Potential changes in geomorphic features and associated aquatic habitat types that may result from effects of Project operation on riparian vegetation and ice processes. Effects of changes in flow regime and sediment supply on substrate characteristics in lateral habitat units. Changes in upstream connectivity (breaching) of lateral habitats due to alteration of flow regime and possibly channel aggradation/degradation. These changes may induce further changes in the morphology of lateral habitats, including:

- potential for accumulation of sediments at the mouth;
- potential for accumulation of fine sediment supplied during backwater connection with the mainstem;
- potential for changes in riparian vegetation that could alter the width of lateral habitat units.

Project effects at representative sites on the magnitude, frequency, and spatial distribution of hydraulic conditions that control bed mobilization, sediment transport, sediment deposition, and bank erosion.

Potential for change in patterns of bedload deposits at tributary mouths that may alter tributary access or tributary confluence habitat.

Potential for changes in accumulation of LWD and related effects on hydraulics, erosion, scour, and sediment transport.

Relating potential changes in ice cover and ice jams and the related potential effects on hydraulics; flow distribution between the main channel, lateral features, and floodplains; sediment transport; and erosion.

## 1.2 Objectives

The objective of this technical memorandum is to document the procedures for modeling the fluvial geomorphology of the Susitna River below Watana Dam. The overall goal is to model

and evaluate the potential Project effects of the proposed Susitna-Watana Hydroelectric Project on the fluvial geomorphology of the Susitna River and tributaries, and provide input to other team members for evaluating potential Project effects on habitat. The results of this and other geomorphology studies will be used in combination with geomorphic principles and criteria/thresholds defining probable channel forms to predict the potential for alterations of channel morphology. The purpose of this technical memorandum is to explain the proposed approach, including which models will be used, for the Susitna River fluvial geomorphology modeling..

Specific objectives include:

- Identify the 1-D sediment-transport model that will be used for reach-scale modeling and 2-D sediment-transport model that will be used for local-scale modeling, including
  - Providing the rationale and criteria for model selection;
  - Specifying the selected models; and
  - Providing an overview of model development of the selected models.
- Identify the location and extent of the 1-D and 2-D models that will be performed.
- Provide a description of the processes and methods for incorporating ice and LWD into the 1-D and 2-D geomorphic modeling.
- Describe the modifications to the study plan for evaluating geomorphic changes at the confluence of the Susitna, Chulitna, and Talkeetna Rivers.

As with the reach-scale 1-D sediment-transport analysis of the Susitna River, the objectives for evaluating geomorphic change at the Three Rivers Confluence are to compare existing conditions to with-Project scenarios related to 1) hydraulic interactions; 2) sediment-transport interactions; 3) channel form (aggradation, degradation, and width), and to relate these outcomes to potential Project effects.

There are no additional analyses for the Three Rivers Confluence anticipated beyond what is currently planned for the 1-D modeling of the Susitna River because the Chulitna and Talkeetna Rivers will be included as tributary reaches in the 1-D modeling. The reach-scale 1-D modeling of the Susitna, Chulitna, and Talkeetna Rivers will provide information on potential Project effects on hydraulics, sediment transport, and channel form through the analysis of:

- Velocity
- Depth
- Water-surface elevation
- Sediment loads
- Effective discharge
- Coincident flows and stage
- Aerial photo analysis of channel change
- Bed material gradation
- Aggradation and degradation
- Channel profiles
- Channel width
- Channel plan form

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## 2. OVERALL MODELING APPROACH

### 2.1 Background

The proposed modeling approach considers the need to address both reach-scale and local-scale conditions and the practicality of developing and applying various models based on data collection needs, computational time, analysis effort, and model limitations. Based on these considerations, an approach that uses 1-D models to address reach-scale issues and 2-D models to address local-scale issues will be used. A comparison of the capabilities of 1-D and 2-D models is provided in Table 2-1. Based on these capabilities and the need to evaluate potential Project effects over the majority of the system and at small habitat scales, a combination of 1-D and 2-D modeling approaches is required. Considering the broad physical expanse of the Susitna River system, the general hydraulic and sediment-transport characteristics of the various geomorphic reaches that make up the overall study area will be evaluated using 1-D computer models. The 2-D models will be used to evaluate the detailed hydraulic and sediment-transport characteristics at locations where it is necessary to consider the more complex flow patterns to understand and quantify flow distribution, habitat, breaching, and erosion/deposition issues related to changing hydrology, sediment supply, ice, and LWD conditions.

The 2-D models will be applied to the 10 Focus Areas that are representative of important habitat conditions and the various geomorphic reaches and associated channel classification types. These sites were chosen in coordination with the Fish and Aquatics Instream Flow, Riparian Instream Flow, Ice Processes, and Fish and Aquatic Resources studies to facilitate maximum integration of available information between the studies (see Sections 6.6.4.1.2.4, 8.5.4.2.1.2, and 8.6.3.2 of the Revised Study Plan (RSP), AEA 2012; R2 Resource Consultants 2013a, 2013b).

In addition to the reach-scale 1-D models for existing and with-project conditions, 1-D models will be developed for a selected subset of tributaries to provide sediment inputs to both the reach-scale model and the 2-D Focus Area models. These tributaries will be evaluated using models developed with cross section and bed material data collected near the mouth. Temporary gages and stage-discharge relationships at selected tributaries from other studies will provide a basis for estimating the flow record, and the models will be used to evaluate sediment loads. Because it is not practical to develop these models for all tributaries, a subset of tributaries will be modeled, and the resulting information will be used to develop flow and sediment supplies for other ungaged tributaries. The reach-scale model will be used to develop boundary conditions for the 2-D models that include water-surface elevation versus discharge rating curves for the downstream boundary, and the sediment supply at the upstream boundary.

Section 4, Model Application, provides locations and extents of the reach-scale 1-D model, local-scale 2-D models, and tributary models. Integration of the 1-D reach-scale modeling with the local-scale 2-D Focus Area modeling will provide the following advantages:

- The 1-D model will allow for efficient assessment of the hydraulic conditions and sediment-transport balance over the length of the study reach between Watana Dam and Susitna Station.

- The 1-D model reaches will extend up the Chulitna and Talkeetna Rivers to more fully represent these sediment sink/sources and to evaluate potential Project effects on the morphology and flooding potential of these tributary channels.
- The 1-D model uses cross-sectional data that are being obtained as part of the Open-Water Flow Routing portion of the Instream Flow studies plus additional cross sections to represent stream-wise variation in planform and profile.
- The 1-D model will provide the boundary conditions for the 2-D model in the Focus Areas, including starting water-surface elevations and upstream sediment supply.
- The 1-D model will provide reach-scale evaluation of potential sediment-transport effects due to changes in LWD amounts.
- The 2-D model applied at the Focus Areas, which are also being evaluated for the ice processes and riparian instream flow studies, will allow for the fullest level of integration of these efforts, particularly as they relate to assessments of potential changes in channel width and pattern.
- The 2-D model will provide additional information on erosion and sedimentation processes related to ice jam surge, channel and lateral features blockage by ice, and flows diverted onto floodplain areas by ice jams.
- The 2-D model at the Focus Areas will provide an understanding of the hydraulic conditions and sediment-transport processes that contribute to formation of individual habitat types.
- The 2-D model at the Focus Areas will be used to evaluate flow conditions and bed mobilization around LWD obstructions.
- The 2-D model provides a much more detailed and accurate representation of the complex hydraulic interaction between the main channel and the lateral habitats than is possible with a 1-D model.

## 2.2 Comprehensive Modeling Approach

As described above, 1-D modeling will be used to evaluate reach-scale channel morphology and 2-D modeling will be used at the focus areas for channel morphology and habitat analyses. These models require input (boundary conditions) on inflowing water and sediment, and downstream water surface (stage-discharge relationships). Sediment sampling will provide bed material gradations for the 1- and 2-D morphology modeling and field observations and calibration will be used to establish roughness values for all the morphology and hydraulic models. Therefore, the various types of models will need to be conducted in a sequence where certain models or analyses provide input to other models. For example, the dam operations and flow routing models will be used to provide flow hydrographs to the 1- and 2-D morphology models and the 2-D hydraulic models will provide hydraulic results for the habitat analysis models.

Table 2.2 illustrates the series of four types of models that will comprise the majority of the fluvial geomorphology modeling component of the study. For each of these model types the hydrology, sediment, hydraulic, and geometric (channel and floodplain) input and results are summarized. The source of the input information is identified when it is provided by another

study component. The type of information that will be used by other study components is identified for the fluvial geomorphic modeling results.

A prerequisite for the 1-D reach-scale morphology models is to determine the sediment supplied by each of the tributaries. Table 2.2 shows 1-D Tributary Sediment Modeling is the first modeling task. This modeling will be conducted for a range of flows to develop sediment rating curves at all tributaries located at Focus Areas, selected tributaries in the Lower Susitna River Segment for sediment supply and limited habitat analyses, and other selected tributaries in the Middle Susitna River Segment for sediment supply only. The range of tributaries will be used to develop sediment inflow for other tributaries throughout the model domain. Some of these tributaries will also be analyzed to provide information for the aquatic habitat and barrier studies.

The 1-D reach-scale morphology modeling will be run for a 50-year continuous flow record for Existing conditions and with-Project operational scenarios. The inflows to the model are the outflows from the dam for these conditions plus tributary inflows. Similarly, sediment passing the dam site will be included at the upstream limit of the model for these four conditions. Tributary sediment inflow will also be included. The only hydraulic boundary condition for this model is the stage-discharge relationship at the Susitna Station gage. The existing (2012 and 2013) channel and floodplain geometry will be the starting condition and the model will simulate potential channel change throughout the 50-year license period.

The reach-scale modeling will provide information to the 2-D local-scale morphology modeling efforts and to other study components. Local-scale models will be developed at the Focus Areas representing conditions at years-0, -25, and -50. If bed elevations or channel widths change over the 50 year period, the reach-scale model results will not only be used to alter the future (years-25 and -50) geometry, but will provide future downstream stage-discharge and upstream sediment supply rating curves to the local-scale models. The geometry and rating curve information must all be changed to maintain consistency between the models and to maintain internal consistency of the specific local-scale model. Because the local-scale models will be run for approximate 6-month open-water hydrographs, AEA does not anticipate that the rating curves will change appreciably. This assumption will be tested by evaluating the reach-scale model results and a shifting rating curve could be used if necessary.

The reach-scale models will also provide information to other studies. For example, aquatic and riparian habitat studies will use stage-discharge information at specific locations over the 50-year license period. There may also be the need to incorporate future channel change into the River1D ice model or flow routing models. This would only be necessary if the magnitude of geometric change would significantly affect the results of these studies.

The 2-D local-scale morphology models of the focus areas will not be run for the full 50-year period, but will be run for initial conditions and at years 25 and 50. These short duration runs (~6 months) will be performed for a range of hydrologic conditions including wet, average, and dry years with warm and cool Pacific Decadal Oscillation. This range of hydrologic conditions will be used to interpret the local-scale morphology models and compare Existing and with-Project conditions in the main channel, secondary channels, other lateral features, islands, and floodplain areas. Just as the channel changes in the reach-scale models are used to develop the

future geometry of the local-scale morphology models, the local-scale morphology model results will be used to modify lateral feature geometry in the 2-D local-scale hydraulic models.

The local-scale hydraulic models are necessary because they have much greater mesh refinement than can be achieved in the morphology models and they are steady-state models run for a range of flows rather than dynamic models run for seasonal hydrographs. The habitat analyses require a sequence of steady flows that can be applied to the range of flow magnitudes, durations, and timings of the analysis scenarios. The 2-D hydraulic modeling provides depth, velocity, water-surface elevation and other parameters for the range of flows throughout the local-scale model domains. These data will be used by the aquatic habitat, riparian habitat, and barrier studies to evaluate potential Project effects.

Though not specifically included in Table 2.2, additional 2-D morphology modeling will be conducted for a range of ice blockage and breakup conditions to evaluate erosion and deposition potential. The specific conditions for these simulations will be coordinated with input from agencies and other study components. Also not included in the table are changes in LWD that may occur over time. Descriptions of ice and LWD effects on sediment transport and model simulations are described in Section 4.2 for reach-scale modeling and 4.3 for local scale modeling.

### 3. SELECTION OF HYDRAULIC AND BED EVOLUTION MODELS

Many computer programs are available for performing movable boundary sediment-transport simulations. The choice of an appropriate model for this study depends on a number of factors, including: (1) the level of detail required to meet the overall study objective, (2) the class, type, and regime of flows that must be modeled, (3) characteristics of the bed material and wash load and, and (4) data necessary for model development and calibration. In addition, because of the wide range of sediment sizes present in the Susitna River, both the 1-D and 2-D models must be capable of routing sediment by size fractions, and ideally be capable of addressing deposition of fine sediments (wash load).

A variety of candidate models were evaluated for application on the Susitna River. The models fall into three categories of availability: (1) public domain, (2) commercial, and (3) proprietary. Public domain models are often developed by federal agencies or at universities and are available without cost. While they typically include a user interface, a commercial interface may also be available for these models. Commercial models are also available, though there are costs associated with acquiring the initial license, annual renewals, and support. Proprietary models are available only by contracting with the developer to perform an analysis. Proprietary models were not included as candidates. The candidate models for the 1-D and 2-D portions of the study are discussed below.

#### 3.1 1-D Models

Most 1-D movable-boundary, sediment-transport models are designed to simulate changes in the cross-sectional geometry and river profile due to scour and deposition over relatively long periods of time. In general, the flow record of interest is discretized into a quasi-unsteady sequence of steady flows of variable discharge and duration. For each model time-step and corresponding discharge, the water-surface profile is calculated using the step-backwater method to compute the energy slope, velocity, depth, and other hydraulic variables at each cross section in the network. The sediment-transport capacity is then calculated at each cross section based on input bed material information and the computed hydraulics, and the aggradation or degradation volume is computed by comparing the transport capacity with the upstream sediment supply (i.e., the supply from the next upstream cross section for locations not identified as an upstream boundary condition). The resulting aggradation/degradation volume is then applied over the cross-sectional control volume (i.e., the sub-channel concept), and the shape of the cross section is adjusted accordingly. The computations proceed from time-step to time-step, using the updated cross-sectional and bed material gradations from the previous time-step.

The 1-D sediment-transport models should not be applied to situations where 2-D and 3-D flow conditions control the sediment-transport characteristics because they do not consider secondary currents, transverse movement and variation, turbulence, and lateral diffusion; thus, the 1-D models cannot simulate such phenomena as point bar formation, pool-riffle formation, and planform changes such as river meandering or local bank erosion. The 1-D models typically distribute the volume of aggradation or degradation across the entire wetted portion of the channel cross section after each time-step; thus, the effects of channel braiding are not directly

considered. The 1-D models are, however, useful in evaluating the general sediment-transport characteristics and overall event or long term sediment balance of a given reach, and they are useful in providing boundary conditions for local-scale 2-D models.

### 3.1.1 Overview of 1-D Model Development

The following steps will be followed to develop the 1-D sediment-transport model. With few exceptions (as noted) the model development will be very similar regardless of the selected model. An overview of calibration and validation is included below. Additional information on model parameterization, calibration, validation, and sensitivity analysis will be provided in the study reports. Review and quality control procedures will be implemented throughout the model development process and are not indicated as individual steps. The steps are:

1. Determine the overall model layout.
  - Downstream boundary selected at a location of known stage-flow conditions.
  - Upstream boundary location(s) of known discharge and sediment supply information.
  - Tributaries that will be modeled geometrically with sediment routing.
  - Flow change locations of tributaries that are modeled as flow and sediment inputs.
  - Identification of split flow reaches around islands or in multiple-channel locations.
2. Develop cross-sectional data.
  - Determine cross section locations to represent the channel network.
  - Obtain channel cross-sectional geometry from land and bathymetric survey data.
  - Extend surveyed channel cross sections over islands and into floodplains using land-based survey and light detecting and ranging (LiDAR) data.
  - Determine channel and floodplain flow distances between cross sections.
3. Develop flow resistance (roughness) data for cross sections.
  - Channel base roughness based on bed material size.
  - Adjust base roughness to account for other sources of flow resistance such as channel irregularities, obstructions (including LWD), bed forms, and channel sinuosity. Note: project-related changes in amounts of LWD and sediment size can be related to flow resistance values.
  - Channel bank and floodplain (overbank) roughness based on land use, vegetative ground cover, and obstructions using field observations and aerial photography.
4. Develop bed and bank material gradation and layer information.
  - Surface sampling,
  - Subsurface sampling, and
  - Bank material samples.
5. Develop inflow hydrographs and sediment inflows for existing and with-project conditions.
  - For quasi-unsteady models, develop step hydrographs for the main channel and tributary inputs.
  - For fully unsteady models, use complete flow hydrographs.

- Develop sediment inflow rating curves based on tributary models or gaging station records that include sediment measurements.
6. Other considerations.
    - Bridge constrictions and geometries.
    - Ineffective flow areas around bridges and other rapid expansion and contraction areas.
    - Use of depth- or flow-variable roughness input.
  7. Test the hydraulic model over a range of flow conditions.
    - Evaluate cross-sectional spacing to determine the need for interpolated cross sections.
    - Review for potential geometric input errors in reach lengths or station-elevation data in areas of appreciable change or instability in hydraulic results.
  8. Calibrate and validate the hydraulic model.
    - Adjust flow resistance input values (within reasonable limits) to calibrate the hydraulic results using available data including:
      - Water-surface elevations at the time of cross-sectional survey,
      - Water-surface elevations collected at other flows,
      - Gaging station records,
      - Water level loggers at Focus Areas and other locations,
      - Discharge and velocity measurements including main channel and lateral features, and
      - High water marks reported from extreme flood events.
  9. Test the sediment-transport model.
    - Conduct a sediment-transport time-step sensitivity analysis to evaluate appropriate computational time steps for different flow magnitudes.
  10. Calibrate and validate the sediment-transport model.
    - Adjust sediment input values, bed layer properties, sediment-transport time step (within reasonable limits) to calibrate the hydraulic results using available data including: 1) Gage station measurements sediment loads, specific gage plots, flow area, width, depth, and velocity measurements, 2) Comparison cross sections, and 3) Longitudinal profiles.
  11. Run and evaluate the results of the sediment-transport simulations.

### 3.1.2 Selection Criteria for 1-D Models

The criteria for selecting a 1-D model for this project are primarily based on required functionality given the specific conditions of the Susitna River and its tributaries. There are several desirable characteristics as well, which may influence the decision if models are otherwise similar in their capabilities and performance. The desirable characteristics include: public domain, high level of experience with the model, and advanced graphical user interface for model input and review of results.

The required characteristics include:

- The model must accommodate sufficiently large number of cross sections to model over 100 miles of river including split flow reaches.
- The model must be capable of storing sufficiently large number of hydrograph ordinates to model flows over the 50-year license period.
- The model must be capable of simulating sufficient number and range of sediment sizes to represent the range of materials.
- Sediment-transport calculations must be performed by size fraction, especially to simulate bed material sorting and armoring processes in coarse bed channels.
- The model must include either (or both) the Parker (1990) or Wilcock and Crowe (2003) bedload sediment-transport equations, as these are the most applicable to the range of coarse bed conditions in the Susitna River and tributaries.
- Closed loop sediment-transport capability must be included to model sediment transported around islands and in multiple channel reaches. This is especially common in the Lower Susitna River Segment but is also important in the Middle River.

### 3.1.3 Potential 1-D Models

The 1-D models that are being considered for this study are:

- U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Centers-River Analysis System (HEC-RAS), version 4.1 (USACE 2010),
- U.S. Bureau of Reclamation's Sedimentation and River Hydraulics-One Dimension (SRH-1D), version 2.8 (Huang and Greimann 2011),
- Danish Hydraulic Institute's (DHI's) MIKE 11, version 2011 (DHI 2011a), and
- Mobile Boundary Hydraulics' (MBH's) HEC-6T, version 5.13.22\_08 (MBH 2010).

#### 3.1.3.1 HEC-RAS

HEC-RAS, version 4.1.0 (USACE 2010) is a publicly available software package developed by the USACE to perform steady flow water-surface profile computations, unsteady flow simulations, movable boundary sediment-transport computations, and water quality analysis. HEC-RAS includes a Windows-based graphical user interface that provides functionality for file management, data entry and editing, river analyses, tabulation and graphical displays of input/output data, and reporting facilities. The sediment-transport module is capable of performing sediment-transport and movable boundary calculations resulting from scour and deposition over moderate time periods, and uses the same general computational procedures that were the basis of HEC-6 and HEC-6T (USACE 1993; MBH 2010). In HEC-RAS, the sediment transport potential is estimated by grain-size fraction, which allows for simulation of hydraulic sorting and armoring. This model is designed to simulate long term trends of scour and deposition in streams and river channels that could result from modifying the frequency and duration of the water discharge and stage, sediment supply, or direct modifications to channel geometry. Benefits of the HEC-RAS software include widespread industry acceptance, public availability, and ease of use. Potential limitations of the program include excessive computer run-times, file size output limitations, and the inherent problems associated with 1-D modeling of aggradation and degradation by equal adjustment of the wetted portion of the bed that can result in unrealistic channel geometries. Another significant limitation of using HEC-RAS for

this project is that it does not currently incorporate “looped” networks (split flows around islands), which are common in the Middle and Lower Susitna River segments.

### 3.1.3.2 *SRH-1D*

SRH-1D (Huang and Greimann 2011) is a publicly available, mobile-boundary hydraulic and sediment-transport computer model for open channels that is capable of simulating steady or unsteady flow conditions, internal boundary conditions, looped river networks, cohesive and non-cohesive sediment transport (Ruark et al. 2011), and lateral inflows. The hydraulic and sediment-transport algorithms in SRH-1D are similar to those in HEC-RAS 4.1 and HEC-6T except that it also includes the capability to perform fully unsteady sediment-transport simulations. Advantages of SRH-1D include robust algorithms for hydraulic conditions and sediment routing, including sediment sorting. Potential disadvantages include limited testing for a broad range of conditions outside the U.S. Bureau of Reclamation and the lack of graphical user interface, which complicates data input and display of output.

### 3.1.3.3 *MIKE 11*

DHI’s MIKE 11 is a commercial software package developed for 1-D dynamic modeling of rivers, watersheds, morphology, and water quality. The model has the ability to solve the complete non-linear St. Venant equations (in only the streamwise direction) for open channel flow, so the model can be applied to any flow regime. MIKE 11 provides the choice of diffusive and kinematic wave approximation and performs simplified channel routing using either the Muskingum or Muskingum-Cunge methods. The program includes a module for simulating erosion and deposition of non-cohesive sediments. Advantages of MIKE 11 include its robust hydrodynamic capabilities (though not necessarily better than HEC-RAS), the user-friendly graphical interface, and good reporting and presentation capabilities. Disadvantages primarily stem from the commercial nature of this model and associated high cost of the software license. The MIKE 11 model does not include either the Parker (1990) or Wilcock and Crowe (2003) sediment-transport equations, which are favored for simulating bed material transport and sorting processes in coarse bed channels.

### 3.1.3.4 *HEC-6T*

HEC-6T is a commercially available program that was developed by William A. Thomas, former Chief of the Research Branch at the USACE Hydrologic Engineering Center. Mr. Thomas planned, designed, wrote, and applied the publically available version of HEC-6; HEC-6T is a commercial enhancement of the original version. HEC-6T is a DOS-based program that includes a Windows-based graphical user interface for input data manipulation and post-processing of simulation results. Limitations of this program include reduced capabilities for modeling numerous ineffective flow areas as compared to HEC-RAS 4.1 and limited capabilities of the graphical user interface. The model uses a quasi-unsteady flow representation. Advantages of HEC-6T are its wide application experience, looped channel capability, and large number of sediment-transport equations (including both Parker and Wilcock and Crowe), sediment sizes, and hydrograph ordinates. This model includes algorithms to limit the potential for unrealistic cross-sectional geometry. Model input is limited to 5,000 cross sections, which should be more than sufficient for the analysis of the Susitna River and tributaries as an average 250-foot cross-sectional spacing, which is less than half the channel width for much of the river, would be able

to cover nearly 240 miles of channel. This software is relatively inexpensive; the fact that it is commercial is not a significant limitation. The fluvial geomorphology modeling team has extensive experience with this program.

### 3.1.4 Selection of 1-D Model

Specific model characteristics and selection criteria are summarized in Table 3-1 along with an evaluation of each candidate model relative to the criteria. Based on the information provided above and experience with these models, the geomorphology study team will use HEC-6T for the reach-scale sediment-transport analysis. HEC-6T is capable of modeling looped networks, which eliminated HEC-RAS from consideration. It also includes both the Parker (1990) and Wilcock and Crowe (2003) sediment-transport relationships, which eliminated MIKE 11. The advantages of HEC-6T over SRH-1D include a high level of team experience with the model and its broader range of project applications. An advantage of SRH-1D is full unsteady flow analysis that can directly simulate flow attenuation. This is not an overriding consideration as quasi-unsteady analyses have been used successfully for many large rivers. The selection is supported by the modeling team's confidence that HEC-6T is capable of effectively and efficiently modeling the processes that are important for this scale of geomorphic analysis.

## 3.2 2-D Models

The 2-D models provide a much more detailed and accurate representation of the flow field than 1-D models because they predict both the magnitude and direction (in the horizontal plane) of the velocity, whereas 1-D models only predict magnitude of velocity in the downstream direction. Because the 2-D models input includes the complete bed topography at the resolution of the mesh, they also provide a more accurate representation of velocity, flow depth, and water-surface elevation throughout the model domain. In contrast, 1-D models assign a single water-surface elevation across each cross section. The velocity distribution can be estimated based on the distribution of conveyance across the cross section. The 2-D models vary water-surface elevation and distribute velocity based on the equations of motion (continuity and Newton's second law) and, therefore, account for flow conditions up- and downstream of the location of interest. As a result, 2-D models are superior in defining detailed hydraulic conditions in areas of special interest such as key habitat units.

The 2-D models are often categorized based on the solution technique and grid structure. Finite difference models use a regular grid, which simplifies the solution but limits the level of detail that can be achieved. Finite element and finite volume models use an irregular mesh that allows for more detail in areas of interest or in areas where there is appreciable variability. A subset of finite element models uses a curvilinear grid, which shares advantages and disadvantages of both regular grid and irregular mesh. For the requirements of this project, only models that use an irregular mesh are considered because of the highly variable channel and floodplain configurations (main channel, secondary channels, side sloughs, upland sloughs, tributaries, islands, and floodplains) and the need to provide accurate and detailed results for habitat evaluation.

The 2-D sediment-transport models are much more in their infancy. Publicly available 2-D sediment-transport models had very limited capability. One of the earliest available models,

STUDH (McAnally 1989) could only be used to simulate a single grain-size of fine sediment for evaluating sand transport. Models with capability to simulate coarse beds and multiple grain-size analyses are much more recent.

The 2-D hydraulic models of a specific location should be developed to accurately represent the geometry (bathymetry and topography) and variability of flow resistance, with appropriate boundary conditions. The mesh should include greater detail in areas with appreciable variability in geometry, velocity magnitude, velocity direction, depth, and roughness. The required boundary conditions include downstream water-surface elevation and upstream discharge (mainstem and tributary sources). The model boundaries should be located where flow is generally one-dimensional, although this requirement is not absolute and the effects can be reduced by extending the model limits up- or downstream from the areas of interest. 2-D sediment-transport models must include from good quality hydraulic modeling capability, and they must accurately represent surface and subsurface sediments, sediment depths, erodibility, and appropriate starting and boundary conditions. 2-D models are fully dynamic, which is a requirement for sediment routing, though many can be operated in a steady state. A sediment-transport simulation routes the sediment through the network and adjusts the elevation of the grid points (nodes) due to erosion and deposition. Modeled changes in node elevations provide a feedback on the hydraulic simulation due to changes in flow depth and conveyance. Unlike 1-D models, which aggrade or degrade the wetted portion of each cross section in concert, 2-D models adjust nodes individually based on the spatial variability of velocity, depth, sediment supply, and sediment-transport capacity.

### 3.2.1 Overview of 2-D Model Development

The following steps will be followed to develop the 2-D hydraulic and sediment-transport models of the Focus Areas. The model development and application will be similar regardless of the selected model. An overview of model calibration and validation is included below. Additional information on model parameterization, calibration, validation, and sensitivity analysis will be provided in the study reports. Review and quality control procedures will be implemented throughout the model development process and are not indicated as individual steps. The steps are:

1. Determine the overall model layout.
  - Downstream boundary stage-flow conditions developed from 1-D model,
  - Upstream (i.e., inflowing) discharge and sediment supply from 1-D model, and
  - Tributary flow and sediment input from tributary models.
2. Develop geometric base data.
  - Data from TIN (Triangulated Irregular Network) surface representation from land and bathymetric survey including necessary breaklines, and
  - Data from LiDAR bare earth data set for unsurveyed island and floodplain areas.
3. Develop model network.
  - Determine node and element locations and configurations to accurately represent geometry (bathymetry and topography) and changes in roughness. This may be either a network of triangular or a combination of triangular and quadrilateral elements, depending on the selected model.

- Refine the network in areas of appreciable change or areas of significant habitat interest.
  - Determine the node elevations from the geometric data.
  - Review mesh quality to assure that element size transitions and other modeling requirements are reasonably met. These include increased mesh refinement where there is appreciable geometric change or where velocity magnitude or directions changes occur. Identifying where additional model refinement is needed is somewhat based on experience and judgment. Large element sizes may miss large-scale flow separation (circulation) or may have numerical instabilities (oscillating or greatly changing velocities). If the instabilities are too large the model will terminate. Areas of instability are easily identified in the model results and these areas will be refined. The model results will also be reviewed to determine if there are currents that are not “reasonably” depicted based on our experience and these areas will be refined.
4. Develop flow resistance (roughness) and turbulence stress data.
    - Channel base roughness based on bed material size.
    - Adjust base roughness to account for other sources of flow resistance such as obstructions (including LWD) and bed forms. Note: project-related changes in amounts of LWD and sediment size can be related to flow resistance values. Also note that LWD will be simulated by including large debris areas as part of the geometry.
    - Channel bank and floodplain (overbank) roughness based on land use, vegetative ground cover, and obstructions using field observations and aerial photography.
    - Turbulence stress data, such as eddy viscosity coefficients, are used to incorporate internal flow stresses. Reasonable values depend on each model’s numerical representation of these stresses. ADCP data will be used to calibrate these coefficients.
  5. Develop bed and bank material gradation and layer information.
    - Surface sampling,
    - Subsurface sampling, and
    - Bank material samples.
  6. Develop water and sediment inflows for existing and with-project conditions.
    - For fully unsteady models, use complete flow hydrographs.
    - Steady flow simulations will be performed for habitat analysis based on the range of flows in the simulation record.
    - Develop sediment inflow rating curves based on tributary models and from the 1-D reach-scale model.
  7. Other considerations.
    - Ice jam breakup hydrographs.
    - Ice jam blockage of main channel or lateral features causing redistribution of flow.
    - LWD as obstructions or changes in roughness.
    - Erodibility of floodplain areas.
  8. Test the hydraulic model over a range of flow conditions.

- Further evaluate mesh quality and the need for additional mesh refinement for areas with appreciable changes in velocity magnitude or direction to adequately capture flow transitions.
9. Calibrate and validate the hydraulic model.
- Adjust flow resistance input values (within reasonable limits) to calibrate the hydraulic results. Calibration and validation will be performed using available data including:
    - Measured water-surface elevations throughout the focus areas during site survey and water-surface elevations measured at other times.
    - Measured velocities collected using acoustic doppler current profiler along selected cross sections and longitudinal profiles. Note that flow resistance values in 2-D models are often lower than comparable 1-D models because 2-D models directly account for processes that 1-D models must treat as lumped flow resistance parameters.
    - Water level loggers.
    - Discharge distribution between main channel and secondary channels.
    - High water mark information if available.
10. Test the sediment-transport model.
- Conduct a sediment-transport time-step sensitivity analysis to evaluate appropriate computational time steps for different flow magnitudes. These tests identify the longest stable time-step for model applications.
11. Calibrate and validate the sediment-transport model.
- Adjust sediment inflow rates and sizes, bed layer properties, sediment-transport time step (within reasonable limits) to calibrate the hydraulic results using available data including:
    - Main channel bed level changes observed in the 1-D modeling,
    - Comparisons of cross sections using 1980s and current data and between the 1-D and 2-D models, and
    - Longitudinal profiles.
12. Run and evaluate the results of the sediment-transport simulations.

### 3.2.2 Selection Criteria of 2-D Models

The criteria for selecting a 2-D model for this project are primarily based on required functionality based on the specific conditions of the Middle Susitna River Segment. As with 1-D models, there are also several desirable characteristics that may influence the decision if models are otherwise similar in their capabilities and performance. The desirable characteristics include: public domain, high level of experience with the model, moderate to fast execution speed, and advanced graphical user interface for model input and reviewing results. The required characteristics include:

- Capability for sufficiently large number of elements to model the Focus Areas at the required spatial resolution.

- Flexible mesh (irregular mesh) to accurately depict geometric and hydraulic variability.
- Capability to simulate a sufficiently number and range of sediment sizes to represent the range of materials in each Focus Area.
- Sediment-transport calculations must be performed by size fraction, especially to simulate bed material sorting and armoring processes in coarse bed channels.
- The model must include either (or both) the Parker (1990) or Wilcock and Crowe (2003) bed-load sediment-transport equations, as these are the most applicable to the range of coarse bed conditions in the Susitna River and tributaries. The model must be numerically stable under a wide range of flow conditions, especially as portions of the network wet and dry.

### 3.2.3 Potential 2-D Models

Potential 2-D models that are being considered for this study are:

- U.S. Bureau of Reclamation's SRH-2D, version 3 (Lai 2008; Greimann and Lai 2008),
- USACE's Adaptive Hydraulics ADH, version 4.3 (USACE 2013),
- U.S. Geological Survey's (USGS) Multi-Dimensional Surface-Water Modeling System (MD\_SWMS) suite, which includes SToRM or System for Transport and River Modeling and FaSTMECH or Flow and Sediment Transport with Morphologic Evolution of Channels models (McDonald et al. 2005; Nelson et al. 2010),
- DHI's MIKE 21, version 2011 (DHI 2011b),
- River2D modeling suite (Steffler and Blackburn 2002; Kwan 2009), and
- RiverFLO-2D model (Hydronia 2012).

#### 3.2.3.1 SRH-2D

The U.S. Bureau of Reclamation's SRH-2D (Lai 2008) is a finite-volume, hydrodynamic model that computes water-surface elevations and horizontal velocity components by solving the depth-averaged St. Venant equations for free-surface flows in 2-D flow fields. SRH-2D is a well-tested 2-D model that can effectively simulate steady or unsteady flows and is capable of modeling subcritical, transcritical, and supercritical flow conditions. The model uses an irregular mesh composed of a combination of triangular and quadrilateral elements. SRH-2D incorporates very robust and stable numerical schemes with a seamless wetting-drying algorithm that results in minimal requirements by the user to adjust input parameters during the solution process. A potential limitation of this software is that the mobile bed sediment-transport module is currently not publically available; however, Tetra Tech has gained permission to use the sediment-transport module on a number of other projects. Contact with the model developers indicates that permission would be granted for use in this study. The public download version of the model (Greimann and Lai 2008) includes a morphology module that calculates bedload transport capacities at each model node based on user-defined bed material sediment gradations, but does not simulate routing of that sediment and related adjustments to the channel bed. The advanced version of SRH-2D also includes a second module that uses the capacities from the morphology module to perform sediment-routing calculations and associated bed adjustments. Based on guidance from the model developers and confirmed by Tetra Tech's use of the model for other studies, the maximum practical model size is about 16,000 elements, which could be a potential

limitation in applying the model to larger-scale areas. This size limitation only applies to sediment routing simulations so much more detailed networks can be developed to support habitat simulations. Another potential limitation of the model is that sediment gradations are limited to eight size fractions, though the sizes are user specified so the size-class intervals can be tailored to the site conditions. SRH-2D uses the Manning equation for flow resistance, and does not provide a mechanism to vary the Manning coefficient with depth and discharge. In some cases, such as relatively shallow flow over a coarse bed, the hydraulic roughness can vary appreciably with depth. In these cases, other flow resistance equations that incorporate the roughness height relative to the flow depth may be preferable. The program performs wetting and drying by turning on and off elements. This approach is stable for the finite-volume method. The model is publicly available, with no associated licensing cost.

### 3.2.3.2 ADH

The USACE ADH program was developed by the Coastal and Hydraulics Laboratory (Engineer Research Development Center) to model saturated and unsaturated groundwater, overland flow, 3-D Navier-Stokes flow, and 2-D or 3-D shallow-water, open-channel flow conditions. ADH is a depth-averaged, finite-element hydrodynamic model that has the ability to compute water-surface elevations, horizontal velocity components and sediment-transport characteristics (including simulations to predict aggradation and degradation) for subcritical and supercritical free-surface flows in 2-D flow fields. The ADH mesh is composed of triangular elements with corner nodes that represent the geometry of the modeled reach with the channel topography represented by bed elevations assigned to each node in the mesh. A particular advantage of the ADH mesh is the ability to increase the resolution of the mesh—and thereby the model accuracy—by decreasing the size of the elements during a simulation in order to better predict the hydraulic conditions in areas of high hydraulic variability. However, use of the adaptive mesh option often results in excessively long simulation run times (several days per run) that could be impractical for this study. The model uses either the Manning or roughness height flow resistance equations. Additionally, the wetting and drying algorithm in this model has significant numerical stability limitations when applied to shallow, near-shore flows that occur in rivers like the Susitna River. The ADH model does not include either the Parker (1990) or Wilcock and Crowe (2003) sediment-transport equations, which are favored for coarse bed channels and simulating armoring processes. The model is publically available.

### 3.2.3.3 MD\_SWMS/SToRM

The USGS's MD\_SWMS model (McDonald et al. 2005) is a pre- and post-processing application for computational models of surface-water hydraulics. This system has recently been incorporated into a public-domain software interface for river modeling distributed by the International River Interface Cooperative (iRIC) (Nelson et al. 2010). iRIC is an informal organization made up of academic faculty and government scientists whose goal is to develop, distribute, and provide education for the software. iRIC consists of a graphical user interface that allows the modeler to build and edit data sets, and provides a framework that links the interface with a range of modeling applications. The graphical user interface is an interactive 1-D, 2-D, and 3-D tool that can be used to build and visualize all aspects of computational surface-water applications, including grid building, development of boundary conditions, simulation execution, and post-processing of the simulation results. The models that are

currently included in iRIC are FaSTMECH and STORM, which are part of the MD-SWMS package, as well as NAYS, MORPHO2D, and a Habitat Calculator for assessing fish habitat under 2-D conditions. Of these models, STORM is the most relevant for modeling the Susitna River for purposes of this project, primarily because it uses an unstructured triangular mesh (in contrast to the curvilinear mesh required for FaSTMECH) and provides both steady-flow and unsteady-flow capability. NAYS is a fully unsteady, 2-D model designed for a general, non-orthogonal coordinate system with sophisticated turbulence methods that can evaluate the unsteady aspects of the turbulence, and MORPHO2D is 2-D model capable of analyzing the interactions between sediment transport and vegetation and between surface water and groundwater. Both NAYS and MORPHO2D were developed in Japan, and have not been widely used or tested in the U.S. The STORM model blends some of the features of finite volumes and finite elements, and uses multi-dimensional streamline upwinding methods and a dynamic wetting and drying algorithm that allows for the computation of flooding. Subcritical, supercritical, and transcritical flow regimes (including hydraulic jumps) can be simulated. The program includes advanced turbulence models and an automatic mesh refinement tool to better predict the hydraulic conditions in areas of high hydraulic variability. The most recent version of the STORM model does not include the capability to model sediment-transport, but the program authors are currently working on implementing sediment-transport algorithms that may be available for use in this study (J. Nelson, pers. comm., 2012). MD\_SWMS has been successfully applied to a number of rivers in Alaska, including the Tanana River near Tok (Conaway and Moran 2004) and the Copper River near Cordova (Brabets 1997); some of the modules are currently being validated using high-resolution scour data from the Knik River near Palmer. This modeling package is publicly available, with no associated licensing cost.

#### 3.2.3.4 *MIKE 21*

Developed by DHI, MIKE 21 is a commercial modeling system for 2-D free-surface flows that can be applied in rivers, lakes, coastal, and ocean environments. It has the ability to simulate sediment transport and associated erosion and deposition patterns. The software includes a Windows-based graphical user interface as well as pre- and post-processing modules for use in data preparation and analysis of simulation results, and reporting modules that have graphical presentation capabilities. MIKE 21 has the ability to model a range of 2-D mesh types that include Single Grid, Multiple Grid, Flexible Mesh, and Curvilinear Grid. The MIKE-21 model uses either Manning number (numerically similar to Manning  $n$ ), or Chezy flow resistance equations, but does not include roughness height. Wetting and drying are element-based with a transitional condition where a layer of water is maintained on dry nodes until the element is fully dry. The model does not include either the Parker (1990) or Wilcock and Crowe (2003) sediment-transport equations, which are favored for coarse bed channels and simulating armoring processes. MIKE-21 is commercially available with a relatively expensive licensing cost compared to other available models.

#### 3.2.3.5 *River2D Modeling Suite*

River2D is a 2-D, depth-averaged finite-element hydrodynamic model developed at the University of Alberta and is publically available from the university with no associated licensing cost. The River2D suite consists of four programs: R2D\_Mesh, R2D\_Bed, River2D, and R2D\_Ice, each of which contains a graphical user interface. The R2D\_Mesh program is a pre-

processor that is used to develop the unstructured triangular mesh. R2D\_Bed is used for editing the bed topography data and R2D\_Ice is used to develop the ice thickness topography at each node for simulating ice-covered rivers. Following mesh development, the hydrodynamic simulations are run using the River2D program, which also includes a post-processor for visualizing the model output. River2D is a very robust model capable of simulating complex, transcritical flow conditions using algorithms originally developed in the aerospace industry to analyze the transitions between subsonic and supersonic conditions (transonic flow).

Many 2-D models become numerically unstable due to wetting and drying of elements; however, River2D uniquely handles these conditions by changing the surface flow equations to groundwater-like flow equations in these areas. The model computes a continuous free surface with positive (above ground) and negative (below ground) water depths, which allows the simulation to continue without changing or updating the boundary conditions, increasing model stability. The transmissivity of the subsurface flow is essential for the wetting and drying algorithm but can create surface-flow continuity issues. The model uses only roughness height for flow resistance. For some conditions, such as in vegetated banklines or floodplains, the Manning roughness equation is often preferable.

River2D also has the capability to assess fish habitat using the PHABSIM weighted-usable area approach (Bovee 1982). Habitat suitability indices are input to the model and integrated with the hydraulic output to compute a weighted useable area at each node in the model domain.

River2D Morphology (R2DM) is a depth-averaged, two-dimensional hydrodynamic-morphological and gravel transport model developed at the University of British Columbia. The model was developed based on the River2D program, and is capable of simulating flow hydraulics and computing sediment transport for uni-size and mixed-size sediment using the Wilcock-Crowe (2003) equation over the duration of a hydrograph. R2DM can be used to evaluate the changes in grain-size distributions, including fractions of sand in sediment deposits and on the bed surface. The number of size classes is set at 12 and the sediment sizes are preset in the software ranging from 0.125 mm to 256 mm. The sediment-transport module has been verified using experimental data, and was successfully applied to the Seymour River in North Vancouver, British Columbia (Smiarowski 2010). River2D is available in the most recent version of iRIC (version 2.0).

### 3.2.3.6 *RiverFLO-2D*

RiverFLO-2D is a commercial two-dimensional, depth-averaged finite-element hydrodynamic and mobile-bed model developed by Hydronia LLC. The model uses triangulated mesh (irregular grid) and efficient wetting and drying methods. The wetting and drying algorithm includes partially wet elements by assigning nodes with positive depth as zero velocity. The model used Manning equation to represent surface roughness. RiverFLO-2D is commercial at moderate cost (approximately \$5,000) including the SMS interface. The model includes eight sediment-transport equations but does not include Parker (1990) or Wilcock and Crowe (2003). The sediment is represented by a single (median) particle size except for the Van Rijn equation which also includes  $D_{90}$ . Without a particle size gradation or multiple layers, armoring processes cannot be simulated. This is a significant shortcoming for evaluating potential Project effects. This model is commercially available.

### 3.2.4 Selection of 2-D Model

Table 3-2 provides a summary of the 2-D models, their characteristics, and limitations. Four of the six models can be eliminated based on the model selection criteria (Section 3.2.2). SToRM was eliminated as it does not currently include sediment transport. ADH, MIKE 21, and RiverFLO-2D were eliminated because they do not include either the Parker (1990) or Wilcock and Crowe (2003) sediment-transport equations and RiverFLO-2D does not include sediment gradations. Based on river conditions and project requirements, two of the models (SRH-2D and River2D) are good candidates for sediment-transport analyses related to the project. The SRH-2D model includes both of the desired sediment-transport relationships and the River2D model includes Wilcock and Crowe (2003). Other differences between the models include the method for specifying flow resistance, approach for wetting and drying of elements, and limits on model size (number of elements). SRH-2D only includes the Manning equation and River2D only includes roughness height for estimating hydraulic roughness. Because there are situations where either approach for flow resistance has advantages, this difference was not a deciding factor.

Wetting and drying is a significant issue for 2-D modeling because model instability can be significant when areas of the model are added or eliminated from the network as the water-level changes. Experience with SHR-2D indicates that it performs very well for wetting and drying in shallow areas along the margins of the channel. When the centroid of the element is dry, the element is eliminated and it is reintroduced into the network when the centroid is rewetted. River2D does not eliminate elements from the model, but converts nodes to a subsurface flow controlled by the transmissivity and storativity. Without including transmissivity, the entire mesh needs to be submerged. These parameters should be set such that the amount of flow traveling below the surface is negligible, but can be adjusted to improve transient analysis. If transmissivity is too high, surface-flow continuity could be a problem, especially for simulating low flow conditions or when large portions of the network are “dry.”

Neither model has significant size limitations for hydraulic simulations; both can accommodate more than 100,000 elements. SRH-2D is limited to approximately 16,000 elements for sediment routing simulations, which may be a limitation for the Focus Areas. Significantly larger numbers of elements will be included for habitat simulations, as needed. Although the number of sediment size classes in SRH-2D is limited to eight, they are user specified so they can be adjusted based on site conditions. River2D has 12 size classes, but are preset in the model and sizes greater than 256 mm or less than 0.125 mm are not included. The fluvial geomorphology team has considerable experience using the SRH-2D model for both hydrodynamic and mobile boundary simulations. Other team members have experience using the ice and habitat functionality of River2D. The SRH-2D model does not compute habitat suitability indices directly, but the output can be readily used for that type of analysis with spreadsheet and GIS tools, a procedure that has been used by the modeling team for many projects. Although River2D’s groundwater approach for element wetting and drying is a concern given the potential range of flows needed for sediment-transport analysis, it is not known if this will create continuity problems for the specific simulations that are required for this study. River2D will be one of the tools used for the ice processes modeling. This factor and the habitat functionality that has been incorporated directly into the model represent advantages of using River2D for the project.

Because of the uncertainty in how the models will perform, the geomorphology modeling team members recommend testing the SRH-2D and River2D models for sediment transport and habitat analysis at one Focus Area to assess their capabilities and limitations with respect to the characteristics of the Susitna River and the specific questions that must be answered by the modeling. The primary criteria for making the final model selection will center on the ability of the model to produce representative flow and sediment-transport results for existing conditions, including flow continuity, comparisons to observed velocities and depths, overall flow distribution, sediment-transport capacity, bed evolution, and armoring. Other criteria will include ease of model development, limitations on model size and spatial resolution, execution speed, and convenience performing post-run analyses. Since these models use essentially the same basic types of data, the outcome from the proposed test will not affect the data collection plan.

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## 4. MODEL APPLICATION

The selected models will be used to address hydraulics, sediment transport and morphology at reach and local scales. Additional 1-D models will be used to provide input to these models. This section describes the application of the individual models to address specific aspects of the study and the interaction between the models.

The overall river will be simulated using a 1-D reach-scale model applied to existing and with-project operation scenarios. The reach-scale model will extend from the Watana Dam site down to Susitna Station and will include portions of the Talkeetna and Chulitna rivers as tributary reaches. Local-scale modeling will be performed with 2-D models at each of the 10 Focus Areas. Some Lower Susitna River tributaries will be modeled with 1-D models to support habitat evaluation, but also to develop sediment input for the reach-scale model. In the Middle Susitna River Segment, sediment input will be evaluated for tributaries at the Focus Areas to evaluate delta formation, fish barrier analysis, and habitat analysis. The results from tributary analyses at Focus Areas will be supplemented by analyzing sediment supply from other tributaries. Not all tributaries will be modeled, but a sufficient range of tributary conditions will be evaluated to develop sediment and flow input for the tributaries throughout the Middle and Lower Susitna River Segments.

### 4.1 Models and Survey Extent

#### 4.1.1 Reach-Scale Model

Figures 4-1 through 4-10 show the cross sections and channel network for the Susitna River 1-D model that, as previously discussed, will extend from Susitna Station (Project River Mile [PRM] 29.9) to the Watana Dam site (PRM 187.1). The figures show four types of cross sections: (1) cross sections shown in green were surveyed in 2012, (2) cross sections shown in yellow will be surveyed in 2013, (3) lower priority cross sections in red that may be surveyed in 2014, and (4) cross section locations on small secondary channels are contained in red circles. The yellow lines depict the extent of the model cross sections that approximately encompasses the 100-year floodplain. Only the below-water, in-channel areas (similar to the 2012 cross sections) will be surveyed directly. The remaining extent will be developed using detailed LiDAR data. The lower priority sections are not believed to be needed for model development because they are in locations where cross section interpolation should be adequate based on having relatively smooth transitions between up- and downstream surveyed sections. These 2013 sections were prioritized to have sufficient information to develop a complete model recognizing the potential for a shortened survey field season. Additional survey (2014) may be conducted if it is apparent that more cross sections are required in the modeling.

The Terrascan (Tetra Tech customized software) ground classification algorithm will be used to create the bare-earth model from the LiDAR data. The bare-earth class is developed from the set of returns classified as 'Only' and 'Last of Many' by an iterative method. First, a rectangular filter is passed over the "Unclassified" points and a set of local low points is selected to seed the bare-earth class. Then all the unclassified points are compared to the triangulated surface defined by the set of bare-earth points and those that are found to be close enough to fall within a certain

angle and distance of the surface are added to the bare-earth class (ASPRS Class 2). The process is repeated with the expanded bare-earth class until the number of points being added to the bare-earth class declines.

The figures also show the reaches (blue lines) and junctions (red dots). When flow splits around islands or there are significant and distinct flow paths, the model will include separate reaches. Junctions are required where flow and sediment splits or re-connects. The most complex area of reaches occurs between the Yentna River confluence and PRM 44.5 (Figure 4-1). This area is quite complex from a 1-D modeling perspective; thus, some simplification was required, especially between PRMs 34 through 38.

Tributaries that are modeled only as point-source flow and sediment input do not require junctions, but tributaries that are modeled as reaches do. Tributaries that will be modeled as reaches are the Talkeetna and Chulitna rivers. The Yentna River will be modeled as a flow/sediment input based on flow data from the upstream gage and sediment rating curves. Based on the discussion at the June 14, 2012, Water Resources TWG meeting and review comments and recommendations in the April 1, 2013, Study Plan Determination, the Three Rivers Confluence area (Susitna, Talkeetna, and Chulitna confluence) can be adequately modeled for purposes of this study with the 1-D sediment-transport model (Figure 4-11). Figure 4-11 shows the cross sections that are prioritized for survey in 2013. More cross sections will be developed for the Chulitna River based on LiDAR data and some additional cross sections may be surveyed in 2014 on the Talkeetna River, if necessary. The existing gage on the Talkeetna River reach is at the upstream limit of the survey reach, and this will be the upstream extent of the model.

The modeled reach of the Chulitna River will extend approximately 10 miles to a location of channel narrowing. Model topography that will be developed from the LiDAR data will be collected during low flow. The surveyed bathymetry from the lower Chulitna River will be used to guide adjustments to the low flow channel to account for the missing topography below the water surface in the LiDAR data. The LiDAR data will be used to estimate water-surface slope (elevation drop over channel distance). Using slope, roughness, discharge, and flow top-width, AEA will be able to estimate the flow area and average depth at each cross section. The channel form from the surveyed cross sections will be used to guide the development of the below water channel shape. This approach is feasible because the LiDAR will be collected at low flow when flow depths are shallow on this wide and braided section of the Chulitna River.

#### **4.1.2 Local-Scale Focus Area Models**

In addition to the large-scale 1-D model of the Middle and Lower Susitna River segments, local-scale 2-D models will also be developed in the 10 Focus Areas located in the Middle River. The 10 focus areas are shown in Figures 4-5 through 4-10 and are designated by the downstream PRM as FA104, FA113, FA115, FA128, FA138, FA141, FA144, FA151, FA173, and FA184. Each of the Focus Areas is shown in detail in Figures 4-12 through 4-21. At each of the Focus Areas, detailed survey (land and bathymetric) will be performed including the areas along the water's edge and below water. Some floodplain survey will also be performed, but the primary topographic data source for the floodplain areas will be the LiDAR data (see Section 4.1.1 for discussion of development of bare-earth model). The survey and LiDAR data will be used to generate a detailed TIN surface-representation of the area that will be the basis for assigning elevations to the nodes of the 2-D model networks.

The Riparian Instream Focus Areas (FAs) that are co-located with the geomorphology FAs 104, 115, 128, 138, and 173 extend into the vegetated islands and floodplain areas adjacent to the channel (Figures 4-12 through 4-21). The 2-D hydraulic and sediment-transport model will include main channel, secondary channels, sloughs, tributaries, islands and floodplains. The 2-D model limits will extend up to one channel width up- and downstream from the Focus Area limits to reduce boundary condition effects within the primary area of interest, though in many cases the model limits will coincide with the FA limits. In most cases, surveyed cross sections are located relatively close to the Focus Area limits and can be used to extend the models. At FA104 (Figure 4-12), the 2-D model will be extended approximately one channel width up- and downstream of the FA. At FA113 (Figure 4-13), the model downstream boundary will be located at PRM 113.6. The upstream boundary of FA113 is coincident with the downstream boundary of FA115 (Figure 4-14) and these FAs will probably be included in a single 2-D model. If the combined model is too large, then two overlapping models will be developed to provide coverage of the areas. The upstream boundary of FA115 is suitable as the upstream model boundary.

Neither the upstream nor downstream boundary of FA128 (Figure 4-15) is ideal, but neither can be improved significantly within a reasonable distance of the FA boundary. As a result, the model boundaries will be located approximately one channel width up- and downstream to reduce boundary condition effects.

The upstream boundary of FA138 (Figure 4-16) is suitable for 2-D modeling, but the downstream boundary is not. The model boundary will, therefore, be moved downstream approximately one channel width and rotated perpendicular to flow.

The downstream model boundary at FA142 (Figure 4-17) will be located approximately one channel width downstream to move the boundary condition away from the mouth of Indian River. The upstream boundary is suitable as a 2-D model boundary. Both the up- and downstream model boundaries will be located approximately one channel width from the boundaries at FA144 (Figure 4-18). The upstream boundary at FA151 (Figure 4-19) is close to the mouth of Portage Creek, so extending the model boundary upstream will be considered, though the variable river width at this location may also present additional challenges. The downstream model boundary at FA151 will be located approximately one channel width from the FA boundary. The downstream boundary of FA173 (Figure 4-20) is suitable for 2-D modeling and the upstream model boundary will be moved approximately one-half channel width upstream. Both of the boundaries at FA184 (Figure 4-21) are adequate for 2-D modeling, and moving either could create modeling challenges because moving the downstream boundary would put it into the Tsusena Creek delta and moving the upstream boundary would put it into a widened area with channel bars.

Eight of the Focus Areas encompass 11 tributaries including: Portage Creek, Indian River, Skull Creek, Gash Creek, Slash Creek, Whiskers Creek, and 5 unnamed tributaries (Figure 4-22, Table 4-1). Each of the tributary mouths and a nominal reach length will be included in the Focus Area models to simulate delta processes and tributary bed response. The length of the reaches will be determined in the field, but are anticipated to be between 0.2 and 0.7 miles. Approximately 5 cross sections will be surveyed in each tributary to develop sediment input rating curves to the Focus Area models.

### 4.1.3 Other Tributary Models

In addition to the Focus Areas, HEC-RAS sediment-transport models will be developed for four tributaries outside the Focus Areas in the Middle River and five additional tributaries in the Lower River (three in 2013 and 2 in 2014). The Middle River tributaries will include short reaches in the downstream portions of Tsusena Creek, Fog Creek, Gold Creek, and Lane Creek to determine sediment inputs to the reach-scale model (see Figure 4-22). In the Lower River, local-scale sediment-transport models will be developed for the mouth and approximately 1-mile reaches of Trapper Creek, Birch Creek, Sheep Creek, Caswell Creek and Deshka River to determine potential morphologic effects of with-Project scenarios and to provide sediment inputs to the reach-scale model (Figure 4-23, Table 4-1).

## 4.2 Reach-Scale 1-D Modeling

### 4.2.1 Bed Evolution and Hydraulic Modeling

The 1-D model will be used to simulate bed evolution throughout the model domain for existing conditions and with-Project operational scenarios. Inclusion of the Chulitna and Talkeetna rivers as modeled reaches will allow direct evaluation of potential Project effects on hydraulic and sediment-transport conditions in the lower portions of these tributaries. This approach provides a more complete evaluation of potential Project effects on these tributaries than would be achieved by treating them only as point-source water and sediment inputs. For example, morphological characteristics of the Chulitna River indicate that this tributary reach is a potential sediment source or sink; treating it as a modeled reach allows for simulation of sediment accumulation or bed lowering. Similarly, the Talkeetna River as a modeled reach will allow simulation of changes in both water-surface elevations and channel geometry. Flow and sediment input will be based on the gaging station records and measurements for the Chulitna and Talkeetna rivers.

The 1-D modeling will compute bed and water-surface elevations, flow depths and velocities throughout the modeled reaches of the mainstem Susitna River and tributaries under each scenario. These data will provide input for evaluating habitat conditions, changes in lateral habitat connectivity, and the potential for developing barriers at tributaries. The model will also provide information to assess changes in bed material composition and effects on fine material transport (wash load) and turbidity. The model will include the transition from an extremely low sediment supply at the dam to the longitudinally increasing sediment loads through tributary inputs and entrainment of existing bed material. The results of the 1-D modeling will be also be used to evaluate changes in effective discharge, which, along with the flow-frequency analyses and potential for changes in vegetation from the riparian instream flow study, will be used to evaluate potential changes in channel width. The Riparian Instream Flow Study will provide data on area and elevation for zones of woody vegetation recruitment. These elevations will be correlated to flow recurrence, which in turn will be used to evaluate morphologic changes along the margins of the main channel, secondary channels, side sloughs, upland sloughs, and tributaries. Data from the Riparian Instream Flow Study, the Fish and Aquatics Instream Flow Study analysis of changes in hydrology operational scenarios, and 1-D sediment-transport analysis provide a basis for adjusting the channel width in the 1-D model throughout the simulation.

As noted in Section 3.1.1 (Overview of 1-D Model Development) the sediment-transport model will be calibrated based on available information. Ideally, the calibration would involve simulating an extended time period where the channel morphologic change has been documented. This possibility has been considered in this case because a survey was conducted in the 1980s. The model would be run from the 1980s to present as a calibration step. However, AEA is not taking this approach because the survey data from the 1980s is not deemed sufficient to develop a 1980s model. AEA will, however, compare 1980s and current cross sections to determine the amount of channel change for that approximate 30-year period.

Another useful tool for assessing variability and trends in channel morphology is specific gage analyses at the long-term USGS gages. These plots are based on measurements of discharge and water-surface elevation through time. At low flow the water surface will closely track bed elevation change and the specific gage plot will identify trends and variability in bed elevation through time. Although limited by the number of available cross sections, channel bed profiles will also be used to assess the channel morphologic change since the 1980s. Although the available information may not be sufficient for a precise calibration of the sediment-transport model, it will be adequate to evaluate potential Project effects as these will be relative comparisons of Existing conditions to the simulated operational scenarios.

It is anticipated that adjustments will be made to the channel width in the with-Project scenario runs at up to five times during each simulation. Long-term width change (narrowing) is expected to occur along the Susitna River based on reductions in ~2-year recurrence interval flows for the with-Project scenarios. Using typical downstream hydraulic geometry relationships, bankfull channel width is proportional to bankfull discharge to the 0.5 power (Leopold and Maddock 1953), though other values of the exponent have been proposed. For example Parker (2010) indicates a power of 0.461 for gravel-bed rivers. A consistent flow frequency ( $Q_2$ ) or effective discharge is used to predict the eventual equilibrium width for the new hydrologic regime.

With a target channel width determined for the new hydrologic regime, we will need to estimate the rate of width change over the 50-year license period. The rate of width adjustment may be greatest in the initial years after closure, so the time interval for simulating width change may be shorter during the initial periods of the simulation and increase with time during the simulation. The rate of width adjustment may also be limited by the supply of sediment available for deposition in the channel margins. This potential limiting factor will be checked and if necessary, the rate of width change modified. One approach for developing the width versus time relationship is the application of rate law, which is an exponential decay function (Graf 1977, Wu et al. 2012). Rate law is not a process-based approach, but is a useful relationship for describing geomorphic response due to a disturbance. We will coordinate with the other study team members and agencies to agree on an amount of channel width change expected to occur over the 50-year license period. For example, the Middle Susitna River Segment may be deemed to reach 80 percent of the ultimate width change and the Lower Susitna River Segment may reach 60 percent. The rate law equation would be used to determine the channel width for intermediate time periods. These channel widths will be imposed on the reach-scale models during the simulation and ultimately on the local-scale 2-D models for future (years-25 and -50) conditions.

The reach-scale models will be run for a 50-year period, corresponding to the length of the FERC license. This 50-year period will be selected from the 61-year record in coordination with the Technical Team. AEA will incorporate at least one large, relatively rare (i.e., 50- to 100-year

recurrence interval) event if one does not already occur in the selected model period. Although it is likely (64% chance) that at flood exceeding the 50-year recurrence flow is contained within any selected 50-year period, if that event is not present it could be included to account for operational effects on this flood. Similarly, there is a 40% chance of a 100-year event occurring in a 50-year period, so this event could be included for similar reasons. The final decision to include such event(s) will be coordinated with the Technical Team.

The simulation time-steps in the 1-D sediment-transport model will vary with discharge to optimize the balance between model stability and total simulation time. The length of the discharge-dependent time-steps will be determined in the early phases of the modeling through a series of tests with the initial, baseline model that will identify the maximum stable time-step for each range of discharges using procedures similar to those spelled out in USACE (1992).

In addition to simulating a long term, continuous period of flows, it will also be possible to include rare flood events associated with unusual climatic conditions or ice-jam breakup to understand conditions that form or maintain the existing habitats and how those conditions may be altered by the project. For these conditions, an appropriate time step will be determined on a case-by-case basis. For example, a time step ranging from several hours to 1 day may be appropriate for a flood event; however, the time step necessary to model breaking of an ice jam may need to be on the order of minutes.

## 4.2.2 Large Woody Debris Effects

### 4.2.2.1 Large Woody Debris Mapping

The effects of LWD on sediment transport and bed evolution will be evaluated using data from 2012 aerial photography to define baseline conditions, and the amounts of LWD will be reduced proportionally within each reach based on the changes in supply as a result of the Project.

The 2012 aerial photographs (1-foot pixel resolution) will be used as a base to digitize existing LWD within the Geomorphic Feature classifications (Table 4-2). Portions of LWD features that extend into the listed GeomFeat polygons in the Middle and Upper River (RM 99 to RM 260) will be digitized, but LWD that is contained wholly within vegetated islands (VI), additional open water (AOW) or background (BG) areas will not be digitized because these features will have little or no effect on hydraulic conditions in the channel. All wood in the Middle and Upper River (RM 99 to RM 260) will be digitized, but only a sub-sample of the wood in the Bar Island Complex features in the Lower River will be digitized to obtain representative wood densities on these mobile features.

Individual Pieces: LWD at least 25 feet long that are wholly within, or extend into, the designated geomorphic features will be digitized as single segment line features from the root wad or thickest end (start of line) to the thinnest end of the LWD (end of line). Digitizing will take place at a 1:1000 scale within ArcMap. In log jams (see below), individual pieces that are over 25 feet in length and are discernible will be digitized.

The following attributes will be assigned to each individual LWD feature:

RootWad (Y or N) – Is there a visible root wad, defined as visible thickened end, on the piece of LWD? (This is a judgment call because the resolution of the photos is not always sufficient to be definitive.)

Jam (Y or N) – Is the LWD contained within a log jam, defined as three or more touching pieces of visible/digitized LWD?

Local\_Scr – Is the LWD definitively from a local (adjacent bank) source, generally determined to be a local source if the LWD extends perpendicular to, or at an oblique angle from, the vegetated bank into the flow (e.g., not parallel to the bank), or if the piece of large wood has the majority of the branches intact, indicating that it was not transported very far from its source.

Channel Position – The channel position of the wood will be identified in the following categories:

- BJ – Bank Adjacent – adjacent to vegetated bank at the side of a channel
- AB – Apex of Bar – at the apex of a bar
- DB – Downstream end of Bar – at the downstream end of an unvegetated bar
- SB – Side of a Bar – along the side or in the middle of an unvegetated bar
- MDC – Middle of the Channel – within the wetted channel
- HSC – Head of a Side Channel – spanning the head of a side channel
- SPC – Span Channel – spanning a small channel at a location other than the head of the channel
- BG – Biogeomorphic, e.g., contained in beaver dams

Image Date – the date of the aerial photograph image that was used for digitizing

Length (ft) – length of the piece of LWD as calculated within ArcMap from length of line feature

Log Jams: In addition to single pieces, if there are large log jams that contain small, un-differentiated pieces of wood, the area of these log jams will also be digitized as a polygon feature. Single, distinguishable pieces of LWD within these polygons will also be digitized as line features as described above. The following attributes will be recorded for log jam features:

RM\_ID – Identifier coded as RM-XXX with XXX being sequential number in an upstream direction

Channel Position – same as used for individual pieces of wood, described above

Image Date – the date of the aerial photograph image that was used for digitizing

Area (sq-ft) of the polygon that will be calculated with ArcMap

#### 4.2.2.2 *Large Woody Debris Modeling*

One of the objectives of the geomorphology study (AEA 2012, Section 6.5.1.1) is to “Assess Large Woody Debris Transport and recruitment, their influence on geomorphic forms and, in conjunction with the Fluvial Geomorphology Modeling Study, effects related to the Project.”

The geomorphology study will evaluate large woody debris sources, loading, and transport in the Susitna River. Loading from upstream and major tributaries will be evaluated for pre- and with-Project scenarios. The fluvial geomorphology modeling study will also provide input on the potential Project effects on large woody debris input. Bank erosion rates under the existing and with-Project scenarios will be evaluated using the Bank Energy Index (BEI) (Mussetter et al. 1995; Mussetter and Harvey 1996), a semi-quantitative index of the total energy applied to the channel banks. One- and 2-D modeling results will be used to compute the BEI values. The BEI values will be correlated to existing bank erosion rates at specific locations. With-Project bank erosion rates will be estimated using this correlation to estimate LWD recruitment.

At the reach-scale, large woody debris increases overall flow resistance, reduces velocity, and reduces sediment transport (Smith et al. 1993, Shields and Grippel 1995; Assani and Petit 1995; Buffington and Montgomery 1999). The cumulative drag force of debris in a particular reach will be distributed over the reach by equating area-distributed drag force to the equivalent shear stress to compute an incremental increase in flow resistance associated with the LWD (Hygelund and Manga 2003). For existing conditions, the amount of debris, type of obstruction, size, and other attributes will be used to evaluate the contribution of debris to total flow resistance. The input flow resistance coefficients will then be modified in the Project-conditions models to reflect changes in LWD due to the Project by proportioning the amounts of debris and the resulting total flow resistance based on the altered LWD supply. Depending on the relative LWD supply, effects on reach-average hydraulics may be negligible in some areas, but could be significant in others. In general, LWD supply from upstream of the dam will be eliminated by the Project, but LWD supplied from tributaries downstream from the dam will be unchanged. If bank erosion rates decrease based on the BEI analysis, then this supply will also be reduced.

Existing debris characteristics, including size, height and frequency, will be evaluated both in the field and by analyzing aerial photography, as described above. For large clusters and large individual pieces, height and size can also be evaluated using the LiDAR data.

#### **4.2.3 Ice Effects**

As part of the ice processes study for the Susitna River, “predictive ice, hydrodynamic and thermal modeling using River1D is planned for the Middle River between the proposed dam and the Three River Confluence near Talkeetna” (Section 7.6.3.2, AEA 2012). Additional ice-related, reach-scale modeling will be performed as part of the fluvial geomorphology modeling study. It is tentatively assumed that the existing bed material is stable (i.e., below incipient motion conditions) under ice conditions, due to reduced velocities and shear stresses associated with low river flows and the ice cover. The validity of this assumption under both existing and with-Project conditions will be tested by performing an incipient motion analysis using shear stress results from the River1D modeling. Should the results indicate that substantial sediment transport should occur at the reach scale, the 1-D model will be adjusted to incorporate appropriate rates of sediment transport for ice covered conditions. AEA anticipates this could be accomplished by extending the simulation period, and adjusting flow magnitudes and durations of the 1-D modeling to account for sediment transported under these conditions.

1-D dynamic modeling will also be performed of ice jam breakup surges to develop inflow hydrographs for 2-D dynamic models. The 1-D modeling will be performed using HEC-RAS and will be similar to dam break simulations of the rapidly released water stored above the ice jam. The 2-D simulations of ice jam surges are discussed in Section 4.3.3.

#### **4.2.4 Summary of Reach-Scale Model Results**

The reach-scale, 1-D modeling will provide a basis for assessing Project effects on the following issues:

Existing status and potential Project effects with respect to dynamic equilibrium with respect to sediment transport.

Changes in both the bed material (sand and coarser sizes) and wash (fine sediment) load under with-project conditions.

Long-term balance between sediment supply and transport capacity, and the resulting aggradation/degradation response of the system.  
Changes in bed material mobility.  
Changes in effective discharge.  
Changes in flow distribution within multiple channel reaches.  
Project-induced changes in supply and transport of finer sediments that influence turbidity.  
Potential for changes in channel dimensions (i.e., width and depth) and channel pattern (i.e., braiding versus single-thread or multiple-thread with static islands).  
Project-induced changes in river stage due to reach-scale changes in hydrology, bed profile, channel dimensions, and hydraulic roughness.  
Characterization of the types, amounts, and features of LWD both in terms of supply of LWD and the overall effects of LWD on sediment transport and channel morphology.  
Changes in ice cover effects on sediment mobilization.  
Boundary conditions for the 2-D local-scale modeling.  
Hydraulic parameters to calculate Bank Energy Index and estimate bank erosion rates.

### 4.3 Local-Scale 2-D Modeling

The 2-D hydraulic modeling will be performed at the Focus Areas to support habitat analysis using steady flow simulation performed over the range of discharges that occur in the study reach. Sediment-transport modeling is inherently unsteady because the sediment is routed through the system and the bed deforms in response to changes in flow and sediment supply. Boundary conditions for all of the 2-D model simulations, including downstream water-surface elevations, and upstream flow and sediment supply, will be obtained from 1-D modeling results. For open-water conditions the downstream flow-stage and upstream flow-sediment supply rating curves will be developed from the 1-D sediment-transport models and upstream flow rates will be from the 1-D open-water flow routing models. For ice cover conditions AEA will develop upstream flow and downstream flow-stage boundary conditions from the River1D models developed by the Ice Processes Study.

The flexible mesh formulation that is available in the SRH-2D and River2D models is ideal for obtaining detailed results in areas of significant change or interest. Large channels require less detail than small channels, and floodplains generally require the lowest resolution because the topographic and hydraulic variability is often the lowest for floodplain areas. In developing the models, the mesh will be refined, as necessary, to capture the effects of appreciable topographic or flow resistance variability. Figure 4-24 shows an example of a fine mesh, though the level of detail is varied throughout the model domain to provide greater mesh refinement in areas of anticipated geometric or hydraulic change. An example of a coarse mesh is shown in Figure 4-25. This level of mesh resolution may be required for 2-D morphology modeling to reduce computer simulation time. For the 2-D sediment-transport models, the element sizes will be as large as practicable, but with sufficient detail to represent variability in bathymetry, topography, roughness, and bed composition.

Areas with significant habitat value will be identified by the aquatic habitat team members, and these areas will be modeled at a level of mesh resolution sufficient to describe the variability in hydraulic conditions that is necessary for the habitat analysis. Figure 4-26 is an example of the mesh requirements of the 2-D hydraulic models used for aquatic habitat analysis. Based on input

from the aquatic and riparian habitat analysis teams, it is anticipated that the mesh resolution of approximately 2 m will be used in key areas of the habitat analysis. Element sizes of up to 10 m will be used for the main channel, and up to 30 m elements in floodplain areas. The element sizes will transition smoothly between these ranges to maintain good mesh quality. These general guidelines represent starting values for the spatial resolution that will be refined and adjusted as necessary throughout the model development phase. The level of mesh refinement will be determined first for hydraulic requirements and then the fine 2 m mesh will be used in areas of detailed habitat analysis. The mesh examples in Figures 4-24 and 4-25 do not fully meet the element size criteria outlined above because greater detail will be incorporated in the lateral features and habitat areas.

### **4.3.1 Bed Evolution and Hydraulic Modeling**

#### *4.3.1.1 Morphology Modeling of Focus Areas*

Due to the intensive computational requirements of 2-D sediment-transport modeling and the potentially long execution times, it is not practical to run the 2-D Focus Area sediment-transport models over a multi-year time-frame. These models will be run over a select set of three seasonal hydrographs to assess river behavior during typical wet, average, and dry annual runoff seasons, and warm or cool Pacific Decadal Oscillation (PDO). The specific seasonal hydrographs will be selected by categorizing each year in the 61-year extended record and selecting a representative year from each subset. The criteria for identifying the runoff categories and the specific hydrographs from each category will be determined in coordination with the other study teams and agencies. Because of the nature of the 2-D model formulation, the time increment for 2-D mobile-boundary simulations is typically on the order of seconds to insure model stability; however, results are reported at longer time intervals to limit output file size.

Riparian vegetation plays a key role in the development of islands and lateral habitats, primarily by protecting surfaces from erosion and promoting sediment deposition. Vegetation can also contribute to channel narrowing by encroaching onto bars and islands, causing riverward growth of banks through trapping of sediments. Conversely, changes in the flow regime and/or ice processes can alter riparian vegetation patterns, including the extent, species composition and age-classes, providing a feedback mechanism between the processes. As a result, the influence of riparian vegetation on the morphology of the Susitna River is an important consideration in these studies. The riparian instream flow and geomorphology studies will be closely coordinated because of the interactions described above. The teams will develop an understanding of the interactions between the processes that are responsible for creation and maintenance of the islands and lateral habitats by coordinating their respective study approaches and integrating the study results. Estimates of the ages of island and floodplain surfaces from the Riparian Instream Flow Study, based on dendrochronology combined with the inundation results from the 2-D modeling, will greatly facilitate this effort by helping to identify rates of sediment deposition and reworking of these surfaces. The turnover analysis based on overlay of aerial photos from the 1950s, 1980s and current conditions will also provide quantification of existing lateral floodplain accretion and erosion rates.

The 2-D morphology modeling will include the analyses of the existing channel geometry with existing hydrology as a baseline for comparison. The existing channel geometry will then be

combined with the hydrology for the range of operational scenarios. These results will be used to evaluate potential, initial Project effects on sediment transport and bed morphology, including changes in bed composition and flow distribution to lateral channels. Runs will also be performed using the projected 25- and 50-year channel geometry and with-Project hydrology. The future channel geometry will include main channel bed level changes from the 1-D model. Width change in the main channel that was incorporated in the 1-D modeling results will also be included in the 2-D models. Changes in sediment supply and downstream boundary conditions will be incorporated from the 1-D modeling. Vegetation encroachment and changes in lateral features will also be incorporated into the 2-D morphology models. These models will be run for the three seasonal hydrographs to be used in the development of the detailed hydraulic models.

#### 4.3.1.2 *Hydraulic Modeling for Habitat Analysis*

Output from the 2-D hydraulic models will be provided to the habitat analysis teams in tabular (either ASCII or spreadsheets, as appropriate) format for each flow condition. The output values for the required hydraulic variables that include depth, velocity, and water-surface elevation, will be provided at each node along with the associated geo-referenced horizontal coordinates and elevations. Additional hydraulic parameters (such as Froude number and shear stress) can be computed from the output variables. These will be selected in consultation with the Instream Flow Habitat study and agencies. The range of flows will be determined in coordination with the instream flow habitat study and can be adjusted, as necessary, during the modeling phase. Habitat will be calculated at each node by combining the Habitat Suitability Criteria (HSC) for each species and life stage with the hydraulic data. The method of calculation will depend on the hydraulic model used for the simulations. If River 2D is the model selected for hydraulic modeling, the habitat may be calculated directly, though GIS may still be used. If the SHR-2D model is selected, a Geographic Information System or GIS-based approach will be used to calculate habitat. There will be several steps required to convert the model output from hydraulic data to habitat data.

The 2-D modeling will include steady-state analyses of either the existing channel or projected future topography. Results for the existing channel topography will provide the baseline for comparison of potential Project effects. Where appropriate, the existing-conditions topography will be adjusted to represent the projected channel form at year-25 and at the end of the 50-year license period, and the models will be re-run to provide a basis for assessing Project effects. The future channel geometry in the 2-D models will include main channel bed level changes from the 1-D model. Predicted width changes in the main channel will also be incorporated, based on the 1-D model results and additional, off-line analyses that consider Project-related changes in the effective discharge analysis, riparian vegetation, and sediment supply. Projected changes in secondary channels and other lateral features will also be incorporated into the models where appropriate. Through this process, model output will be provided for the habitat analysis for existing conditions, initial, with-Project conditions associated with the change in hydrology, and the projected longer-term (50-year) changes in channel morphology combined with operational hydrology.

In summary, the geomorphic modeling will provide the following information:

Existing geometry, vegetation, and bed composition:

- Steady-state simulations over a range of discharges, and

- Hydraulic variables including depth, velocity, and water-surface elevation tied to geo-referenced horizontal coordinates (x, y) as input to the habitat analysis.

The same output as the previous bullet for with-project operational scenarios to represent interim conditions after Project implementation, but before long-term channel adjustments.

The same output as the previous bullet based on Project future-conditions geometry, vegetation, and bed composition for with-project operational scenarios to represent conditions at year-25 and at the end of the 50-year Project license.

The future conditions 2-D models will be developed through a combination of the 1-D model results, 2-D morphology modeling results, and coordination with the other study teams and the agencies.

### **4.3.2 Large Woody Debris Effects**

The data described in Section 4.2.2.1 will also be used to develop 2-D modeling scenarios to assess the effects of changes in the amount and distribution of LWD on local hydraulic and sediment-transport conditions. Projected changes in the size and location of large woody debris will be simulated by adjusting mesh resolution, bed elevations, and the relative erodibility of the affected area. If a large jam is likely to be removed or become smaller with time, the roughness would be reduced and modeled bed elevation will be lowered. The hydraulic effects of large woody debris can also be simulated by locally adjusting flow resistance without changing elevation. In either case, erosion due to the acceleration of flow around the obstruction can be simulated. This erosion is not a complete representation of the scour that can occur at large woody debris accumulations because scour is also related to vertical flow, vortices, and turbulence that are not simulated by the 2-D models. Where appropriate, the additional local scour will be estimated using scour equations developed for other applications. For example, a recently developed equation for abutment scour would be useful for evaluating scour around large log jams. This equation, described in the Federal Highway Administration (FHWA) HEC-18 bridge scour manual (Arneson et al. 2012), relates obstruction shape, bed material mobility, unit discharge upstream, and unit discharge adjacent to the obstruction to potential scour depth. The equation is conservative, as it is intended for design of bridge foundations, but the magnitude of the conservatism can also be determined (Lagasse et al. in press).

### **4.3.3 Ice Effects**

Ice processes influence both the channel morphology and riparian vegetation. For example, ice can prevent vegetation from establishing on bars by annually shearing off or uprooting young vegetation. Similarly, ice can scour vegetation from the banks, increasing their susceptibility to erosion. Both of these influences can affect channel morphology. Ice jams can also directly influence the channel morphology by diverting flows onto the floodplain where new channels can form, particularly when the downstream water-surface elevations are low, allowing the return flows to headcut back into the floodplain. Ice can also move bed material that would not be mobilized under open-water conditions by rafting large cobbles and boulders.

The Geomorphology and Ice Processes studies will work together to identify the key physical processes that interact between the two. A significant portion of the influences of ice processes on morphology are directly related to their effects on riparian vegetation. The Geomorphology and Ice Process studies will also coordinate with the Riparian Instream Flow study to identify

and interpret evidence of ice conditions such as ice scarring locations and elevations on trees. Additional influences of ice processes beyond the riparian vegetation issues that will be incorporated directly into the fluvial geomorphology modeling include:

- Simulation of the effects of surges from ice jam breakup on hydraulics, sediment transport and erosive forces using unsteady-flow 2-D modeling with estimates of breach hydrographs.
- Simulation of the effects of channel blockage by ice on the hydraulic and erosion conditions resulting from diversion of flow onto islands and the floodplain.
- Use of the detailed 2-D model output to assess shear stress magnitudes and patterns in vegetated areas, and the likelihood of removal or scouring.
- Use of the detailed 2-D model output to assess shear stress magnitudes and patterns in unvegetated areas, and the likelihood of direct scour of the boundary materials.
- Application of the 2-D model to investigate whether ice jams are a significant contributor to floodplain and island deposition as a result of ice jams inundating these features and causing sedimentation.

The analyses of ice-affected morphologic change will rely on observations and information from the Ice Processes Study, the Riparian Instream Flow Study, and geomorphology field work. The results of 1-D and 2-D simulations, performed by the Ice Processes Study, will also be used. The information to be developed for both existing and with-Project scenarios will include: (1) size, location, and frequency of ice jams, (2) location, extent, and duration of bank attached ice, (3) location, extent, and duration of ice blockage in main versus secondary channels, (4) model output from 1-D and 2-D ice model simulations, (5) estimates of fine-sediment concentrations during ice cover conditions, and (6) field observations of the impacts of ice movement or flow diversion on floodplain areas. The types of analyses and specific conditions to be evaluated will be coordinated with the other study teams and agencies as information from the 2013 field season is evaluated.

Although sediment transport in ice-affected conditions is not fully understood, Ettema (2010) indicates that bed-load and suspended load equations are able to represent these conditions and that for a given discharge sediment transport potential is less than for open water conditions due to reduced velocity and shear stress. He indicates that bed-load equations compared well with measurements in ice-covered conditions and that expected increases in suspended bed-material load transport, due to temperature effects on water density, viscosity, and particle fall velocity, are supported by lab and field studies. Suspended load is often supply limited, so an increase in this sediment-transport component may depend more on supply than on transport capacity. Ice jams and breakup may exert significant impact on unregulated rivers (Ettema 2010) and where water discharge fluctuates appreciably, such as during winter operation of hydropower dams, ice cover formation and presence may also have significant effects (Ettema 2010; Zabilansky et al. 2002).

The 2-D modeling will be used to evaluate the effects of altered hydrology and ice conditions on local erosion, mobilization, and sedimentation processes. The hydraulic results from the River1D and River2D modeling performed as part of the ice processes study will be reviewed to evaluate whether general mobilization of the bed is possible during ice-cover conditions.

Using ice jam breakup hydrographs, unsteady 2-D models will be used to evaluate the hydraulics and sediment transport for these dynamic flow conditions. The hydrographs will be developed

with unsteady hydraulic routing using HEC-RAS modeling similar to dam-break modeling. Blackburn and Hicks (2003) provide information on simulating ice jam breakup surges and indicate that unsteady-flow, hydraulic routing is applicable to this type of simulation. The location and height of blockages created by ice dams will be determined through coordination with the Ice Processes and Riparian Instream Flow study teams. The unsteady dam break capabilities of the HEC-RAS model will be used to simulate the release of ponded water upstream of the ice dam to generate a flow hydrograph that will be input to the unsteady 2-D models when the flood wave reaches the downstream Focus Area.

Ice cover typically increases active flow area and decreases velocity and bed-load transport. Bank-attached ice can redistribute flow within a channel. As shown in Figure 4-27, in multiple channel areas, partially or completely blocked channels can redistribute flow between channels. Channel blockage can also divert flow onto islands and floodplains. Figures 4-28 through 4-34 show the locations and descriptions of ice jams in 2012 and in the 1980s. This type of information will provide a basis for selecting the FAs where additional 2-D erosion modeling will be performed to evaluate ice effects. We anticipate that three or four FAs will be selected.

Full blockage will be simulated using altered geometry and partial blockage will be modeled with a combination of altered geometry and high flow resistance. These methods will be used to evaluate erosion potential of vegetated and unvegetated areas with ice conditions. The specific locations and characteristics of ice jams will be coordinated with the other study teams and agencies.

Diversion of flow onto vegetated floodplain areas may also contribute to floodplain sedimentation. Data from winter operation of gages and other field measurements or observations will be used to estimate fine-material concentrations. Depending on the material size and type of channel blockage, the fine-material diverted onto vegetated areas may be trapped by vegetation and accumulate on the floodplain surface. The 2-D models will not simulate the accumulation directly, but the results can be post-processed to estimate rates of accumulation and floodplain accretion. This will be done by computing the unit discharge of fine sediment (unit discharge of flow times the fine sediment concentration) delivered to floodplain areas based on the proportion of Rouse-type suspended sediment profiles extending above the top-of-bank. As vegetation will trap some of this sediment, rates of accretion can be estimated. We will work with data collected by the Riparian Instream Flow Study team to evaluate historical rates of sediment accretion to validate the above analytical approach. With-Project accretion rates will be proportioned based on comparison of the expected overbank flows and sediment concentrations with existing conditions flow and sediment concentrations.

#### **4.3.4 Summary of Local-Scale Model Results**

The local-scale, 2-D modeling will provide information on:

- Existing status and potential Project effects with respect to changing morphology in lateral features.
- Detailed hydraulic input to habitat modeling for existing and with-Project conditions.
- Changes in bed material composition.
- Changes in bed material mobility.
- Changes in flow distribution.
- Project-induced changes in supply of finer sediments into floodplains.

- Project-induced changes in river stage on delta formation at tributary mouths.
- Effects of LWD on sediment transport and channel morphology.
- Changes in ice effects on sediment mobilization, lateral features, and floodplains.
- Hydraulic parameters to estimate Bank Energy Index and bank erosion rates.

#### **4.4 Other Tributary Modeling**

In the Lower River, short-reach sediment-transport models will be developed for the mouth area and downstream approximately 1 mile of Trapper Creek (2013), Birch Creek (2013), Sheep Creek (2014), Caswell Creek (2014) and Deshka River (2013) to determine potential morphologic effects of with-Project scenarios and to provide sediment inputs to the reach-scale models. The models will include portions of the main channel or side channels below the tributary mouth to also evaluate change in bed elevation and water surface. The geometry of confluence areas of these models will be developed by performing a sediment budget (sediment continuity analysis) where excess sediment will be represented by expanding the height and/or extent of the tributary delta into the receiving channel. The size of the tributary delta will be adjusted until the long-term sediment-transport capacity of the receiving channel achieves an equilibrium with the sediment supplied by the tributary.

One final set of tributaries models will be developed. These models will be for short reaches of Tsusena Creek, Fog Creek, Gold Creek, and Lane Creek upstream of backwater influence from the Susitna River to estimate sediment input for the 1-D bed evolution models.

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## 5. CONSULTATION DOCUMENTATION

The draft version of this document was made available for review on May 3, 2013 and the material was presented at a Technical Team Meeting on May 21, 2013. The minutes from the meeting were posted on June 4, 2013. The draft document, presentation, minutes, and comments (Agency and public comments with responses) are all available on the Susitna-Watana public website ([www.susitna-watanahydro.org](http://www.susitna-watanahydro.org)). The following additions, clarifications, and corrections to the draft document have been made in this version based on the discussions at the May 21, 2013 meeting and comments received:

### Section 1.1 Background

- Expanded discussion of dynamic equilibrium of the Susitna River
- Expanded discussion of connections and objectives of the geomorphology and fluvial geomorphology modeling study components
- Introduction to simulation scales for reach- and local-scale models for main channel, side channels, other lateral features, islands, floodplains, and aquatic habitats

### Section 1.2 Objectives

- Inclusion of objectives for the Three Rivers Confluence reach-scale modeling

### Section 2.2 Comprehensive Modeling Approach

- Section added to discuss connections between the types of modeling that will be conducted as part of the fluvial geomorphology modeling study
- New table added (Table 2.2) that illustrates model connections, input requirements, and how results will be used by subsequent models
- Discussion of how morphologic change may need to be incorporated by other study components

### Section 3.1.3.2 SRH-1D

- Corrected the number of sediment size classes

### Section 3.2.1 Overview of 2-D Model Development

- Clarification of how model refinement will be related to appreciable change in velocity

### Sections 3.2.3.1 SHR-1D, 3.2.3.5 River2D, and 3.2.4 Selection of 2-D Model

- Correction of number of sediment sizes in SRH-2D, River2D and related discussion

### Section 4.1.1 Reach Scale Model (survey)

- Identification of cross sections that are prioritized for survey in 2013
- Discussion of how LiDAR will be used to develop channel cross sections in the Chulitna River
- Figures 4-1 through 4-11 updated to show 2013 high priority sections and low priority sections

### Section 4.2.1 Bed Morphology and Hydraulic Modeling (1-D)

- Discussion of how comparison cross sections, channel profiles, and specific gage analyses will be used for model calibration
- Discussion of suitability of the 1980s survey data for morphology modeling
- Discussion of how changes in channel width will be simulated over the 50-year license period
- Expanded discussion of potentially including 50- and/or 100-year events into the simulation alternatives

#### Section 4.2.3 Ice Effects

- Expanded discussion of how ice effects could be included in 1-D morphology model simulations

#### Section 4.3 Local-Scale 2-D Modeling

- Discussion of using 1-D model results to develop 2-D Focus Area boundary conditions and channel geometries
- Expanded discussion of mesh refinement for aquatic habitat requirements and inclusion of new figure (Figure 4-26) illustrating the habitat areas

#### Section 4.3.1 Bed Morphology and Hydraulic Modeling (2-D)

- Reordered sub-sections so the order matches the order of modeling tasks
- Included Pacific Decadal Oscillation as a hydrologic condition that will be addressed
- Included year-25 as a time period for Focus Area morphology and hydraulic modeling

#### Section 4.4 Other Tributary Modeling

- Expanded discussion of how some tributary deltas will be simulated with site-specific 1-D models

#### Section 6 References

- Added references related to channel width change

#### Section 7 Tables

- Table 2.2; added to illustrate connections between types of morphology models and results used by other study components
- Tables 3.1 and 3.2; corrected for number of sediment size classes in SRH-1D, SRH-2D, and River2D
- Table 4.1; added note about which tributaries will have data collection in 2013

#### Section 8 Figures

- Updated Figures 4-1 through 4-11 to show prioritized cross section surveys in 2013
- Updated Figure 4-11 showing cross sections on the Chulitna River that will be developed with LiDAR
- Updated Figures 4-12 through 4-21 to show habitat types at the Focus Areas
- Updated Figure 4-22 to show riparian focus areas based on current information
- Included new figure (Figure 4-26) added to illustrate mesh detail requirements for aquatic habitat analyses
- Figure numbers incremented for subsequent figures

## 6. REFERENCES

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## 7. TABLES

**Table 2-1. 1-D versus 2-D model capabilities**

Consideration	1-D Models	2-D Models
Sediment balance	Reach-scale	Local-scale
Aggradation/degradation response	Reach-scale	Local-scale
Changes in bed material gradation	Reach-scale	Local-scale
Sediment accumulation at slough mouths / localized deposition		X
Bed material mobilization	X	X
Effective discharge	X	
Flushing of fines from side slough habitats		X
Complex flows in floodplain and potential erosion		X
Frequency and duration of overbank flooding	Reach-scale	Local-scale
Distribution of flow and flow patterns between channel features	Larger side channels	X
Distribution of flow between channel(s) and floodplains	X	X
Transverse hydraulic gradients		X
Bed deformation (distributed aggradation and degradation)		X
Ice effects on sediment mobilization and erosion	Reach-scale	Local-scale
Large woody debris effects	Reach-scale	Local-scale

**Table 2-2 Model input and results for various study aspects.**

Modeling Task	Input and Results	Hydrology	Sediment	Hydraulics	Channel & Floodplain Geometry
1-D Tributary Sediment Modeling	Input	Range of steady flows	Bed material from site samples	Site-specific D/S stage-discharge	Existing at T = 0 (yr-0) <sup>3</sup>
	Results for:	Results for range of steady flows to develop sediment rating curves at mouth of each tributary			
	1-/2-D Morph.		trib. sediment rating curves		
	Aquatic Habitat			V, D, WSE some trib. mouths	barrier/delta change some trib.
Other studies					
1-D Reach-Scale Morphology Modeling	Input	50-yrs Existing & OS <sup>1</sup>	Existing & OS <sup>2</sup>	stage-discharge at Susitna Sta.	Existing at T = 0 (yr-0) <sup>3</sup>
	Results for:	Results for continuous 50-year simulations throughout 1-D modeling domain			
	2-D Morphology		U/S sed. rating curves at FAs	D/S stage-discharge at FAs	main channel change
	1-D Ice			stage-discharge at 3-Rivers	main channel change <sup>4</sup>
	Flow Routing				main channel change <sup>4</sup>
	Aquatic Habitat		substrate change <sup>4</sup>	stage-discharge relationships	main channel change <sup>4</sup>
Riparian Habitat		sediment supply to overbanks	stage-discharge relationships	bar/island/floodplain change	
2-D Local-Scale Morphology Modeling	Input	<1-yr wet, avg., dry with PDO, Existing & OS <sup>1</sup>	U/S sed. rating curves at FAs for yrs-0,25,50 for Existing & OS <sup>5</sup>	D/S stage-discharge at FAs for yrs-0,25,50 for Existing 3 OS <sup>5</sup>	Existing (yr-0) <sup>3</sup> , yrs-25,50 <sup>5</sup> in main channel
	Results for:	Results for range of <1-yr simulations throughout FA modeling domain			
	2-D Hydraulic		bed material gradation change <sup>4</sup>		lateral feature trends
	2-D Ice				lateral feature trends <sup>4</sup>
	Flow Routing				
	Aquatic Habitat		substrate change <sup>4</sup>		barrier/delta change
Riparian Habitat		sediment supply to overbanks		bar/island/floodplain change	
2-D Local-Scale Hydraulic Modeling	Input	Range of steady flows <sup>6</sup>	Bed material gradation change <sup>7</sup>	D/S stage-discharge at FAs for yrs-0,25,50 for Existing & OS <sup>5</sup>	Existing (yr-0) <sup>3</sup> , yrs-25,50 main channel <sup>5</sup> and lateral features <sup>7</sup>
	Results for:	Results for range of steady flows throughout FA modeling domain			
	Ice, Flow Routing				
	Aquatic Habitat			V, D, WSE, etc. throughout FAs	
Riparian Habitat			V, D, WSE, etc. throughout FAs		

- Notes:
- <sup>1</sup> From flow routing study.
  - <sup>2</sup> From gage data, sediment transport study, and reservoir sedimentation study.
  - <sup>3</sup> From hydrographic survey, land-based survey, and LiDAR. (Survey by Tetra Tech for tributaries.)
  - <sup>4</sup> Only if magnitude of change is sufficiently large to warrant inclusion in other study aspects.
  - <sup>5</sup> From 1-D Reach-Scale morphology models.
  - <sup>6</sup> From habitat study requirements.
  - <sup>7</sup> From 2-D Local-Scale morphology modeling trends.

**Table 3-1. Evaluation of 1-D models**

Model Characteristics and Evaluation Criteria	Models			
	HEC-RAS	SRH-1D	MIKE 11	HEC-6T
<b>General</b>				
Commercial/cost (if applicable)	○	○	● / \$8,000	● / \$3,000
Full or quasi unsteady for sediment transport simulation	Quasi	Both	Full	Quasi
Ice for fixed bed	●	○	○	○
Ice for moveable bed	●	○	○	○
# of transport equations supported	7	13	10	18
Supports user defined transport equation	○	○	○	●
Closed loop capability	○ <sup>1</sup>	●	●	●
Experience with model: High (H); Moderate (M); Low (L)	H	L	M	H
<b>Model Size Limitations</b>				
# of cross sections	NL	NL	NL	5,000
# of hydrograph ordinates	40,000	NL	NL	NL
# of sediment sizes	20	NL	NL	20
<b>Sediment Sizes Supported</b>				
Wash load (silts, clays)	●	●	●	●
Considers settling and resuspension	●	●	●	●
Sand	●	●	●	●
Gravel and cobble	●W	●P,W	●	●P,W

Notes: ● = Yes; ○ = No; NL = No Limit  
 P = Parker (1990), W = Wilcock & Crowe (2003) sediment transport relations  
<sup>1</sup> Not currently available, but in development.

**Table 3-2. Evaluation of 2-D models**

Model Characteristics and Evaluation Criteria	Model					
	SRH-2D	ADH	SToRM	MIKE 21	River2D (R2DM)	River FLO-2D
<b>General</b>						
Commercial/cost (if applicable)	○	○	○	● / \$20k	○	● / \$5k
Unsteady flow capability	●	●	●	●	●	●
Ice for fixed bed	○	●	○	●	●	○
Ice for moveable bed	○	●	○	●	●	○
Number of transport equations supported	4	2	○ <sup>1</sup>	10	2	8
Supports user defined transport equation	○	●	○ <sup>1</sup>	●	○	●
Relative execution speed: Fast (F), Moderate (M), Slow (S)	M	S	F	F	M	F
Model stability: High (H), Moderate (M), Low (L)	H	M	M	H	H	H
Experience with model: High (H), Moderate (M), Low (L)	H	M	L	L	M	L
Mesh Wetting and Drying Approach: Element (E), Node/Partial (N), Sub-Surface (S)	E	N	N	E	S	N
Roughness Equation: Manning n (n), Chezy (C), roughness height (K <sub>s</sub> ), drag coefficient (C <sub>d</sub> , C <sub>d</sub> ∝ 1/C <sup>2</sup> )	n	n, K <sub>s</sub>	C <sub>d</sub> , K <sub>s</sub>	n, C	K <sub>s</sub>	n
Moveable boundary simulation	●	●	○ <sup>1</sup>	●	●	●
<b>Grid Structure/Model Formulation</b>						
Finite element (FE)/Finite Volume (FV)	FV	FE	FV/FE	FV/FE	FE	FE
Grid structure: Flexible Mesh (FM)	FM	FM	FM	FM	FM	FM
<b>Model Size Limitations</b>						
# of grid elements for sediment routing, (U = unlimited)	16k <sup>2</sup>	U	○ <sup>1,3</sup>	U	>100k	>100k
# of sediment sizes (NS = not specified in documentation)	8	NS	○ <sup>1</sup>	NS	12	1
<b>Sediment Sizes Supported</b>						
Wash load (silts, clays)	○	●	○ <sup>1</sup>	●	○	○
Considers settling	○	●	○ <sup>1</sup>	●	○	○
Sand	●	●	○ <sup>1</sup>	●	●	●
Gravel and cobble (P = Parker, W = Wilcock & Crowe)	● P,W	●	○ <sup>1</sup>	●	● W	●
Sediment Gradation/Multiple Layers/Armoring	●	●	○ <sup>1</sup>	●	●	○

Notes: ● = Yes; ○ = No;

<sup>1</sup> Not currently available, but in development.

<sup>2</sup> >100k elements for hydraulic modeling.

<sup>3</sup> Unlimited for hydraulic modeling.

**Table 4-1 Tributary modeling**

Tributary Name	PRM	Entering Bank	Geomorphic Reach	Focus Area	Sediment Input only	1-D or 2-D
Tsusena Creek	184.6	RB	MR-2		X	1-D
Fog Creek	179.3	LB	MR-2		X	1-D
Unnamed	174.3	LB	MR-2	FA173		2-D
Unnamed	173.8	RB	MR-2	FA173		2-D
Portage Creek	152.3	RB	MR-5	FA151		2-D
Unnamed*	144.6	LB	MR-6	FA144		2-D
Indian River*	142.1	RB	MR-6	FA141		2-D
Gold Creek*	140.1	LB	MR-6		X	1-D
Skull Creek*	128.1	LB	MR-6	FA128		2-D
Lane Creek*	117.2	LB	MR-7		X	1-D
Unnamed*	115.4	RB	MR-7	FA115		2-D
Gash Creek*	115.0	LB	MR-7	FA113		2-D
Slash Creek*	114.9	LB	MR-7	FA113		2-D
Unnamed*	113.7	LB	MR-7	FA113		2-D
Whiskers Creek*	105.1	RB	MR-8	FA104		2-D
Trapper Creek*	94.5	RB	LR-1			1-D
Birch Creek*	92.5	LB	LR-1			1-D
Sheep Creek	69.5	LB	LR-2			1-D
Caswell Creek	67.0	LB	LR-2			1-D
Deshka River*	45.0	RB	LR-3			1-D

\*Tributaries that will be analyzed in 2013.

**Table 4-2. Large woody debris digitizing within geomorphic features**

Geomorphic Feature Code	Description	Lower River	Middle River	LWD Digitized?
MC	Main Channel	X	X	Yes
EXP MC	Exposed Substrate Main Channel		X	Yes
SC	Side Channel	X	X	Yes
EXP SC	Exposed Substrate Side Channel		X	Yes
SCC	Side Channel Complex	X		Yes
BIC	Bar Island Complex	X		Sub-sample <sup>1</sup>
BAB	Bar/Attached Bar	X		
SS	Side Slough	X	X	Yes
EXP SS	Exposed Substrate Side Slough		X	Yes
US	Upland Slough	X	X	Yes
EXP US	Exposed Substrate Upland Slough		X	Yes
TR	Tributary	X	X	Yes
EXP TR	Exposed Substrate Tributary		X	Yes
TD	Tributary Delta	X		Yes
TM, MCTM, SCTM, TRTM	Tributary Mouth (Main Channel, Side Channel, Tributary)		X	Yes
VI	Vegetated Island	X	X	No
AOW	Additional Open Water	X	X	No
BG	Background	X	X	No

<sup>1</sup> Due to the high number of pieces of large wood on the Bar Island Complex features in the lower river, the large area of Bar Island Complex, and the likely transient nature of the wood here, these areas will be sub-sampled to obtain a density of large wood and log jams. The density of wood features will be apportioned over the total area of Bar Island Complex to estimate total wood loading.

## 8. FIGURES

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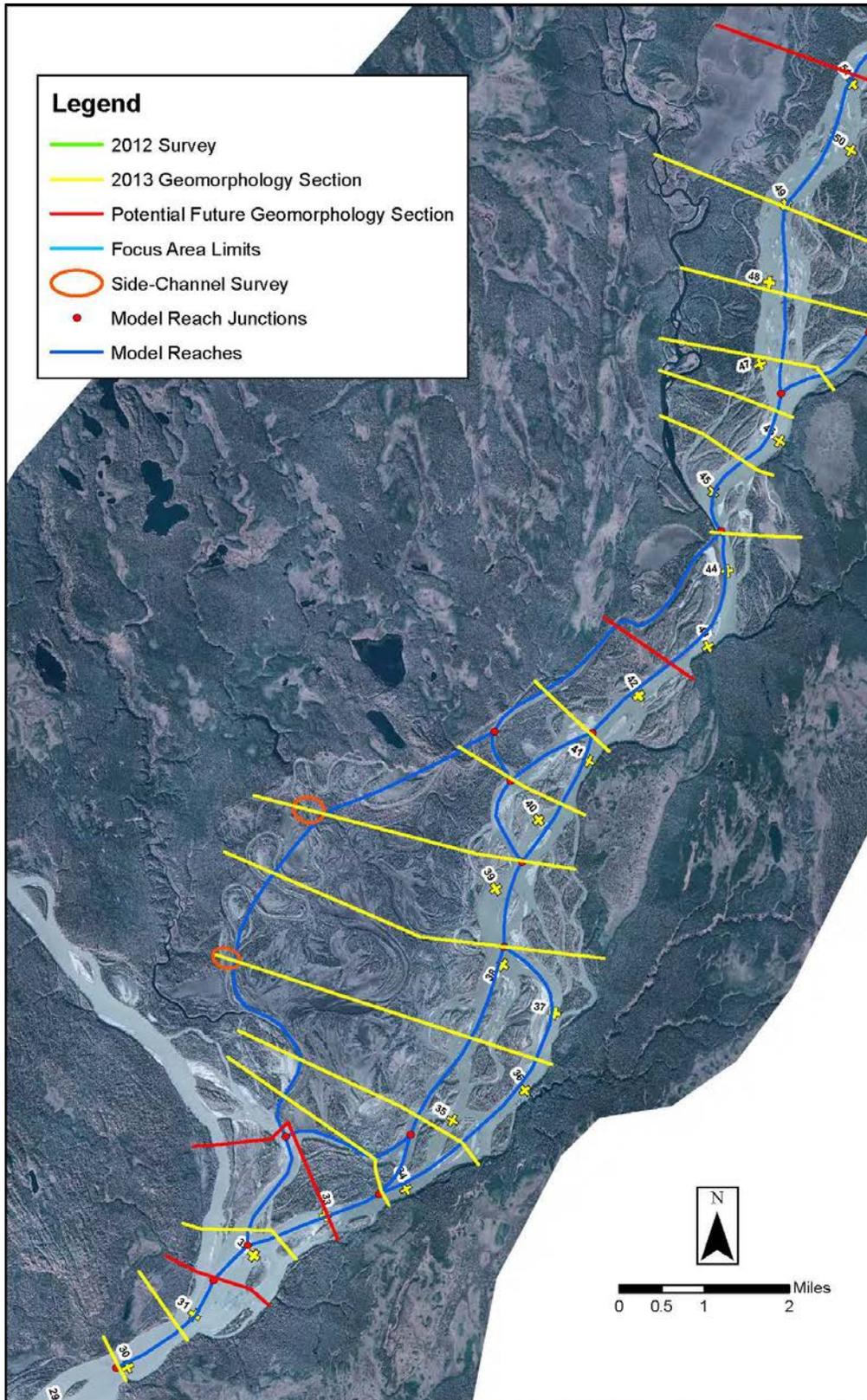


Figure 4-1. Survey and Model Cross Sections from PRM 30 to PRM 47.

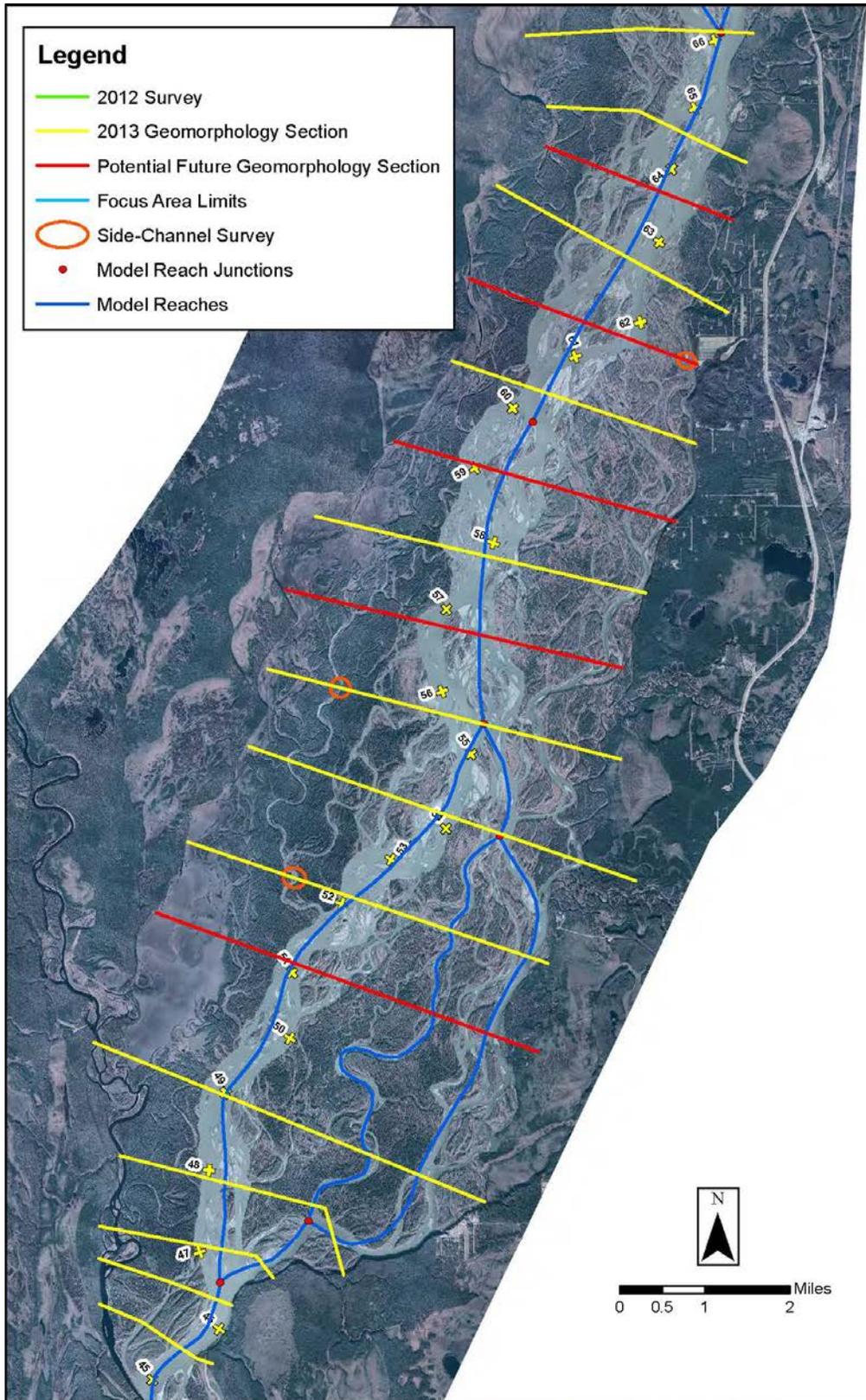


Figure 4-2. Survey and Model Cross Sections from PRM 45 to PRM 66.

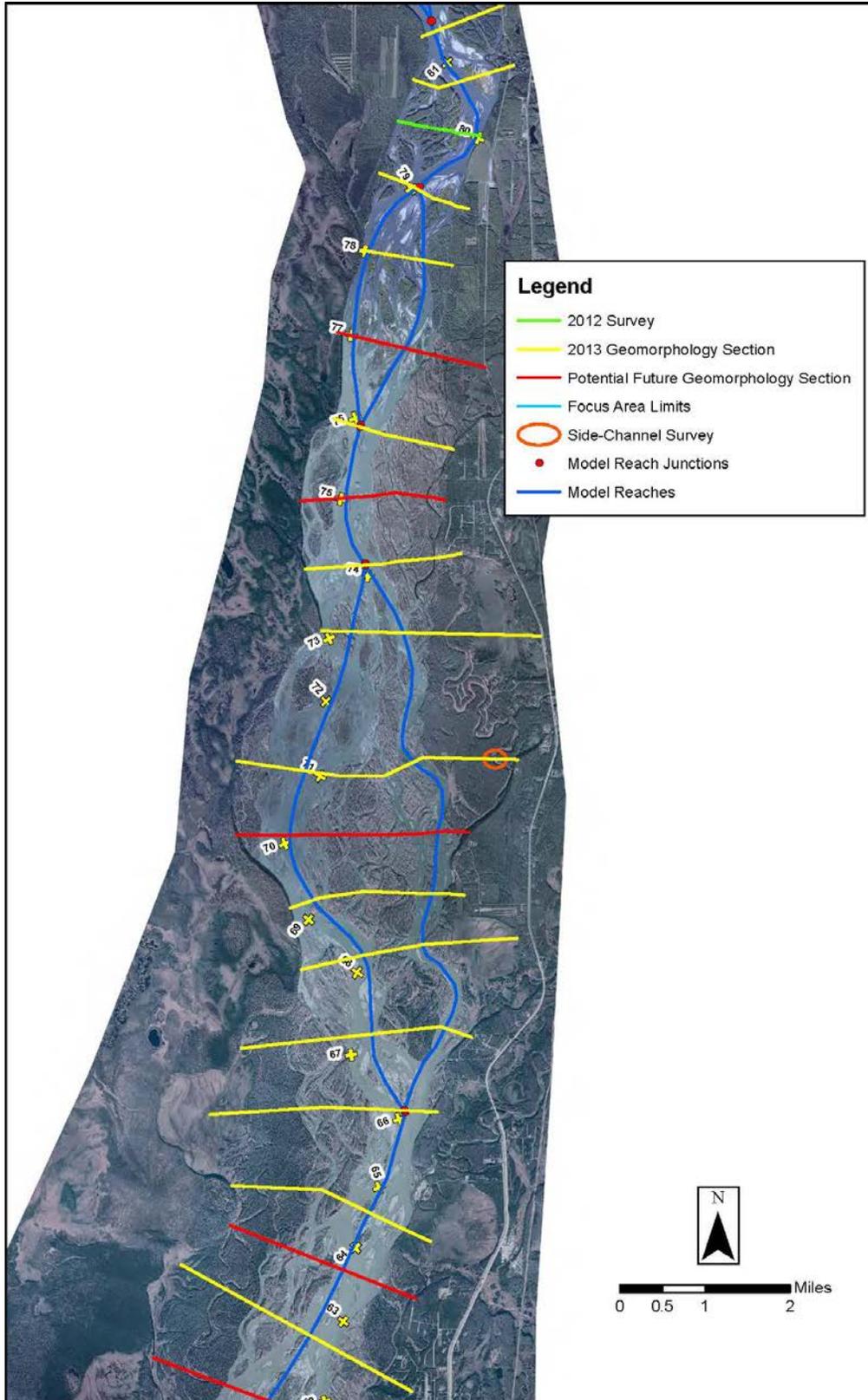


Figure 4-3. Survey and Model Cross Sections from PRM 63 to PRM 81.

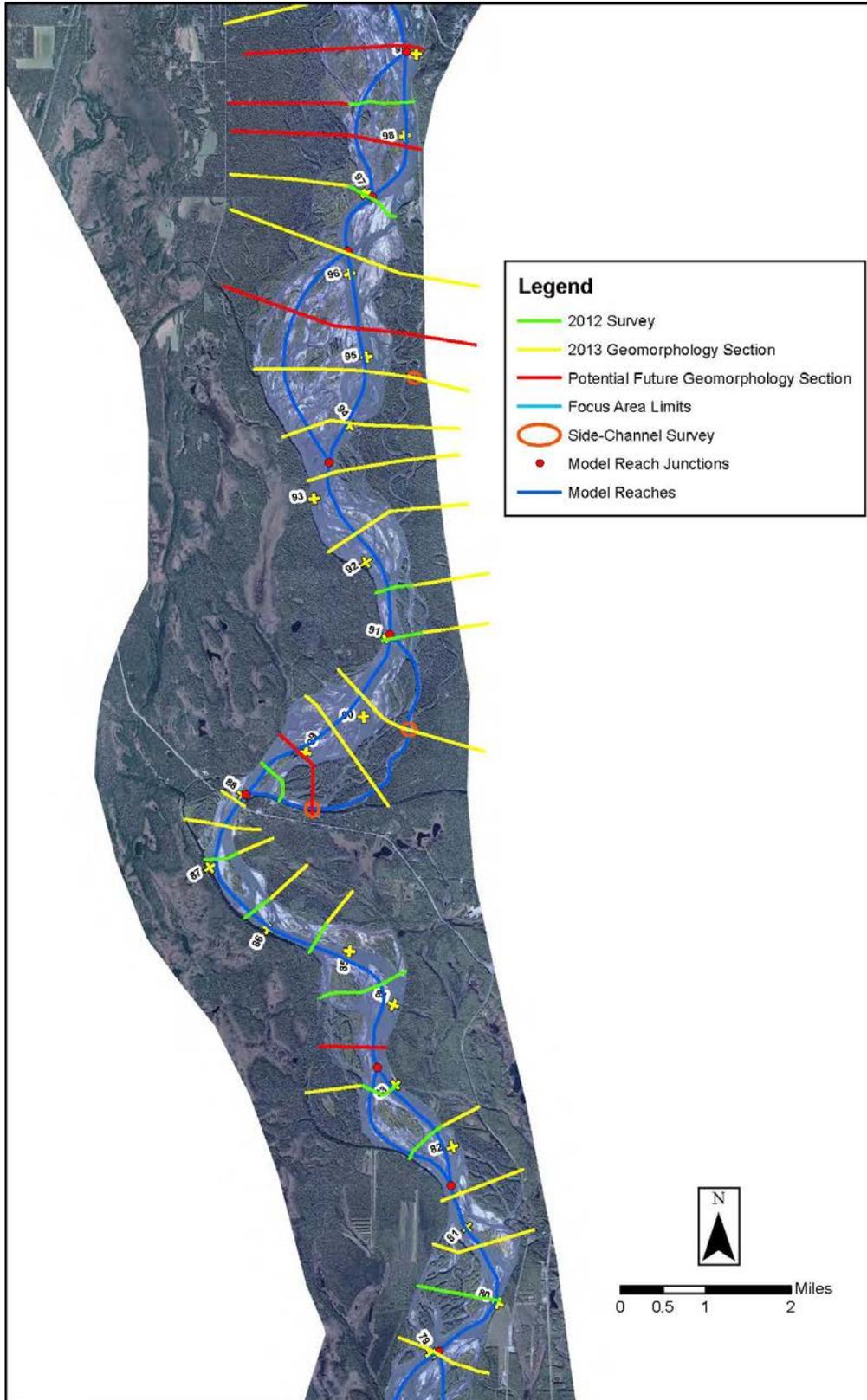


Figure 4-4. Survey and Model Cross Sections from PRM 79 to PRM 99.

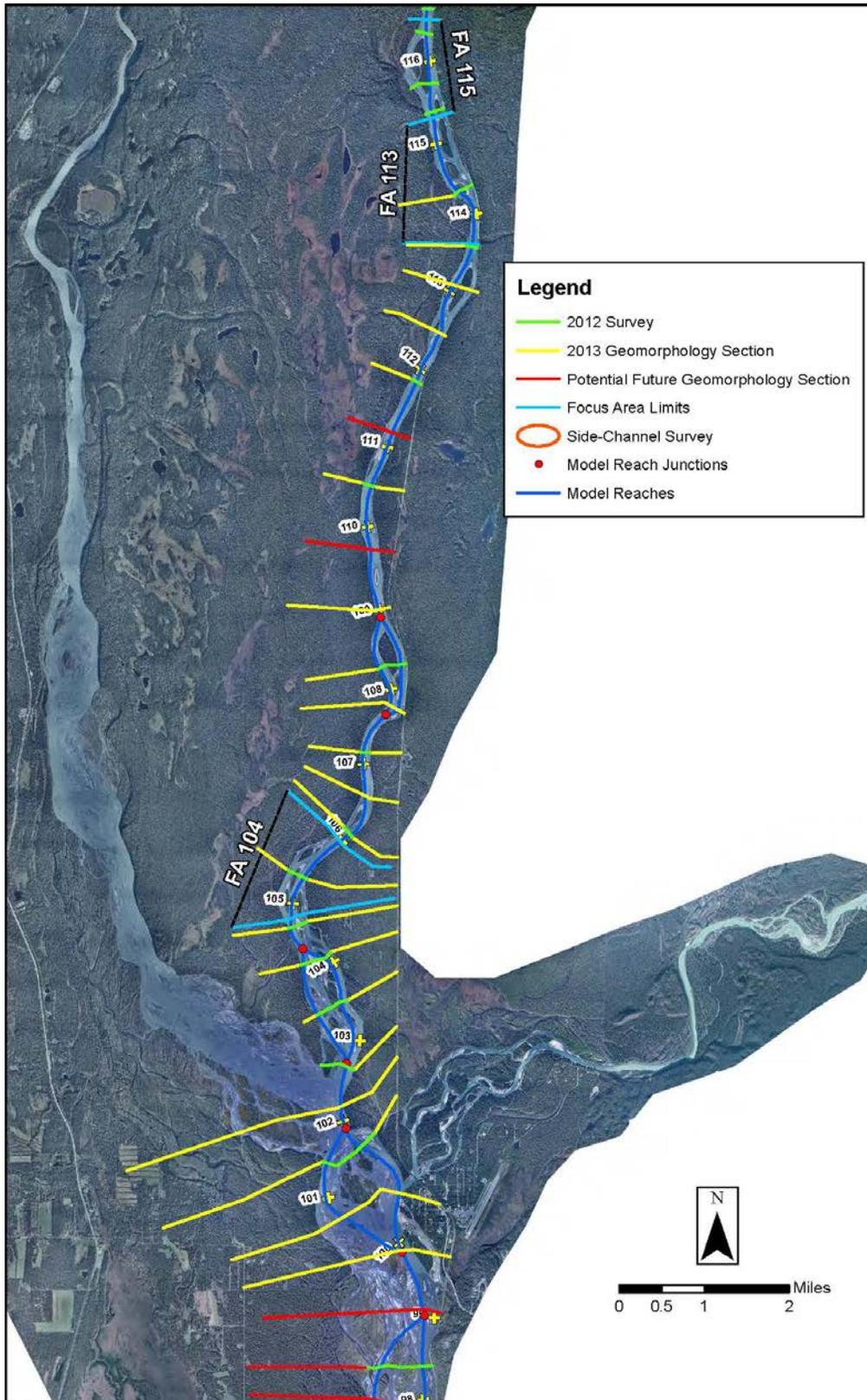
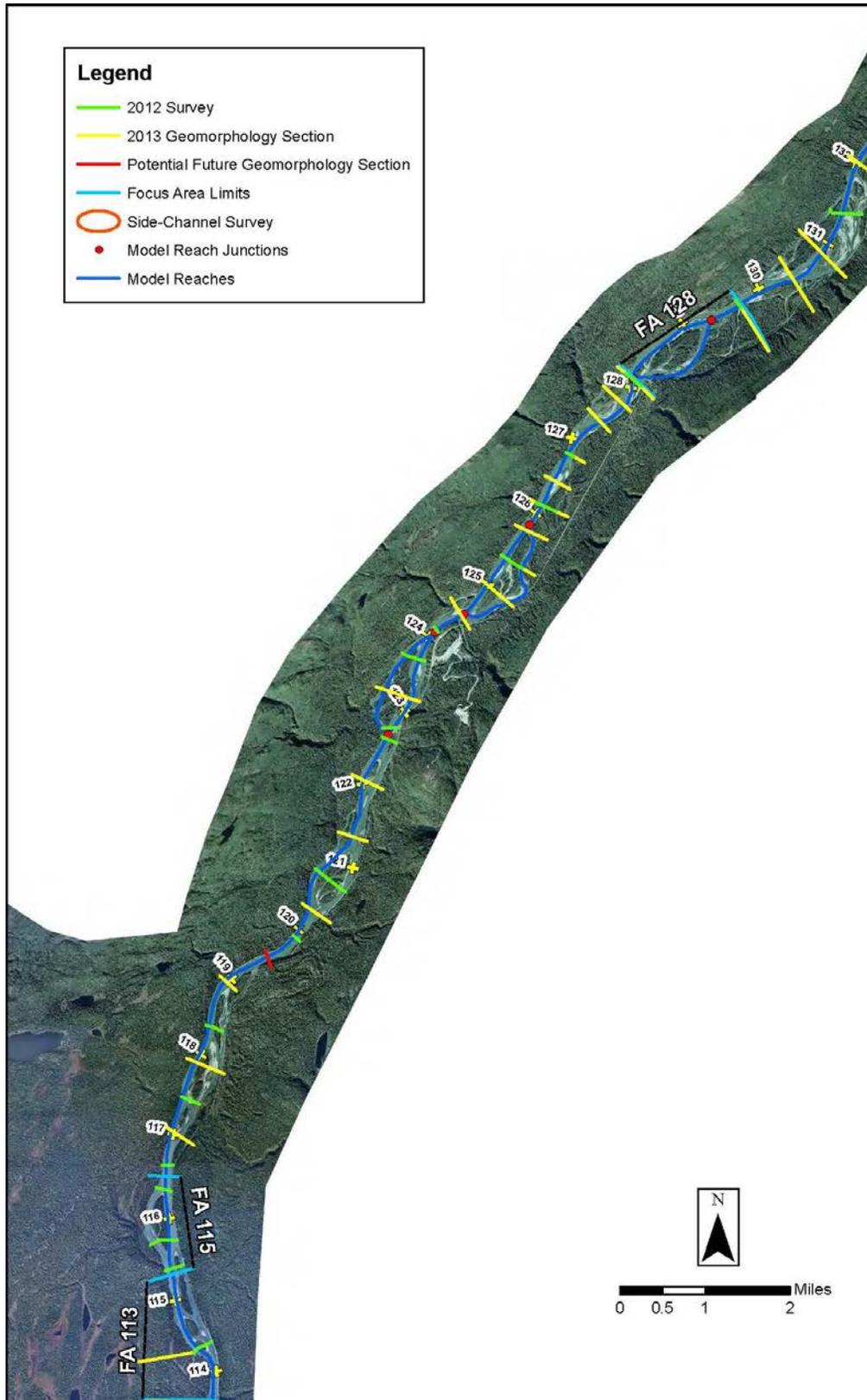


Figure 4-5. Survey and Model Cross Sections from PRM 98 to PRM 116.



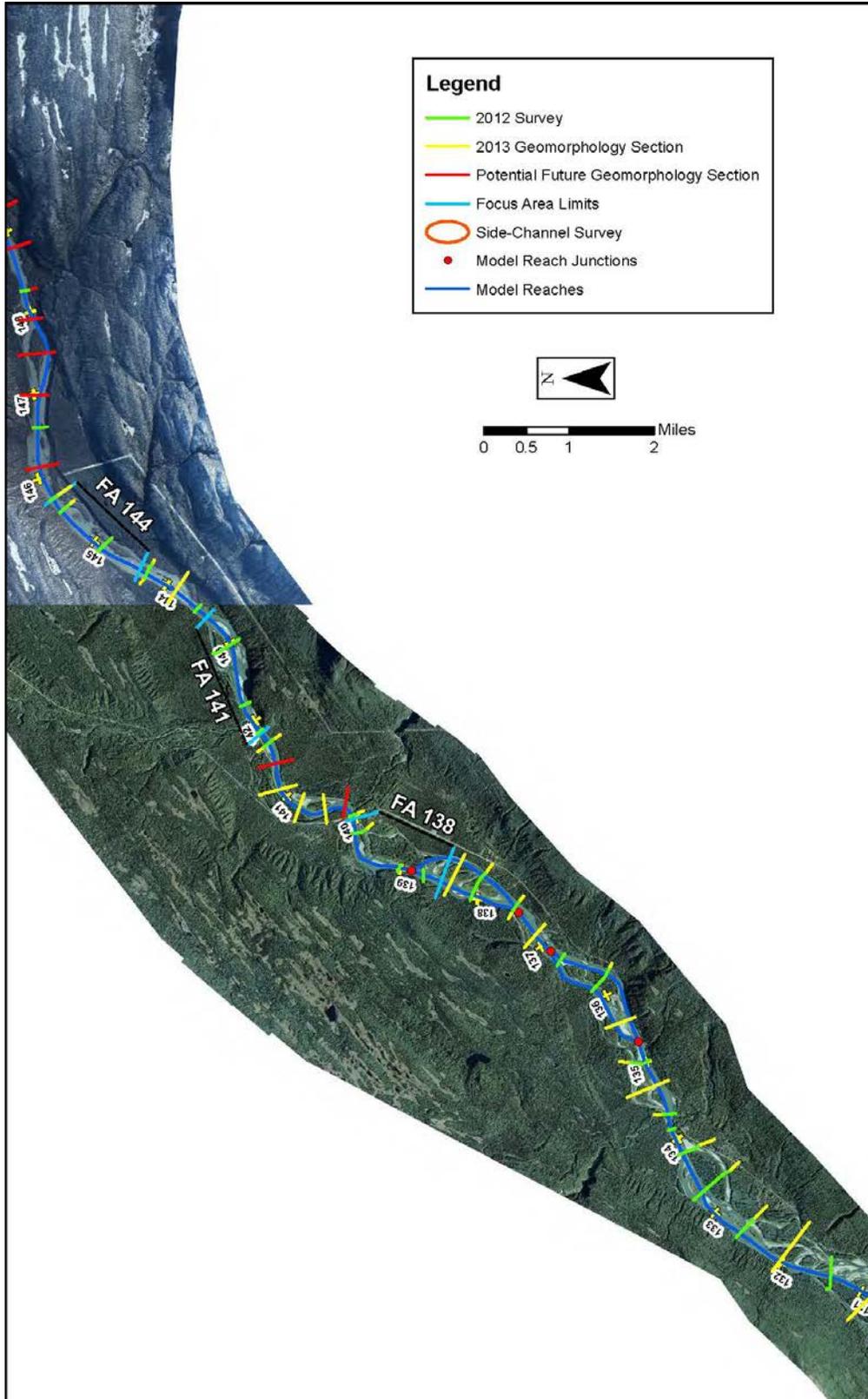


Figure 4-7. Survey and Model Cross Sections from PRM 131 to PRM 148.

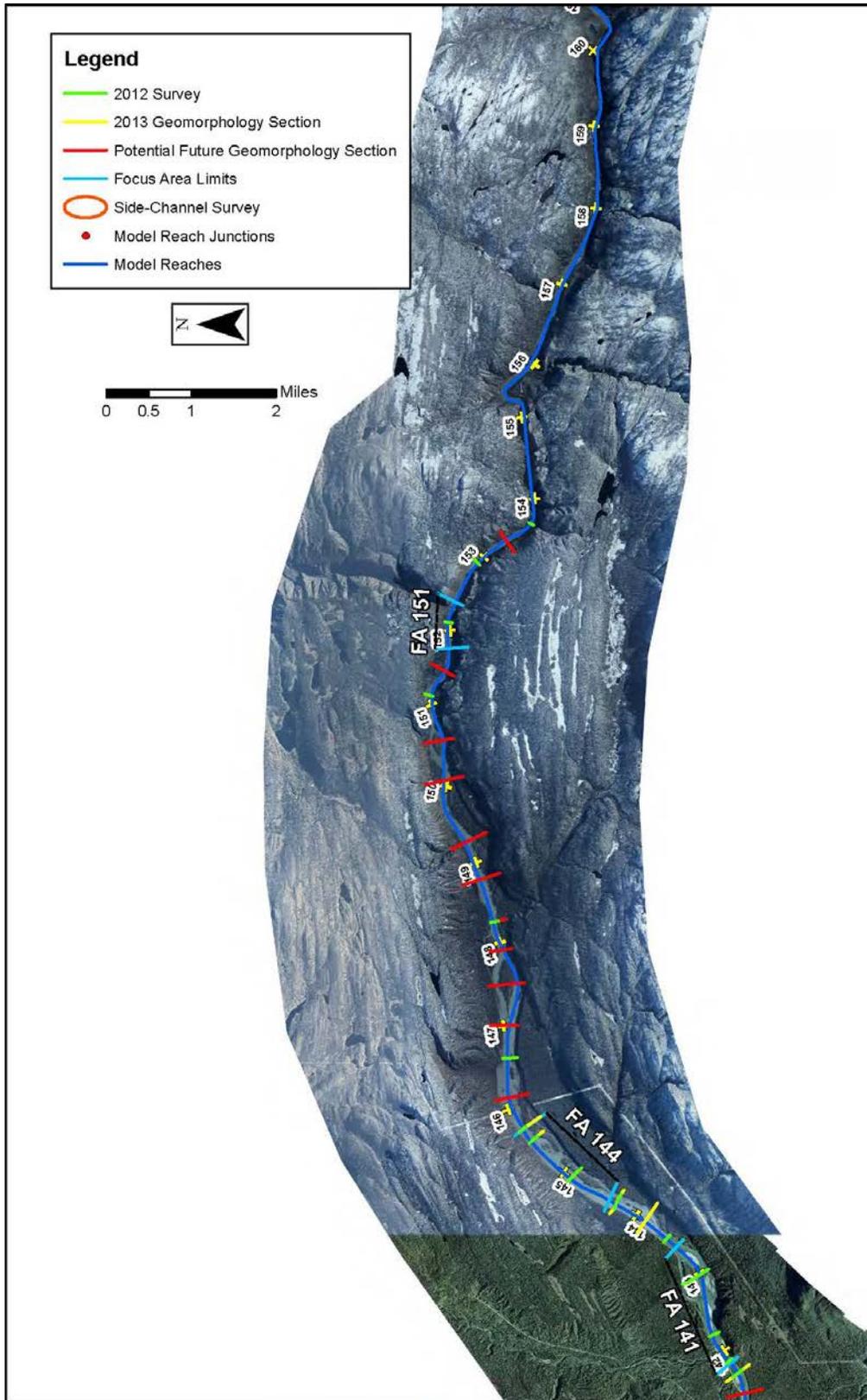


Figure 4-8. Survey and Model Cross Sections from PRM 142 to PRM 154.

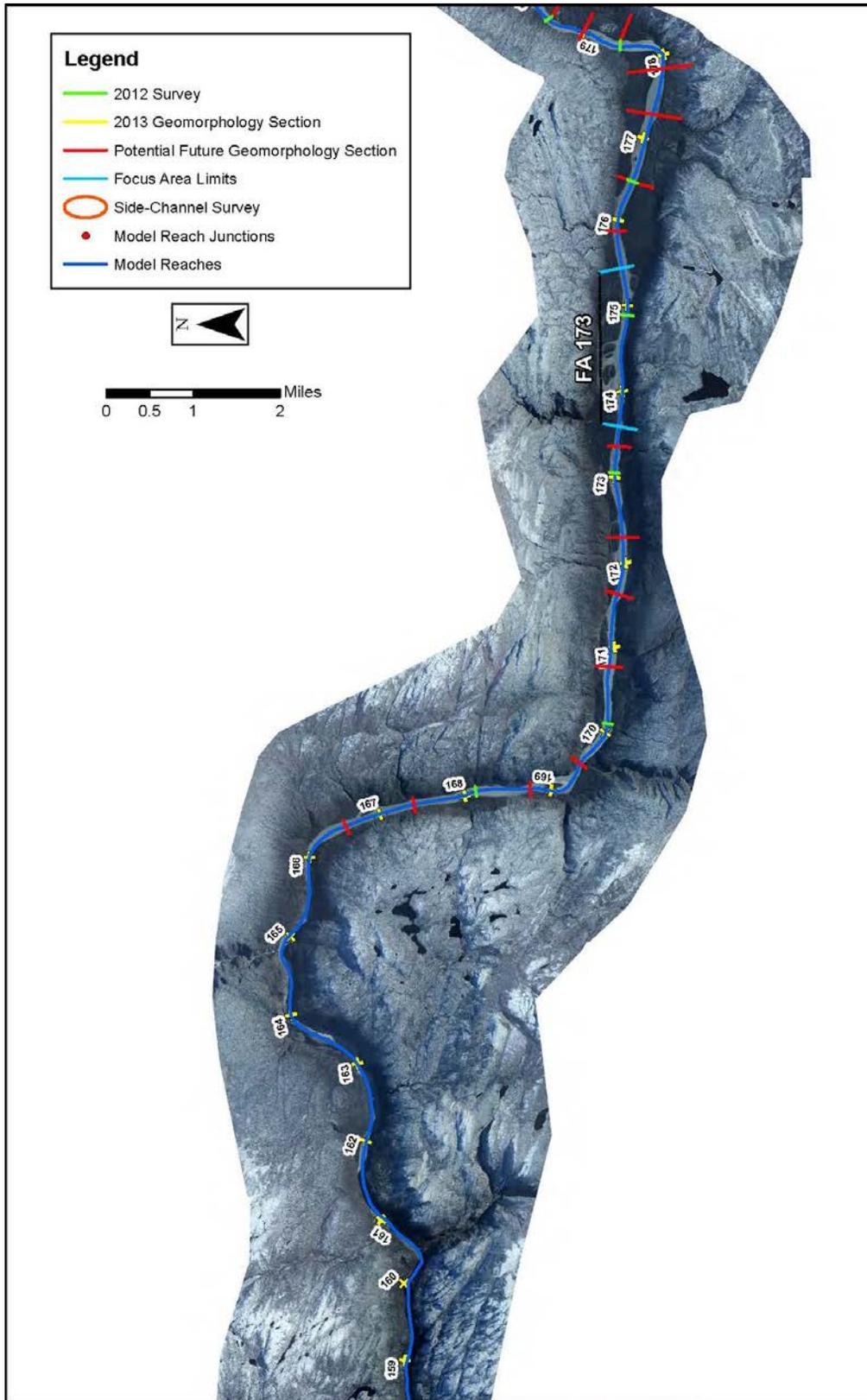


Figure 4-9. Survey and Model Cross Sections from PRM 166 to PRM 179.



Figure 4-10. Survey and Model Cross Sections from PRM 176 to PRM 188.

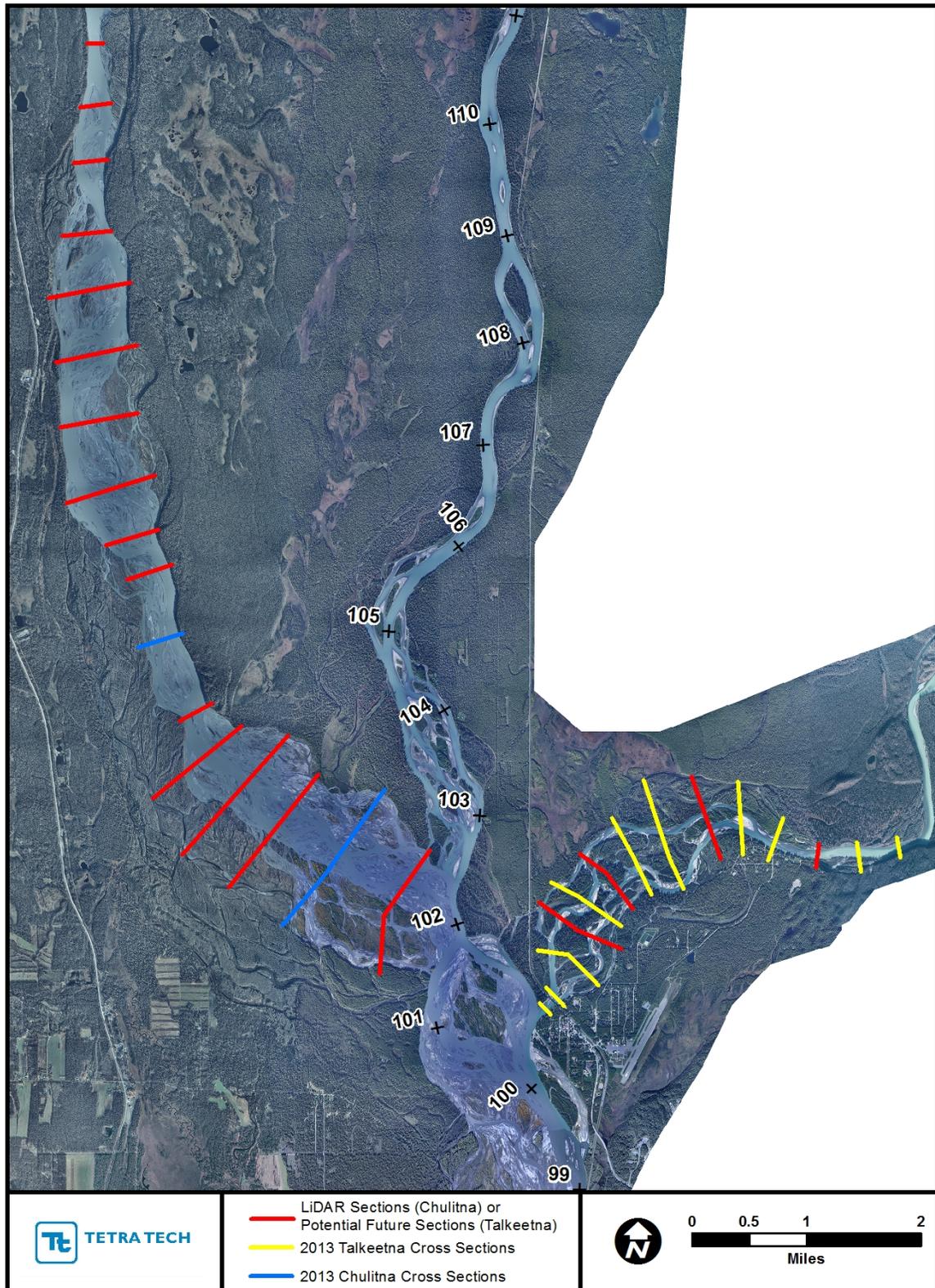


Figure 4-11. Proposed Cross Section Layout for Chulitna and Talkeetna Rivers, 1-D Model Tributary Reaches.

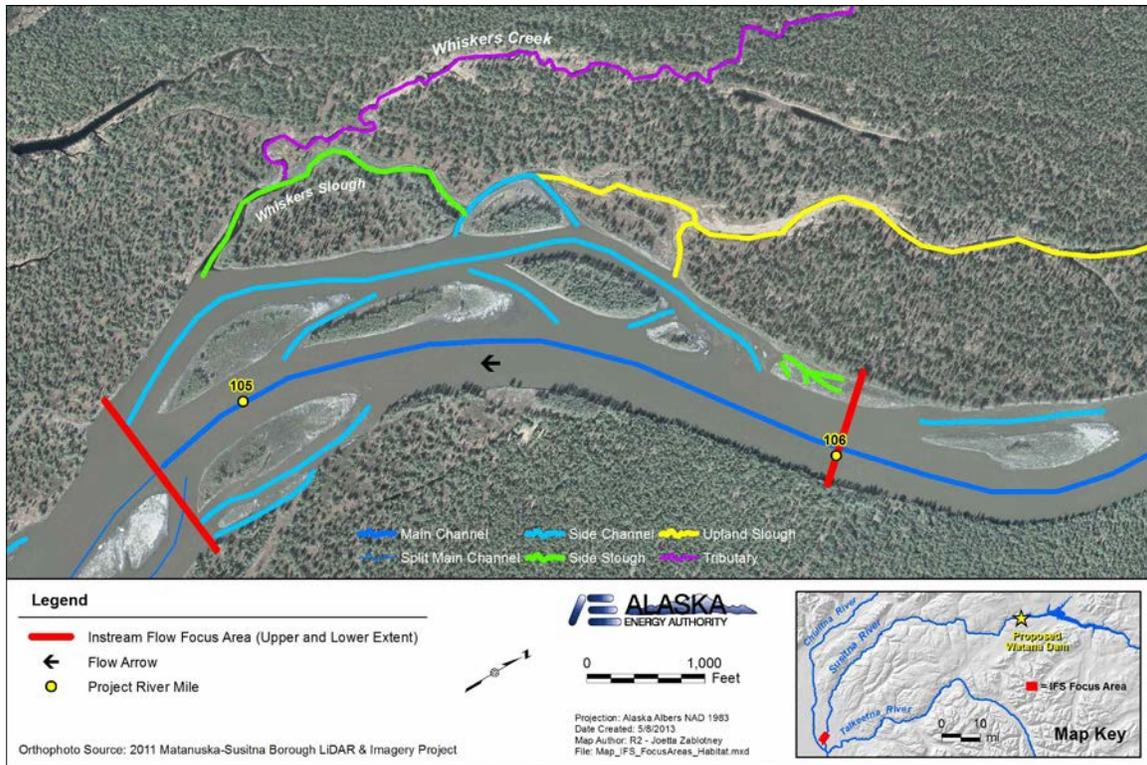


Figure 4-12. FA104 (From R2 Resource Consultants Inc. 2013b).

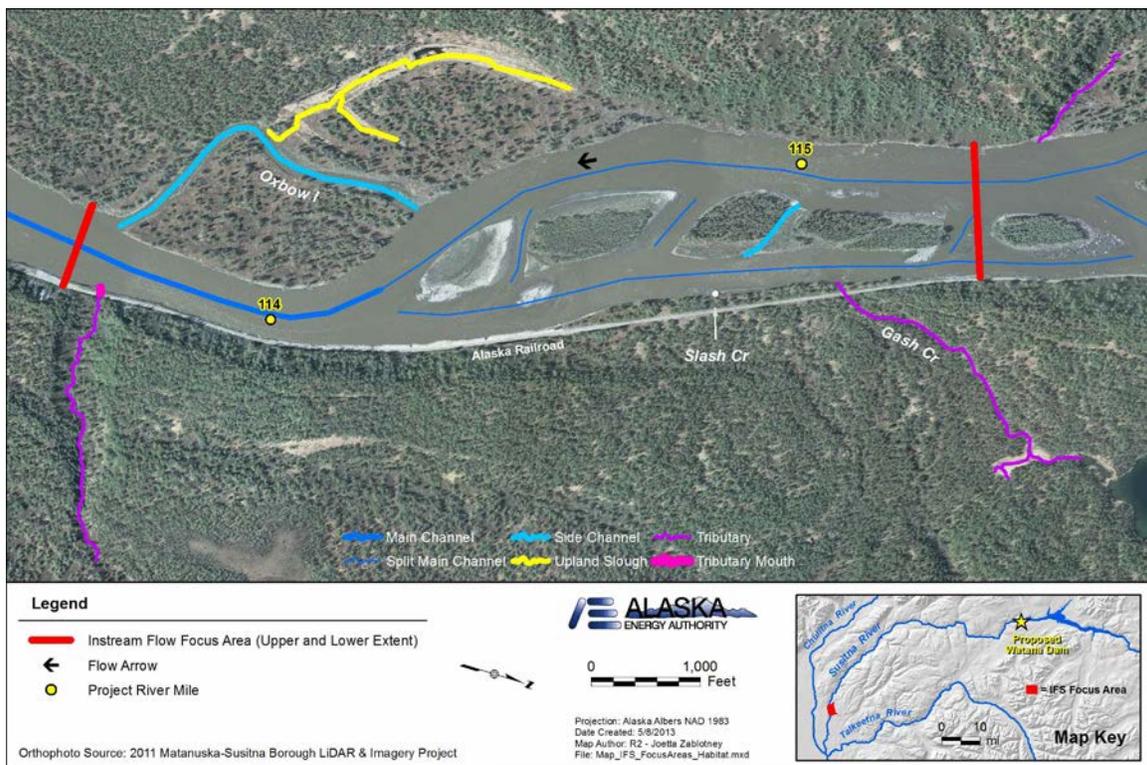


Figure 4-13. FA113 (From R2 Resource Consultants Inc. 2013b).

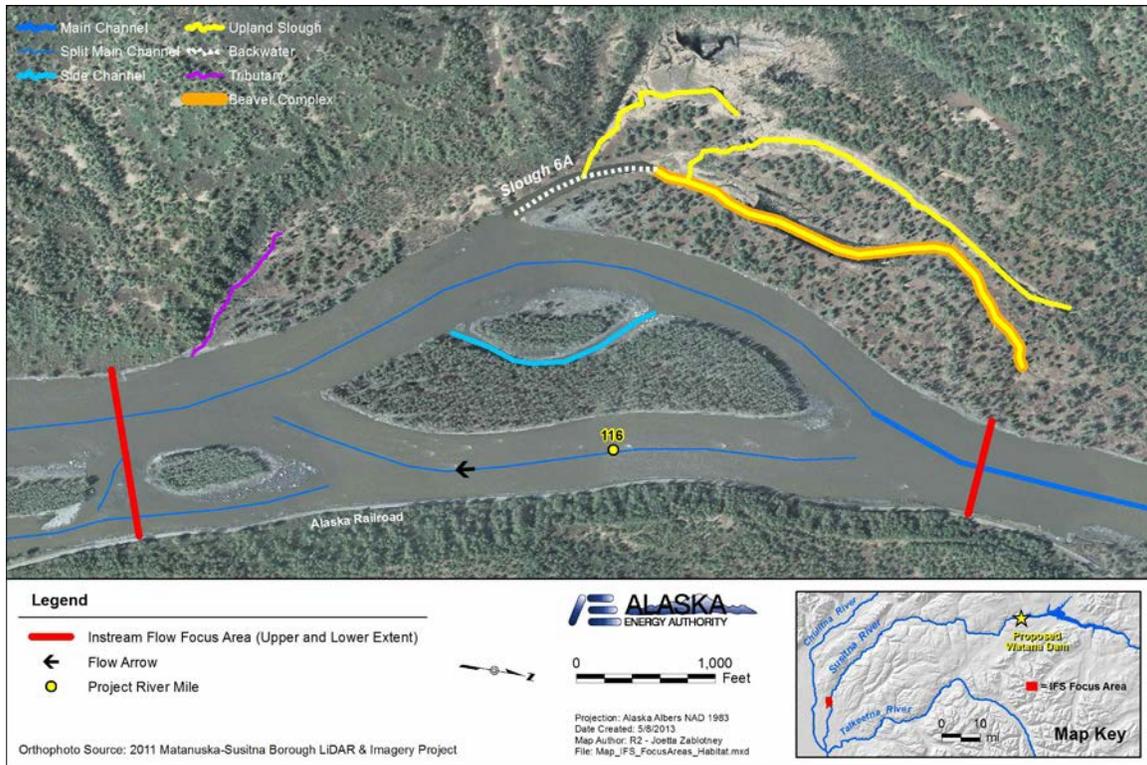


Figure 4-14. FA115 (From R2 Resource Consultants Inc. 2013b).

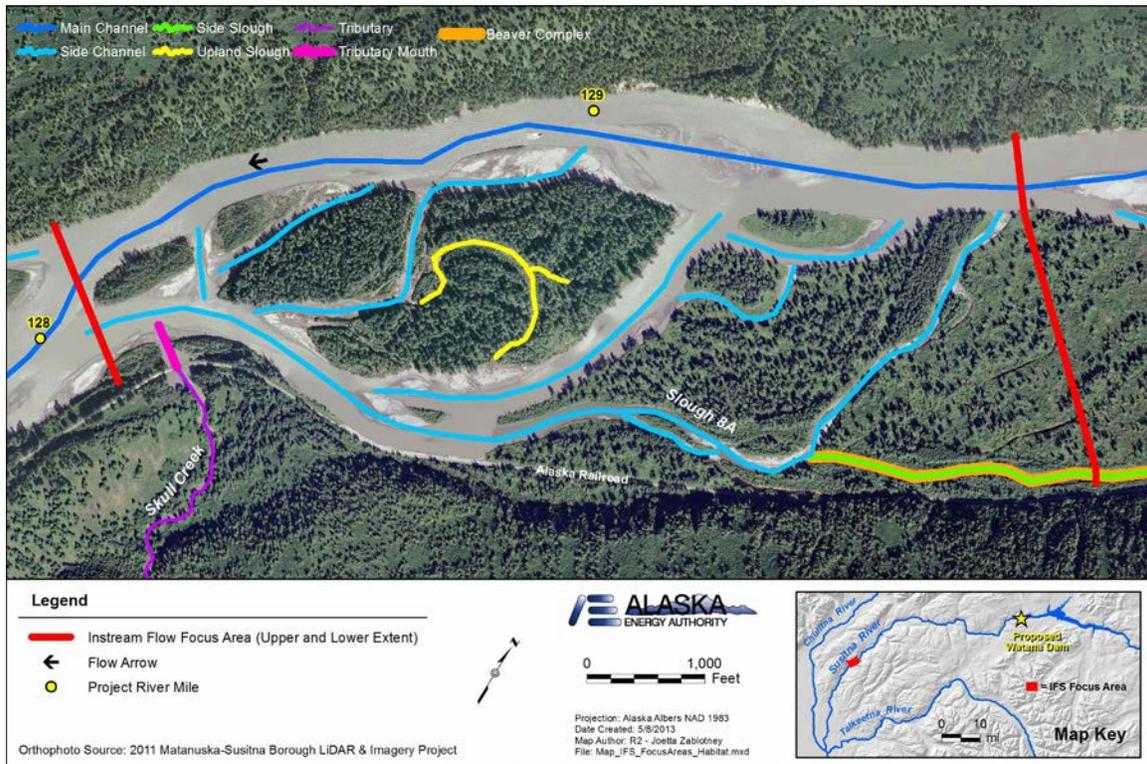


Figure 4-15. FA128 (From R2 Resource Consultants Inc. 2013b).

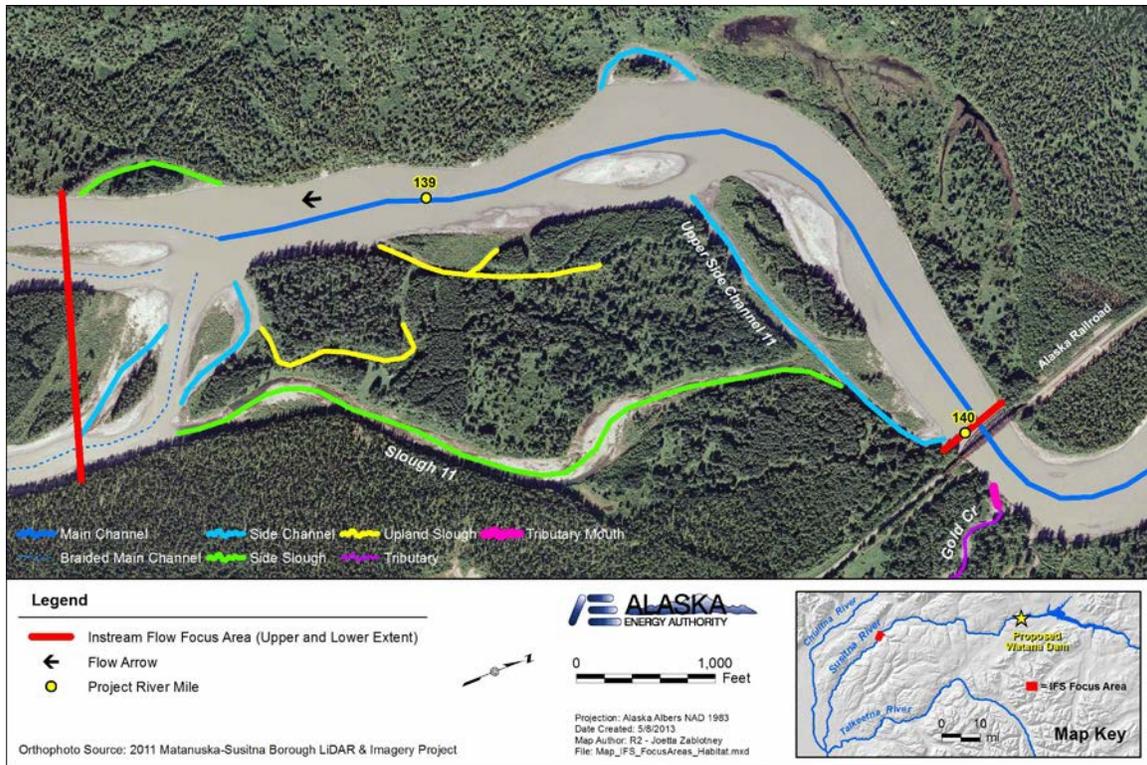


Figure 4-16. FA138 (From R2 Resource Consultants Inc. 2013b).

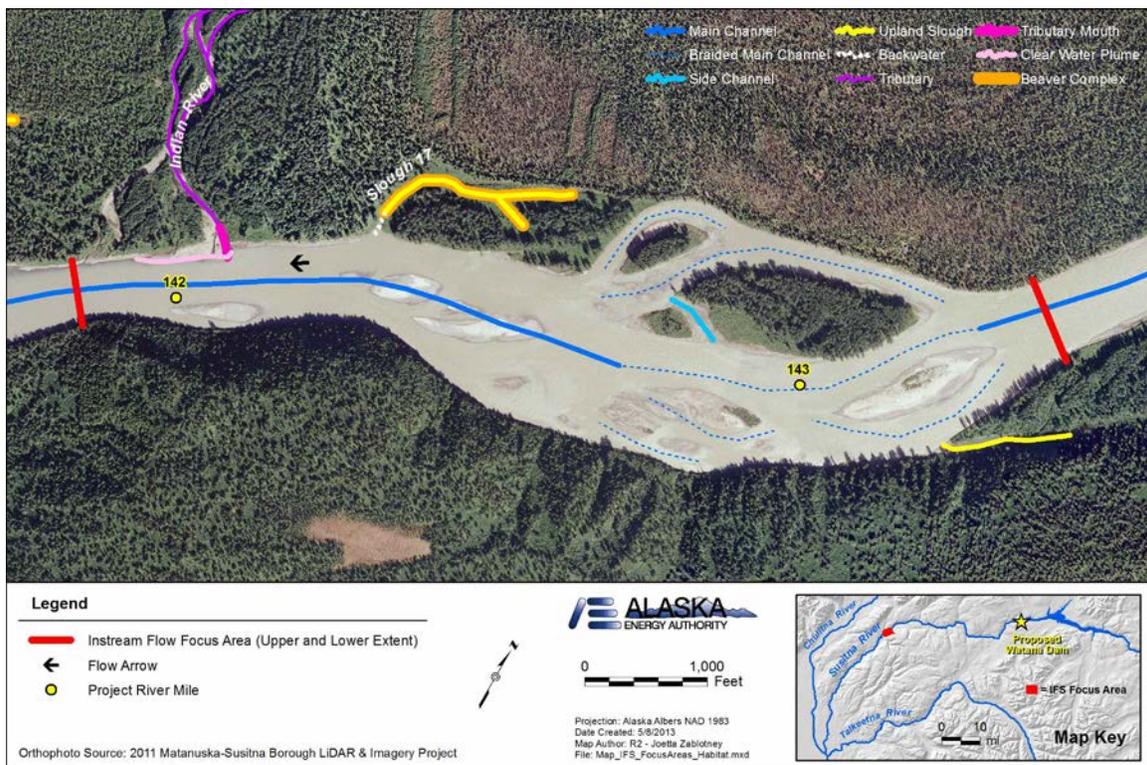


Figure 4-17. FA141 (From R2 Resource Consultants Inc. 2013b).

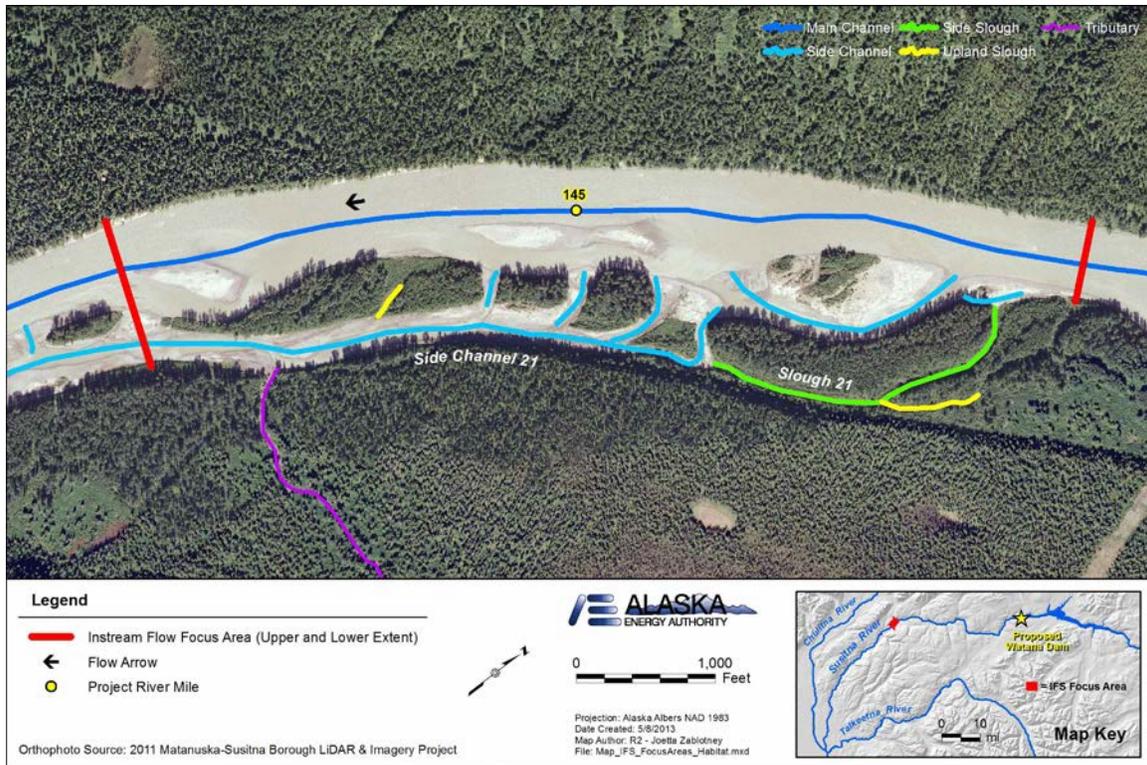


Figure 4-18. FA144 (From R2 Resource Consultants Inc. 2013b).

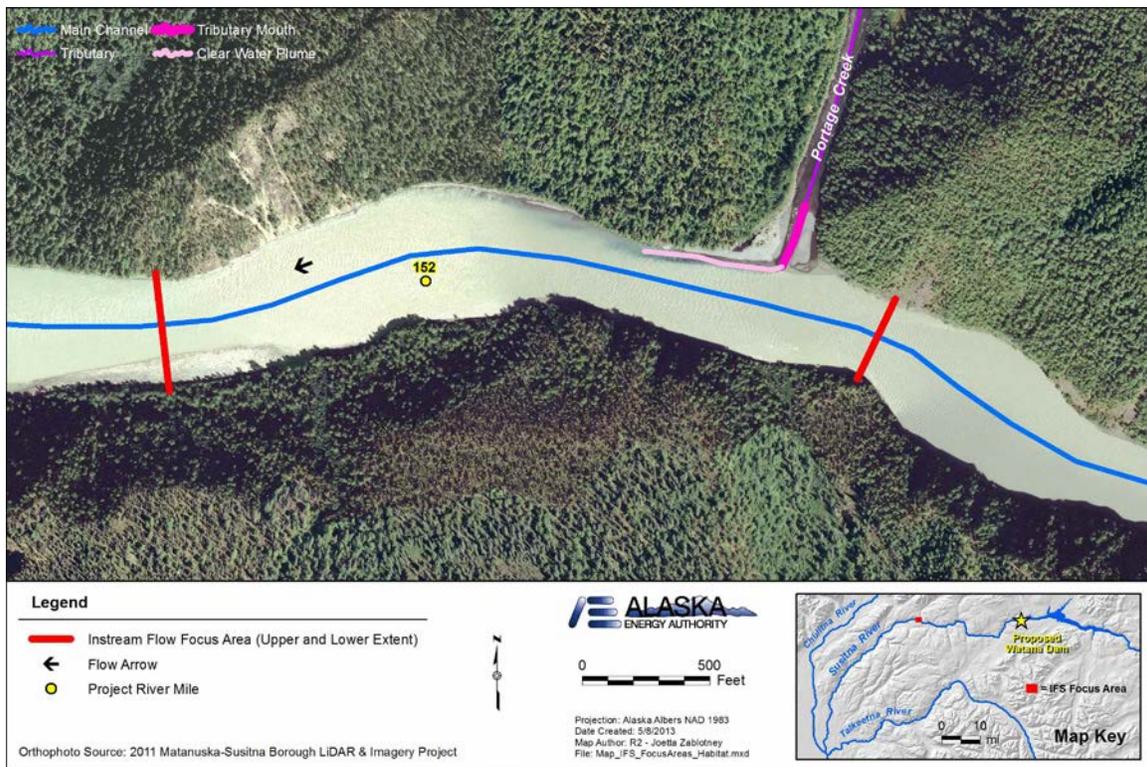


Figure 4-19. FA151 (From R2 Resource Consultants Inc. 2013b).

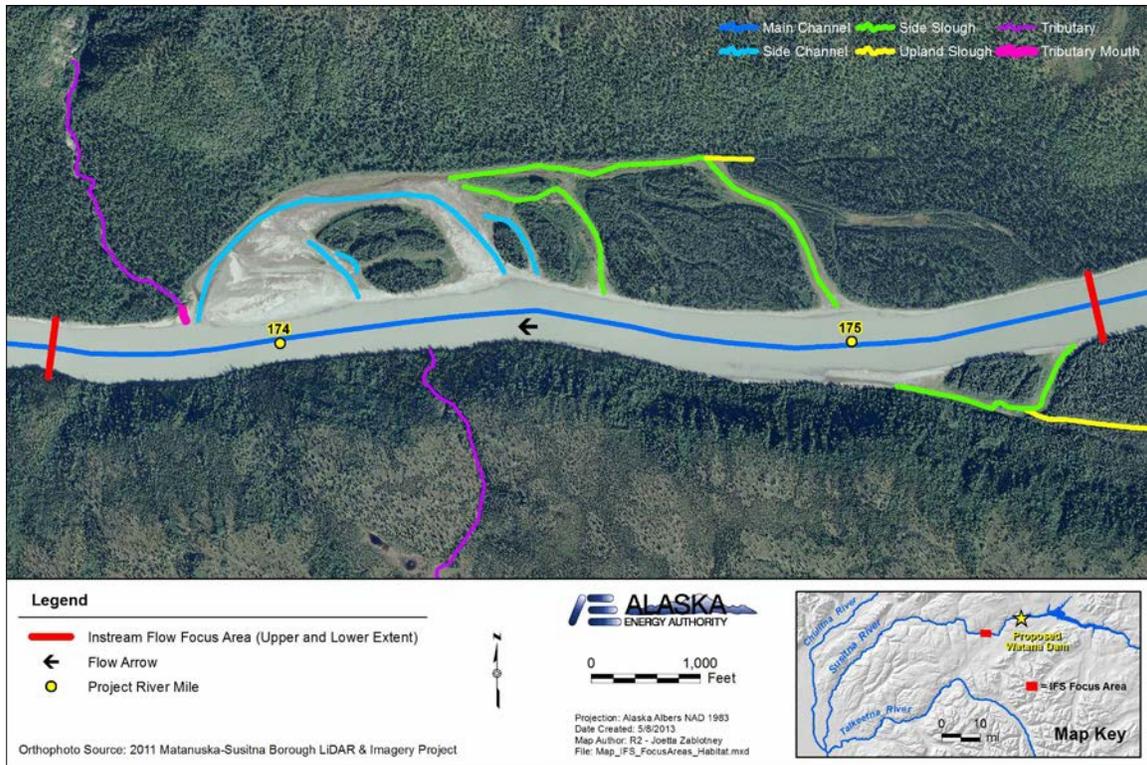


Figure 4-20. FA173 (From R2 Resource Consultants Inc. 2013b).

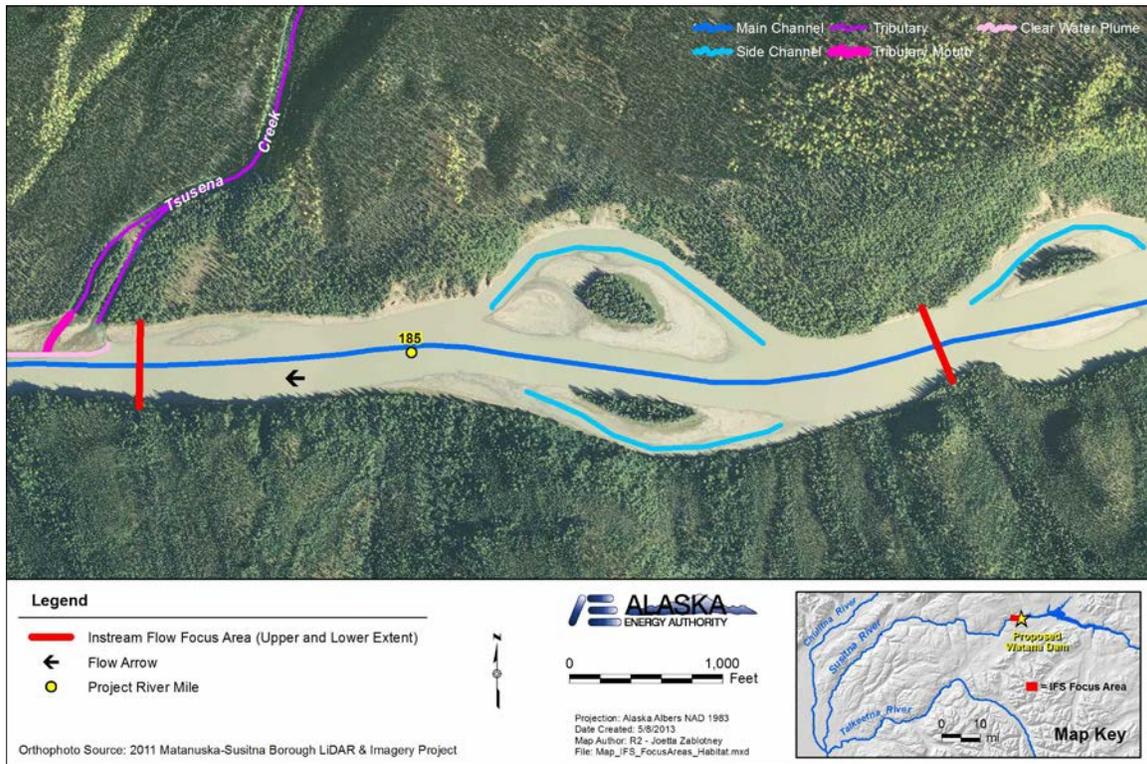


Figure 4-21. FA184 (From R2 Resource Consultants Inc. 2013b).

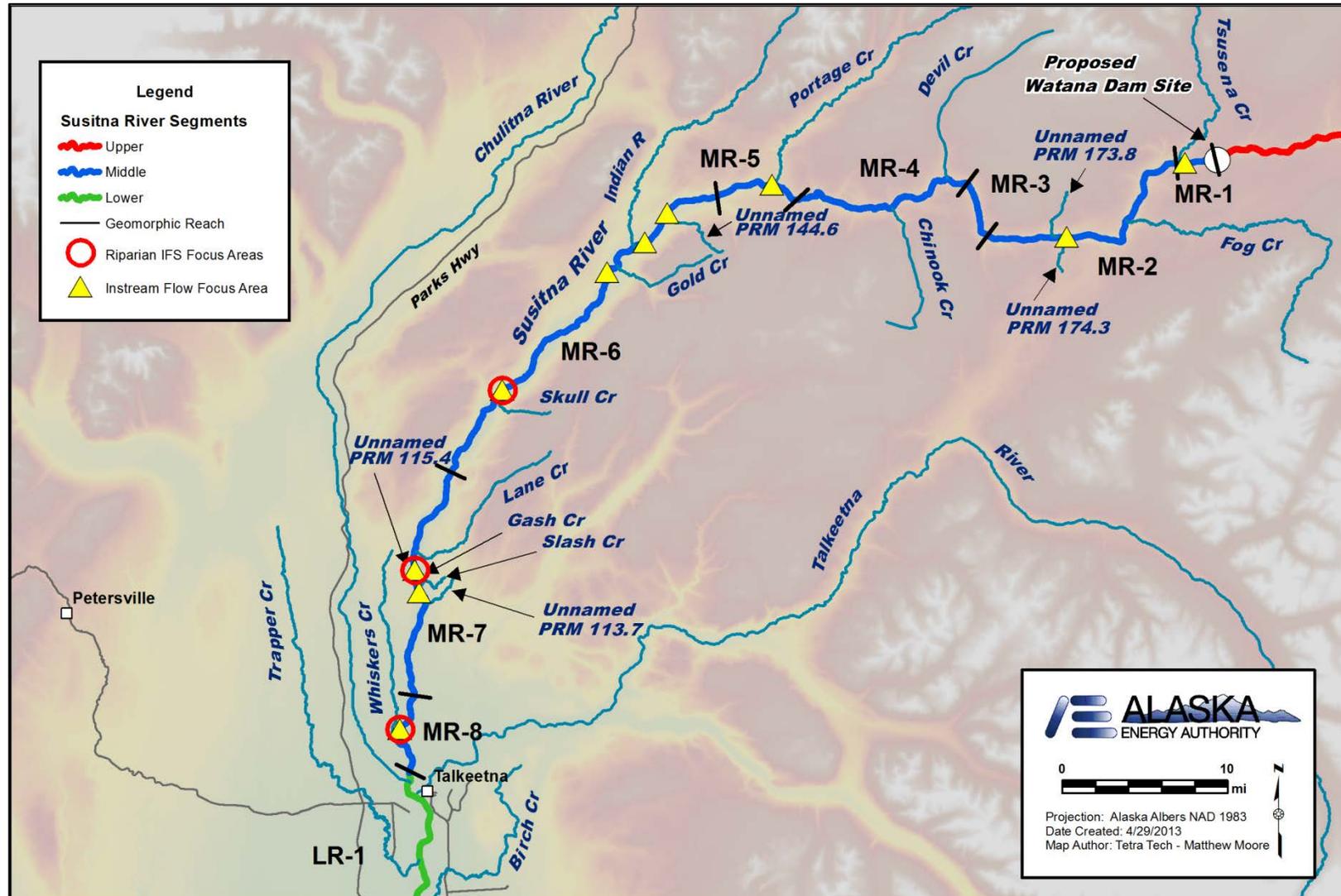


Figure 4-22. Middle River Tributary Locations Relative to Geomorphic Reach and Focus Areas.

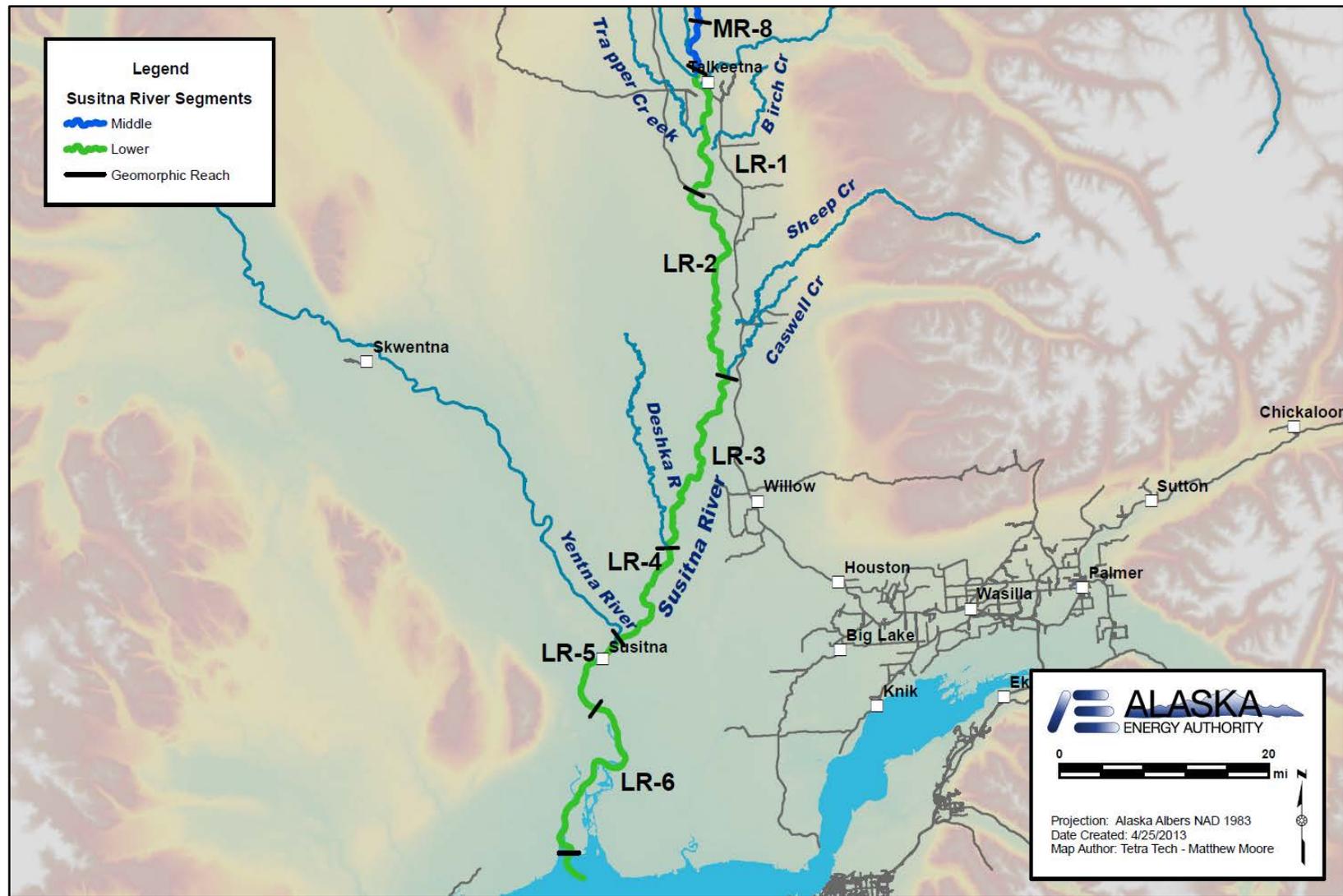


Figure 4-23. Lower River Tributary Locations Relative to Geomorphic Reach.

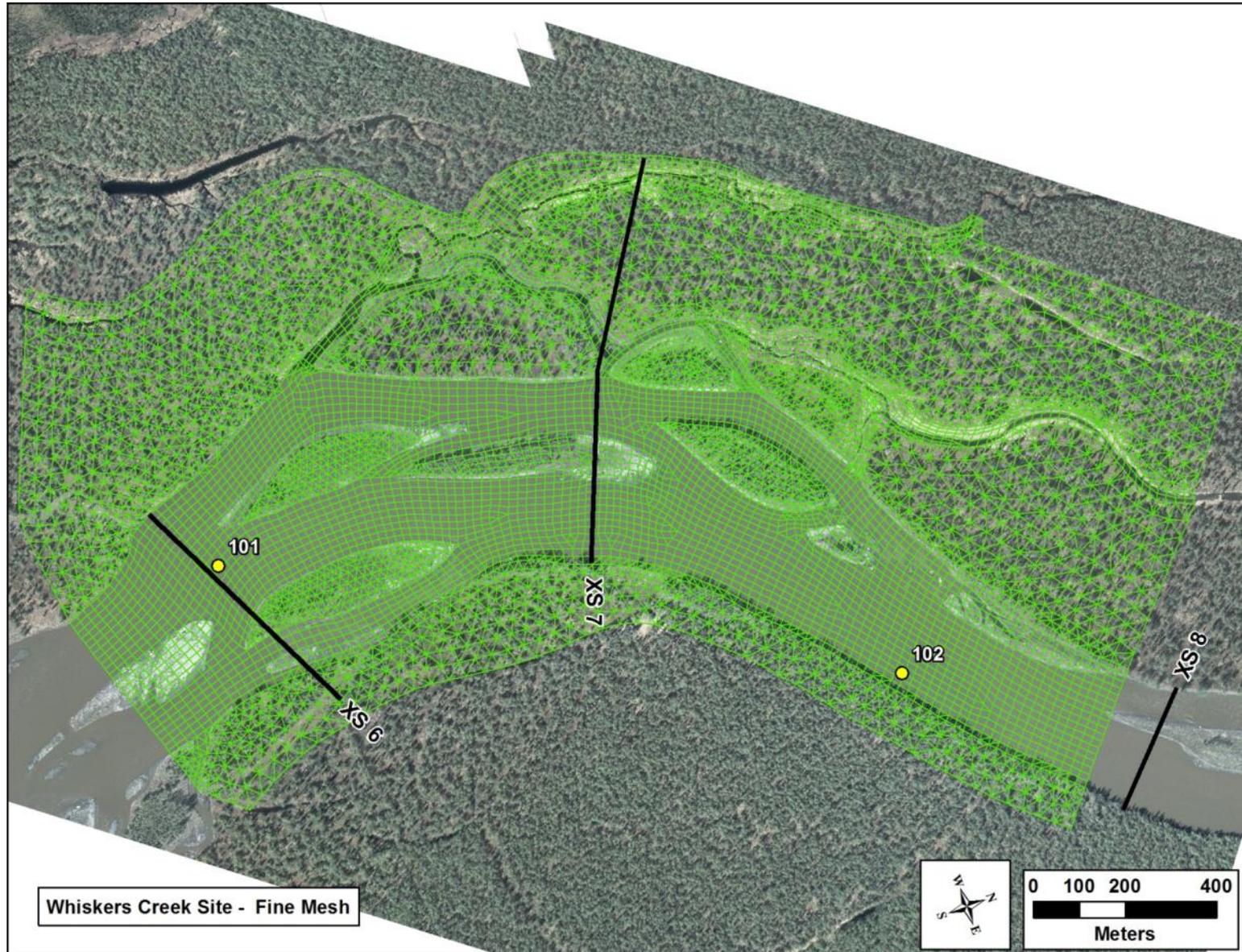


Figure 4-24. Example of Fine Mesh Applied in Whiskers Slough Focus Area.



Figure 4-25. Example of Coarse Mesh Applied in Whiskers Slough Focus Area.

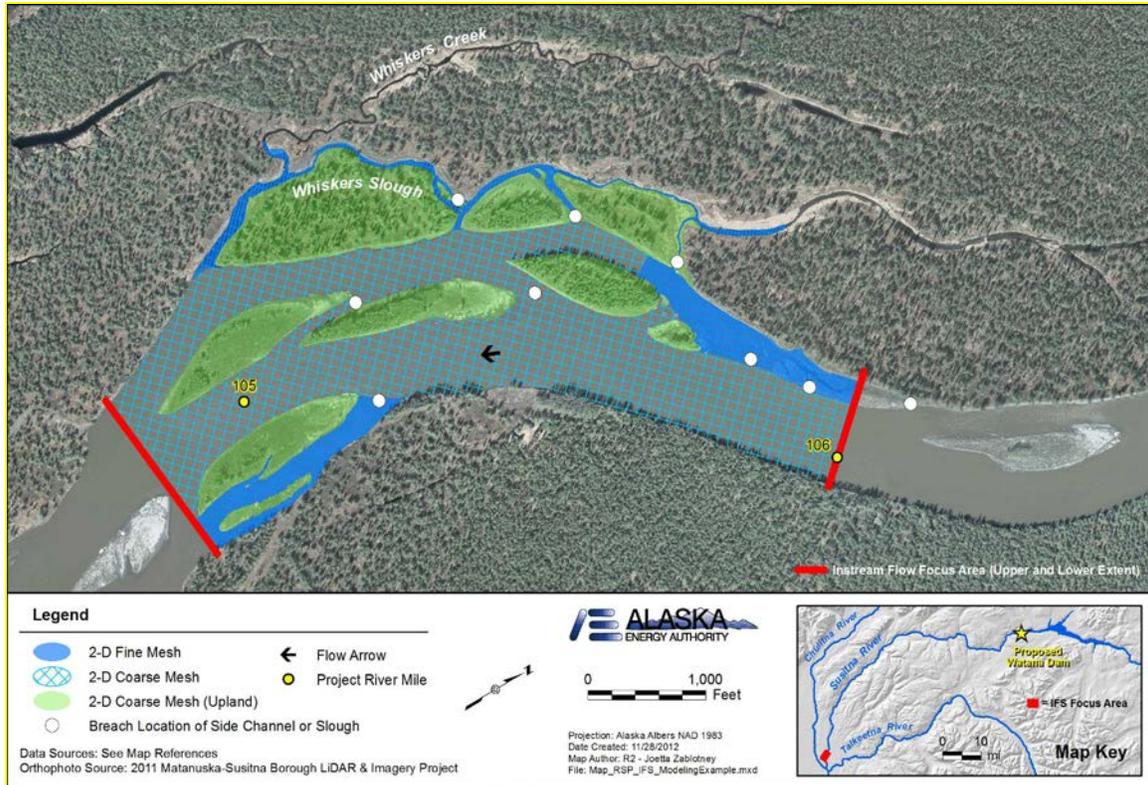


Figure 4-26. Examples of mesh detail for habitat analysis requirements.

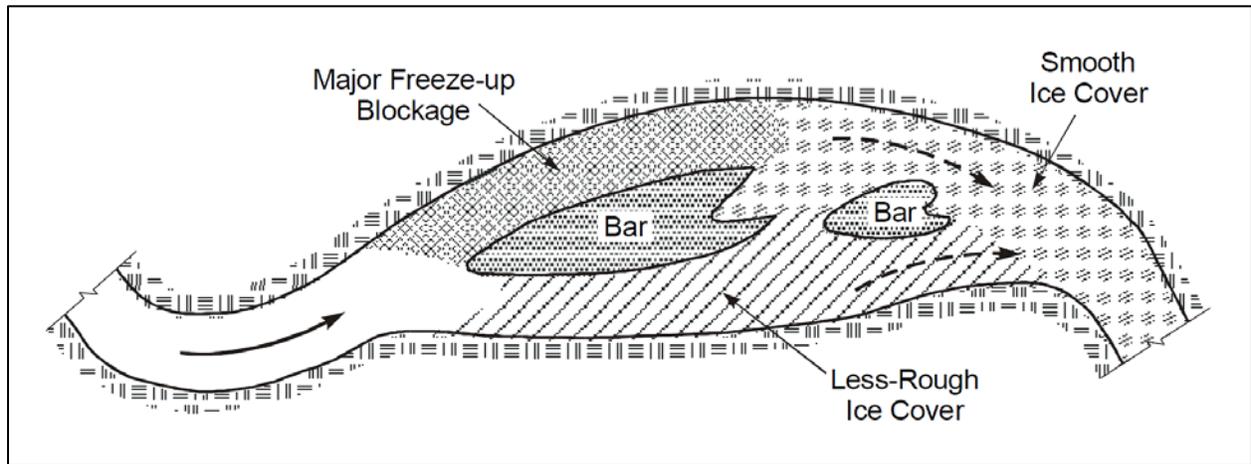


Figure 4-27. Example of Ice Blockage Altering Flow Distribution in Multiple Channel Reaches (Zabilansky et al. 2003).

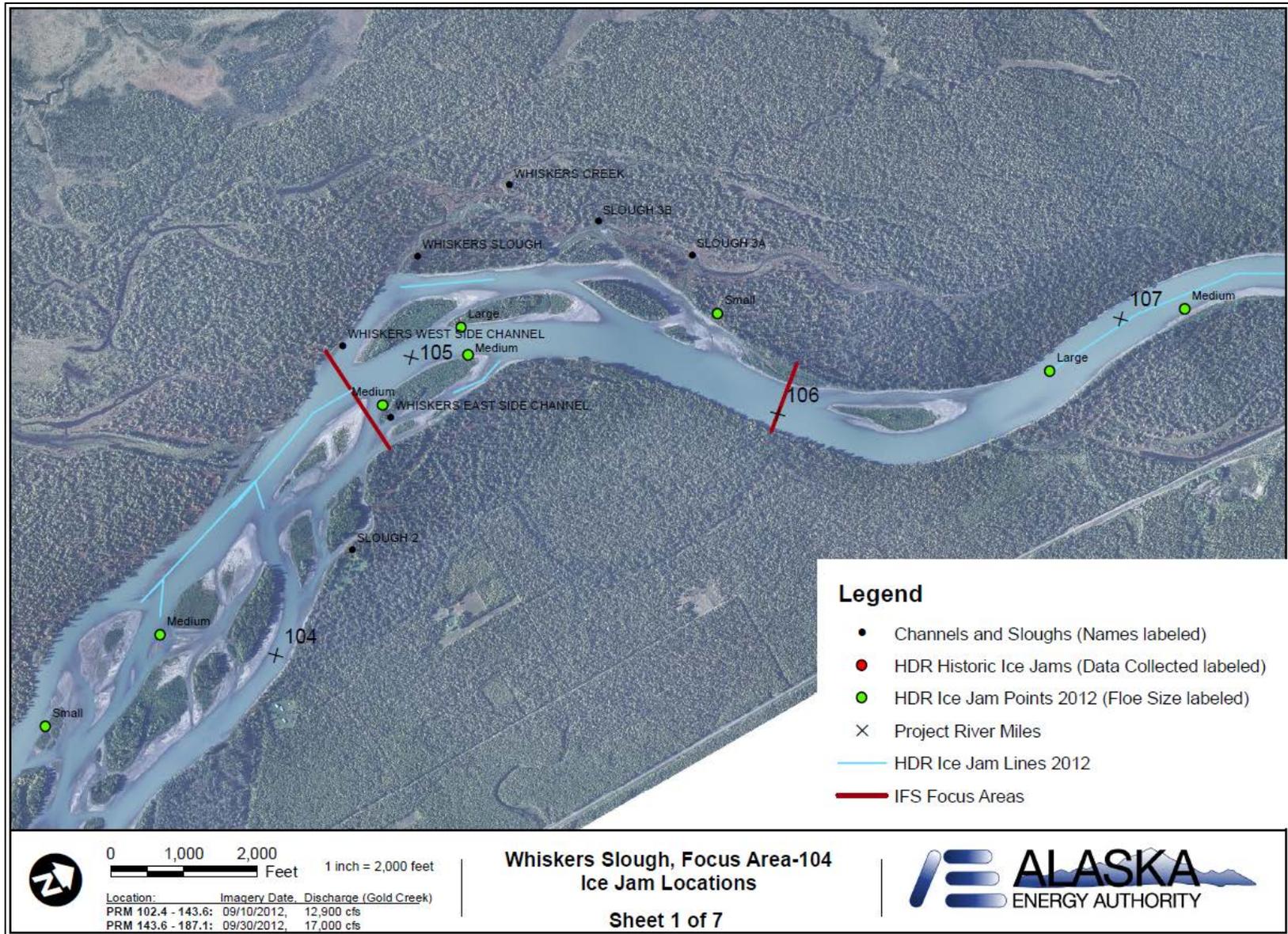


Figure 4-28. Ice Jam Locations at FA104.

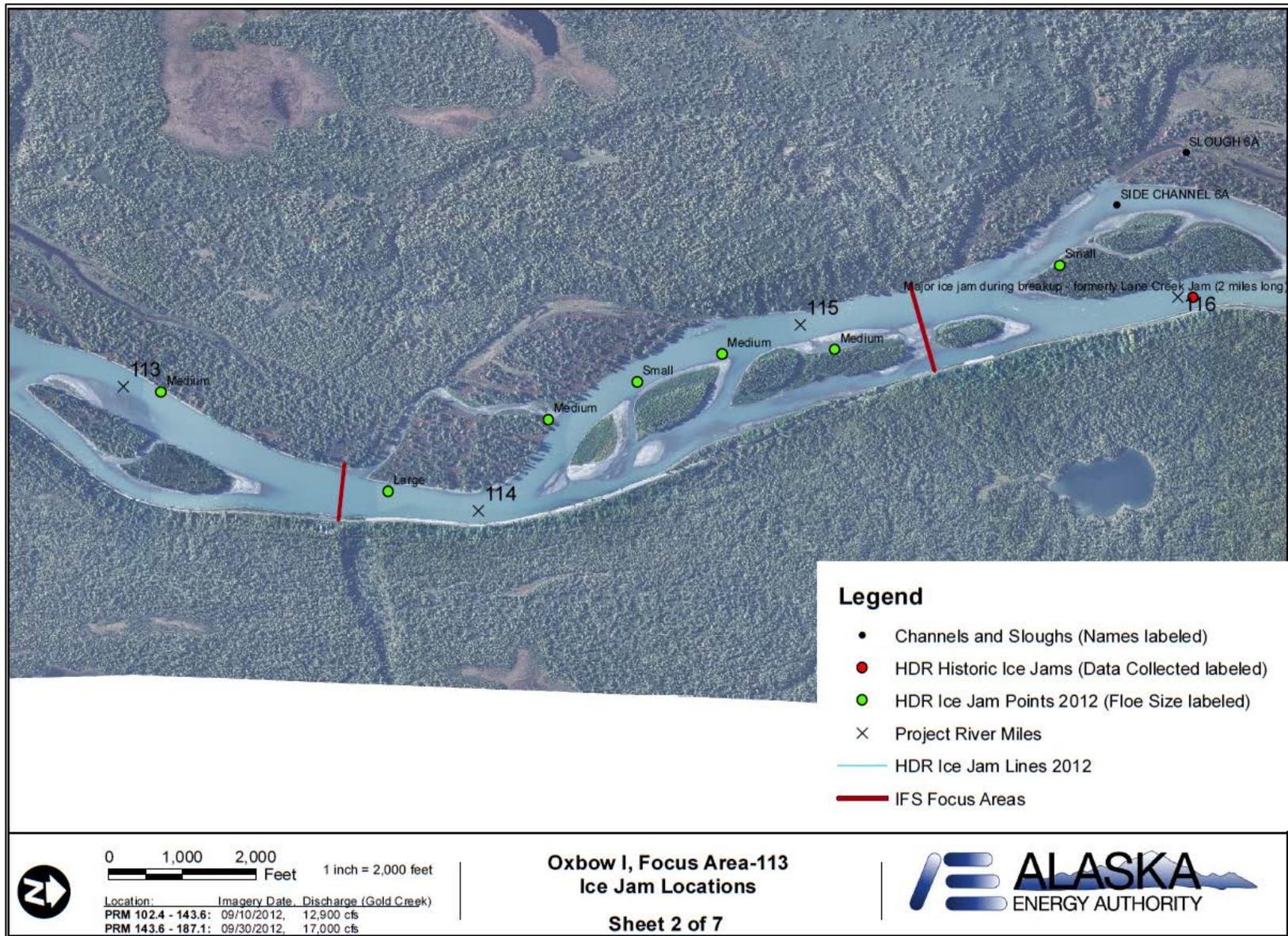


Figure 4-29. Ice Jam Locations at FA113.

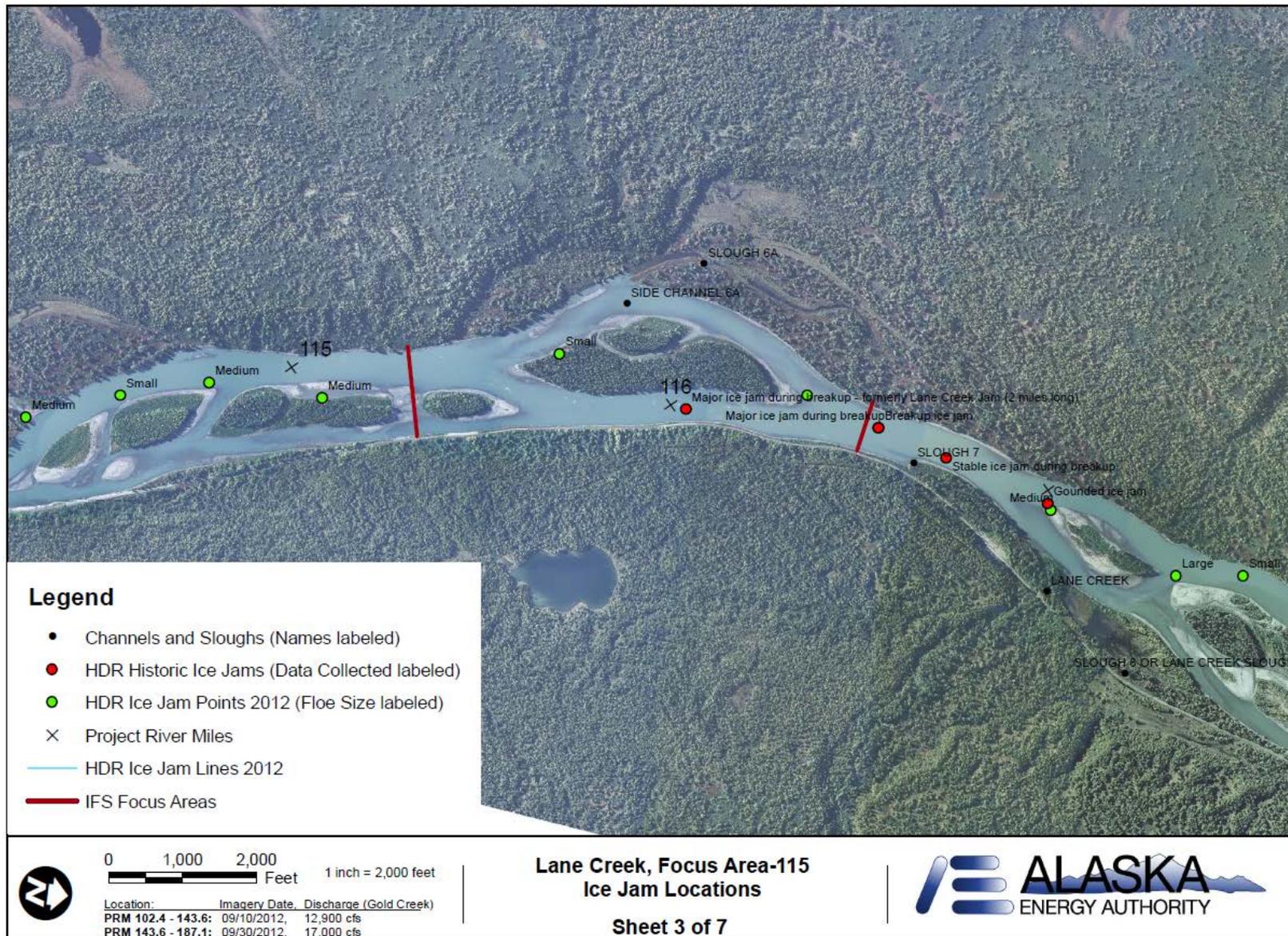


Figure 4-30. Ice Jam Locations at FA115.

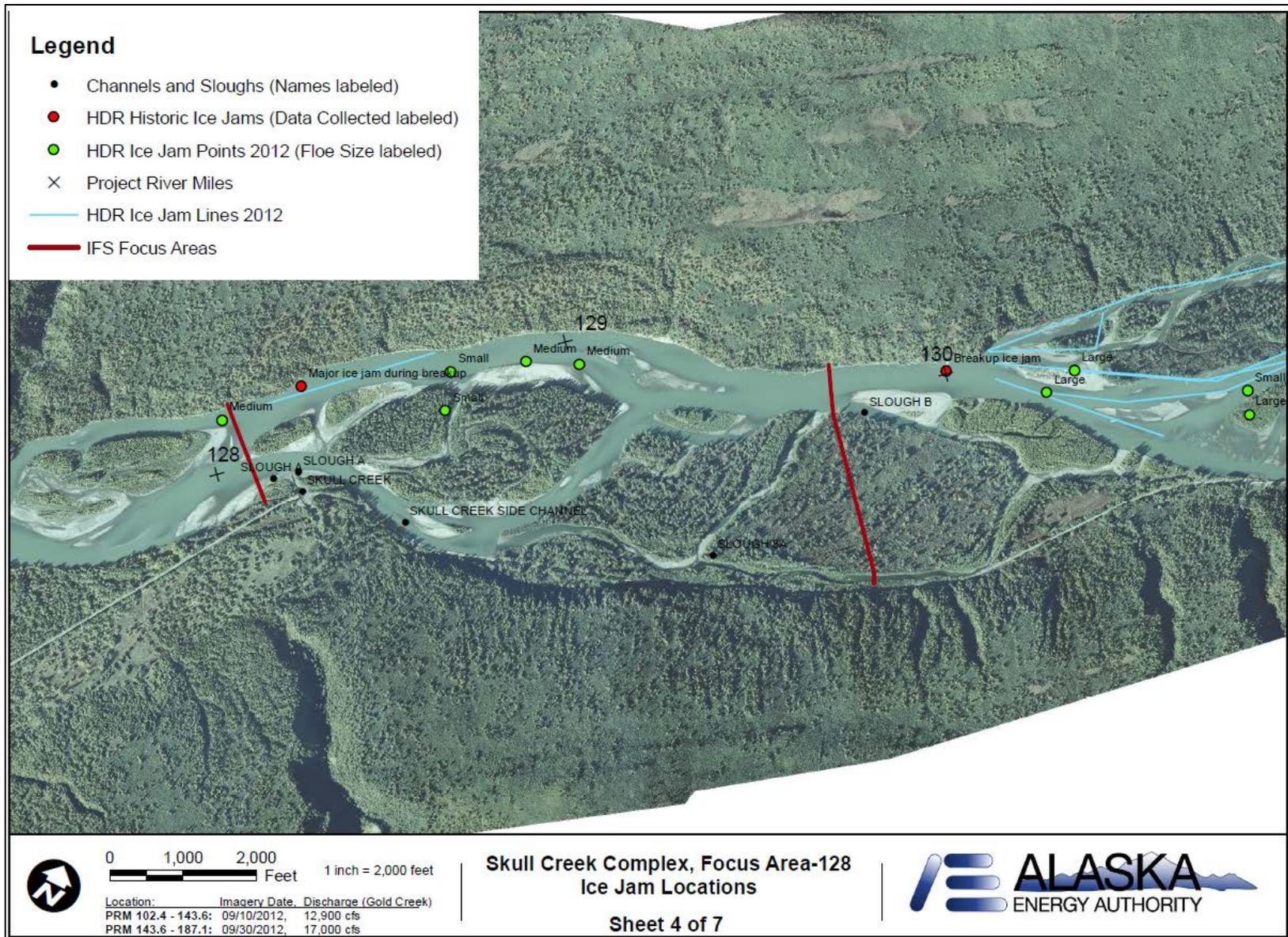


Figure 4-31. Ice Jam Locations at FA128.

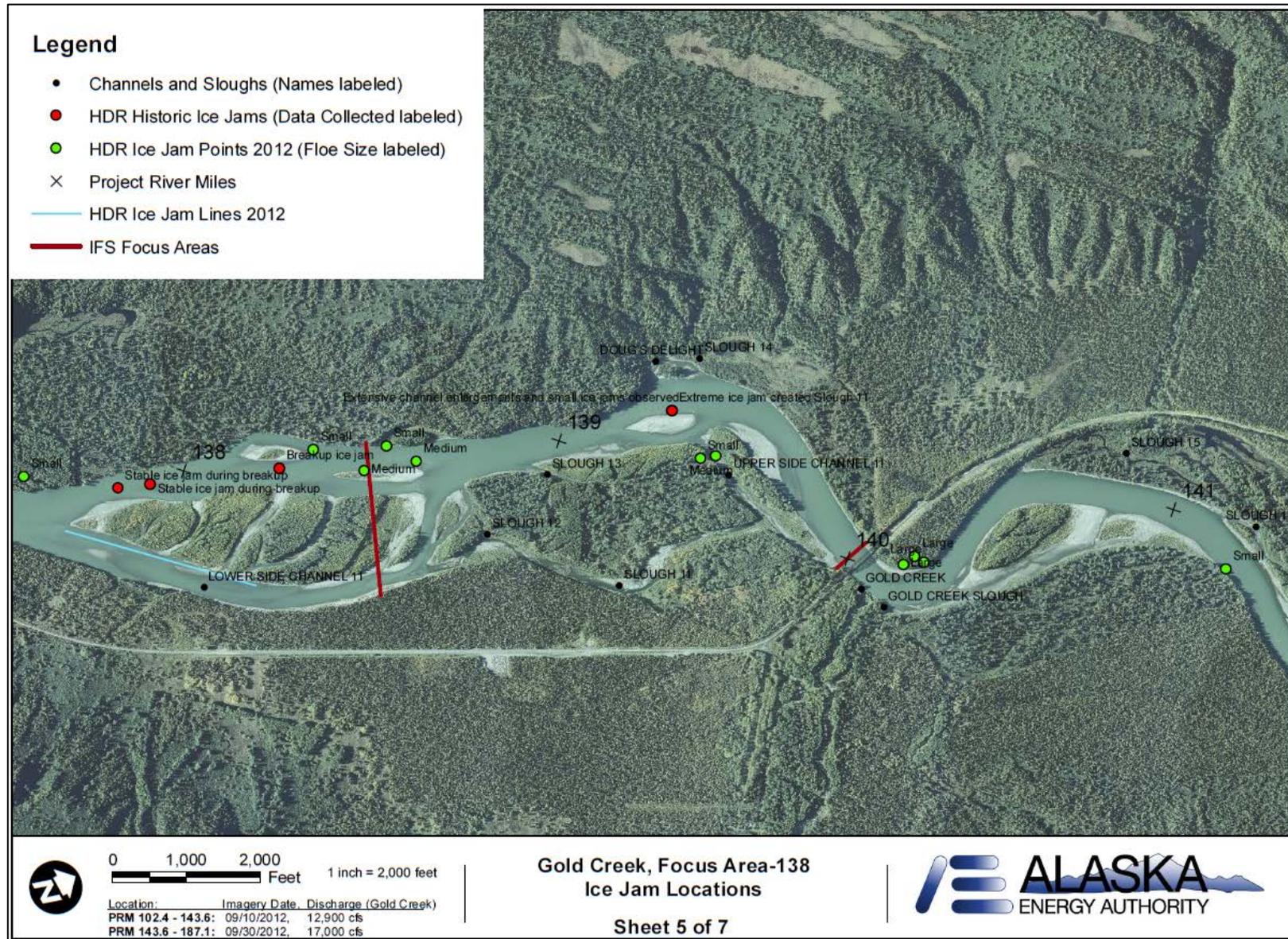


Figure 4-32. Ice Jam Locations at FA138.

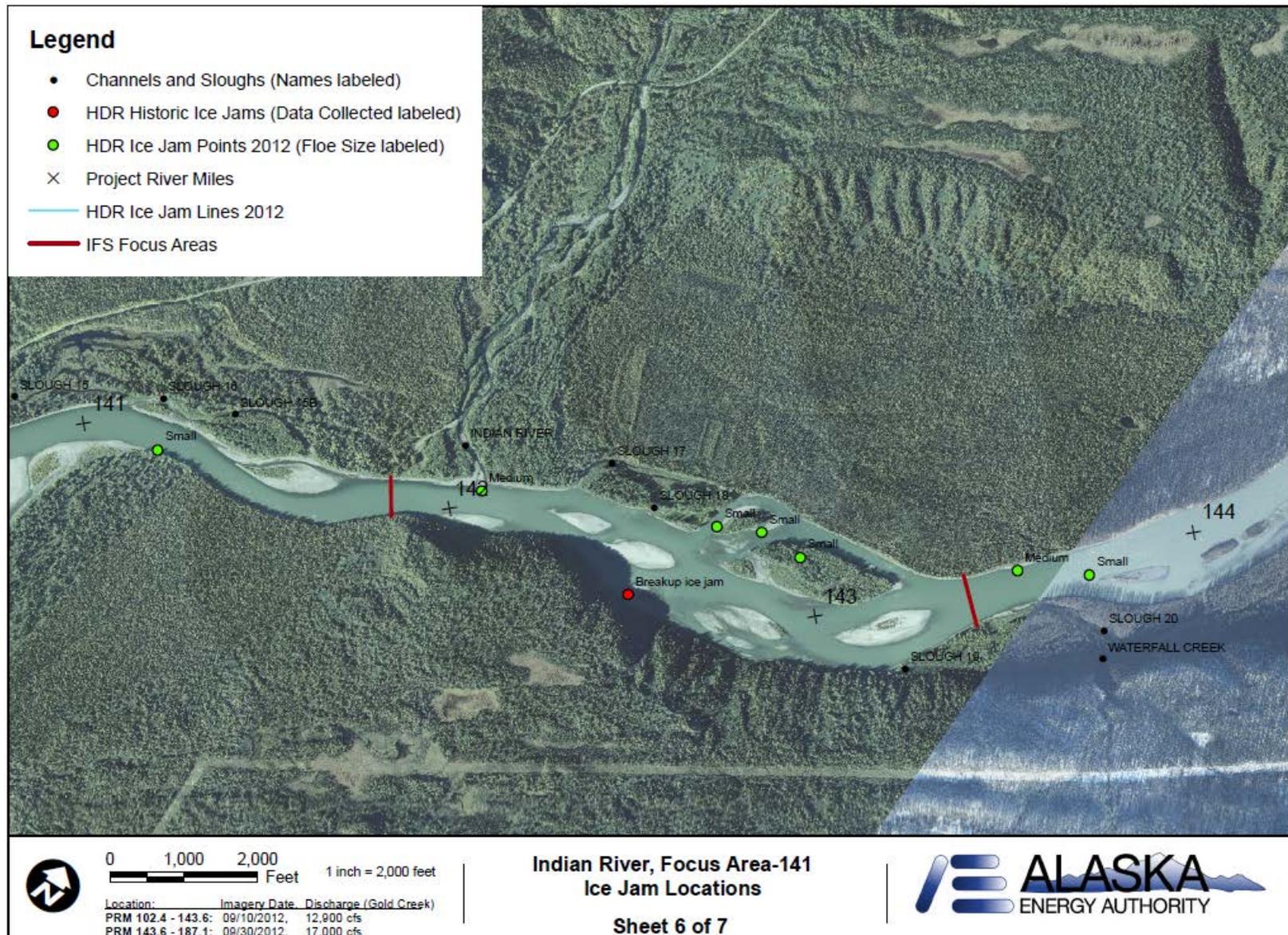


Figure 4-33. Ice Jam Locations at FA141.

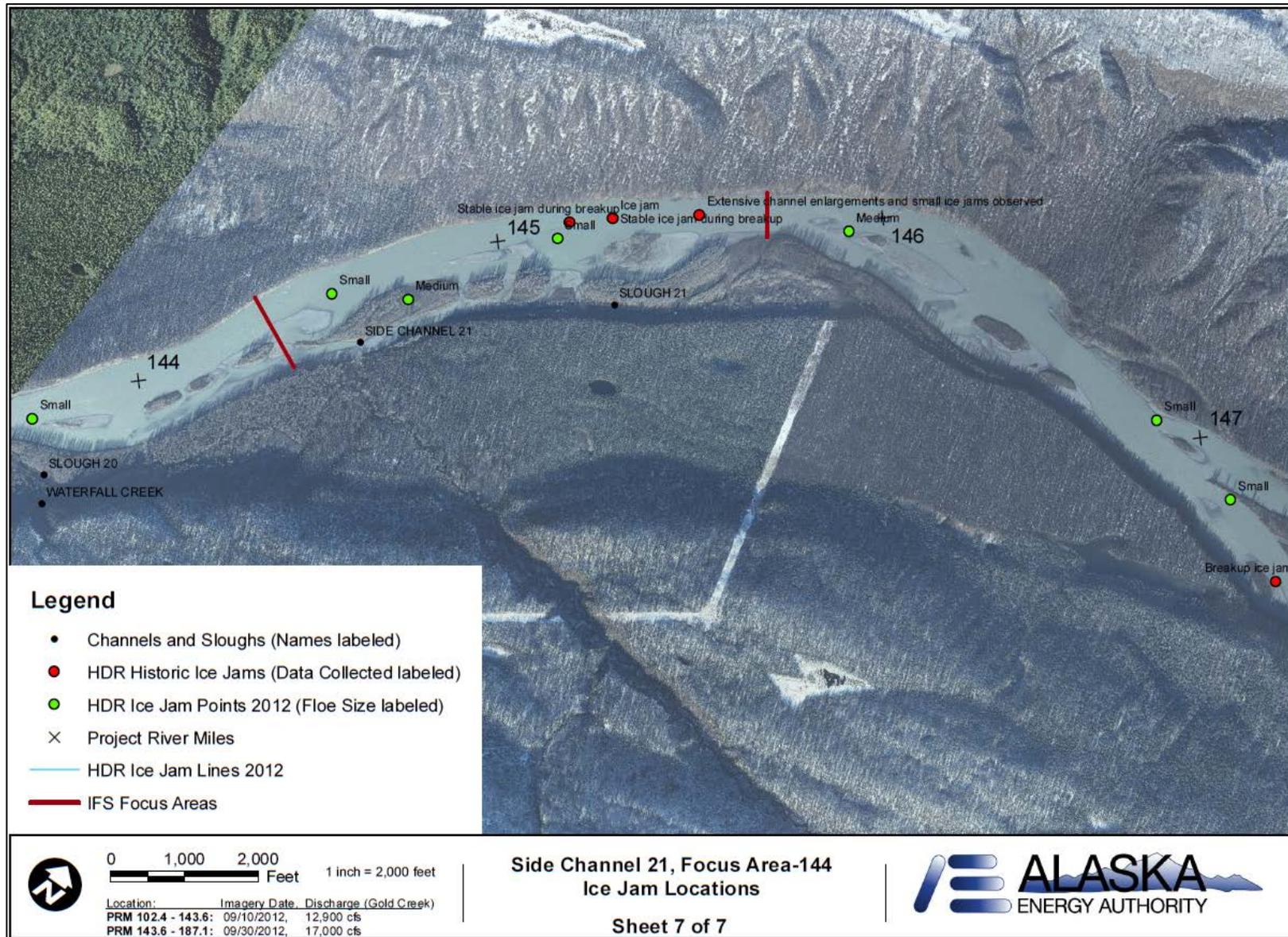


Figure 4-34. Ice Jam Locations at FA144.

## **Attachment B**

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Summary of Consultation on Geomorphology Study Plans

**Table 6.4-1. Summary of Consultation on Geomorphology Study Plans**

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
<b>NMFS General Comments</b>						
1	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	<p>Although these comments are directed at fluvial geomorphology, there is a tremendous amount of overlap with what is really a common technical platform representing the riverine physical environment – how patterns of water and sediment movement over time play out to produce spatial and temporal combinations of hydraulic, topographic, and biotic conditions.</p> <p>The model selection portion is well considered and documented for this stage in the modeling process. However, it is unclear if mobile bed models will be used independently for geomorphic analysis or if they are going to be integrated in the instream flow habitat analysis too?</p> <p>If the mobile bed models will be used in calculating WUA, how will differing project operation scenarios be assessed? Mobile bed modeling requires every hydrologic iteration to be modeled since every flow has the potential to alter the channel compared to fixed bed models where a single bed geometry is used for all flow scenarios.</p>	Mobile-bed (morphology) modeling will not be used to provide hydraulic input to habitat models, which will be steady-state models run for a range of flows. The mobile-bed results will be used in the development of the hydraulic (habitat) models. See Fluvial Geomorphology Modeling Approach Technical Memorandum (TM) at Sections 2.2 and 4.3.
2	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	By utilizing a fixed bed model (for a given channel geometry at a given point in time) over a range of flow conditions (ie. low flow to max flow), any number of hydrologic scenarios can be analyzed without having to re-run the model to calculate associated hydraulic conditions and resulting habitat suitability.	AEA will use the approach as outlined in the TM at Section 4.3.1.2.

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
3	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	There are certainly some complex and uncertain steps in the overall modeling approach – e.g., integrating variation and simulation scales ranging from sub-meter to 100s of kms and potentially seconds and hours to decades; readjusting and analyzing channel dimensions, vegetated zones, representing altered topography in 1-d and 2-d; mechanical ice breakups; and ice behavior with intra-daily load-following.	AEA agrees that there are many complex technical and coordination aspects to the Project. Ice behavior will be evaluated by the Ice Processes Study and this study will coordinate with that study on modeling of morphologic changes related to a range of ice conditions and potential for feedback between the ice and fluvial geomorphology modeling studies. See TM at Section 4.3.3. AEA will also coordinate with the Instream Flow Riparian Study on adjusting vegetation zones related to morphologic change See TM at Section 4.3.3.
4	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	Nonetheless, it is a very professional, rational, and well-considered approach. Given our comments provided below, we don't see a better way to proceed without having results from the current and ongoing field work and analysis that are being conducted. Pure validation with truly independent and replicated data sets is elusive if not impossible in this type of situation. However, there are a couple of activities that might provide some corroborating evidence.	Thank you for the observations. AEA agrees that the field work and early stages of analysis will provide useful insights that will necessitate making adjustments to the approach. AEA also agrees that true validation will be difficult to achieve. For further information regarding calibration and validation, see Revised Study Plan (RSP) Section 6.6.4..
4.1	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	One is to use the historical depiction of channel locations, dimensions, and meta-habitat distribution described in the "Mapping of Geomorphic Features...", FERC 14241, T2012 Tech. Memo to edit the current topography. Then, re-run historical flows with that estimated historical topography to see if it matches the pattern of changes producing current topography.	As part of the Fluvial Geomorphology Study, AEA will use available data from the 1950s, 1980s, and present to evaluate changes in channel form, width, vegetation using cross sections, profiles, aerial photos (dating back to the 1950s), and gage data. AEA does not anticipate running models that represent 1980s to present based on concerns of data adequacy. See TM at Section 3 and Section 4.2.1.

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
4.2	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	Another is to compare simulated stages of mechanical ice-break surges with maps of ice scar elevations. Determining elevation (+/- ~ 15 cm) and year of ice scars is a relatively accurate and inexpensive dendrochronology task (e.g., compared to year and elevation of establishment).	AEA will coordinate with the Riparian Instream Flow Study, Study 8.6, to identify ice scarring in relation to ice-breakup surges and incorporate this information into the ice-surge modeling that will be part of the Fluvial Geomorphic Modeling Study. See TM at Section 4.3.3.
<b>NMFS Specific Comments</b>						
5	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	<p>Page 8: "The 1-D model will provide the boundary conditions for the 2-D model in the Focus Areas, including starting water surface elevations and upstream sediment supply."</p> <p>How will potential changes in channel geometry due to aggradation/degradation and associated WSE from the 1D model output be accounted for in providing boundary conditions to the focus area when the 2D model is using pre-project topography?</p>	<p>The 1-D model will be run for a range of flows that can be used to develop rating curves at the downstream boundaries of the Focus Area 2-D models. Since the Focus Area models will be run for less than one year, we anticipate that the rating curve will be relatively stable for the &lt;1-yr periods, but this hypothesis will be tested with the 1-D model results. If the rating curve shifts over the time span of the 2-D analysis other adjustment will be made, such as segmenting the time span of the 2-D into shorter durations. AEA anticipates using different rating curves for the year-0, -25, and -50 2-D models. Similarly, AEA will use the sediment transport results from the 1-D modeling to provide sediment supply input for the 2-D models. As with the downstream rating curves, the sediment supply rates are also likely to be different for years 0, 25 and 50. TM at Section 3 and Table 2-2.</p>

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
6	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	<p>Page 8: <i>"The 2-D model at the Focus Areas will provide an understanding of the hydraulic conditions and sediment transport processes that contribute to formation of individual habitat types."</i></p> <p>Will the formation of the individual habitat types (new bed geometry) be used in the habitat modeling analysis? i.e. will output from mobile bed 2D model be used to generate "future" channel geometry that would then be used to conduct fixed bed 2D hydraulic/habitat modeling.</p>	<p>Yes. The detailed 2-D hydraulic models that provide input to the habitat models will be run for year-0, -25, and -50 conditions that include new bed geometry and potentially new substrate. See TM at Section 4.3.1.2.</p>

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
7	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	<p>Page 11 - "Calibrate and validate the sediment transport model.</p> <p>Adjust sediment input values, bed layer properties, sediment transport time step (within reasonable limits) to calibrate the hydraulic results using available data including:</p> <p>Gage station measurements sediment loads, specific gage plots, flow area, width, depth, and velocity measurements,</p> <p>Comparison cross sections, and Longitudinal profiles."</p> <p>While the input values can be adjusted to match current gage station measurements as listed in the first bullet, it seems like the calibration of the 1D mobile bed model for the second and third bullets should be conducted utilizing the 1980s cross-sectional data. This type of comparison is needed in order to determine if the model is able to properly simulate the change in channel aggradation/degradation or total volume of sediment transport over the past 30 year time period. Then the model could be used to estimate future channel change and sediment volumes throughout the project extent.</p>	<p>AEA did not incorporate the requested change because AEA is concerned that the 1980s cross-section data will not be sufficient to achieve reliable results. AEA's hypothesis is that the Susitna River and its tributaries are largely unaffected by development, water usage, sediment control, or flood control, and that reaches will be very close to dynamic equilibrium or somewhat constrained and non-alluvial. AEA will test this hypothesis by comparing 1980s and present cross sections, specific gage plots, and with other factors. See TM Section 3 and Section 4.2.1.</p>

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
8	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	<p>Page 16 – “Refine the network in areas of significant change or areas of significant habitat interest.”</p> <p>Identify how ‘significant change’ and ‘areas of significant habitat interest’ will be defined.</p>	<p>By significant change, AEA means significant geometric or hydraulic change. Where the geometry changes rapidly there must be additional refinement of the network. Even in the absence of geometric change, there can be significant change in velocity magnitude or direction. This can occur due to varying flow resistance from vegetation. In addition to the hydraulic requirements, AEA will include a refined network in areas of significant habitat interest identified by the Instream Flow Habitat Study. Other areas that could affect downstream habitat, such as the heads of side sloughs, will also be modeled with additional network refinement. AEA will not simply develop the model and run it for final results. AEA will run the model and review the output to determine if additional refinement is needed. See TM at Section 3.2.1 (Develop Model Network bullet – Review Mesh Quality sub-bullet) for a description of the Model Approach and refinement.</p>

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
9	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	Page 16: How will LWD be represented in River 2D? How will flow both under and through LWD piles be represented and measured?	The 2-D modeling does not include vertical velocity (3-D) so flow under Large Wood Debris (LWD) cannot be directly represented, nor would it be safe to attempt to measure it. Although flow under individual logs is likely due to local scour, flow under or through LWD jams is anticipated to be relatively minor compared to the redirection of flow around the jam because the open spaces are filled with smaller limbs and sediment. Therefore, AEA anticipates including debris jams in the model geometry. If AEA finds a situation where flow through a debris jam needs to be analyzed, AEA can represent the physical obstruction with an extremely high Manning n value that diverts flow around the low-conveyance "obstruction," but would still allow some flow through the area. AEA would adjust the Manning n value to achieve the desired through-flow, but determining the desired amount would be difficult. See TM at Section 3.2.3.5 for description of the processes of the River2D Modeling Suite. See TM at Section 4.3.2 and RSP Section 6.6.4.1.2.7 for a description of modeling Large Woody Debris.
10	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	Page 16: <i>"Develop inflow hydrographs and sediment inflows for existing and with-project conditions"</i>  How many and what range of flows will used to develop inflow hydrographs and sediment transport models?	The range of flows will include the complete 50-year flow record as analyzed in the 1-D models and will provide input to the selected seasonal flow hydrographs and sediment inputs for the 2-D sediment transport models. See TM at Table 2-2.

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
11	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	<p>Page 17: "Calibrate and validate the sediment transport model.</p> <p>Adjust sediment input values, bed layer properties, sediment transport time step (within reasonable limits) to calibrate the hydraulic results using available data including:</p> <p>Main channel bed level changes observed in the 1-D modeling,</p> <p>Comparison cross sections, and Longitudinal profiles."</p> <p>It doesn't seem clear what data will be used to calibrate the 2D mobile bed model. Where will the cross section comparisons and longitudinal profile data come from? Will this be generated from 1980s data or how will it be determine if the model is able to properly simulate the change in channel geometry over time?</p>	<p>The cross sections and longitudinal profiles will come from the 1980s and current data and will primarily be used to calibrate the 1-D sediment transport model. The 2-D model results will need to be consistent with the 1-D model, at least in the main channel and major secondary channels. 1980s cross sections within Focus Areas will also be used directly to compare with 2-D model results. Flow resistance input values, measured water-surface elevations and measured velocities will be used to calibrate the 2-D mobile bed model. See TM at Section 3.2.1 and RSP Section 6.6.4.1.2.5 (description of model calibration and validation).</p>

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
11.1	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	What flows will be used to test the models and what amount of deviation from field measured conditions will be deemed suitable?	AEA will target deviations in bed elevation in the 1- and 2-D models that are commensurate with the amounts of deviation seen in the comparison cross sections from the 1980s and present and in the specific gage analysis. AEA anticipates that the variability will also change from one Focus Area to another due to tributary interactions and other constraints. Until the comparisons are made AEA cannot specify exact amounts. See RSP Section 6.6.4.1.2.5 (guidelines for calibration is reasonable) and TM Table 2-2 (list of model input parameters, including flows).

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
12	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	<p>Page 26: "The modeled reach of the Chulitna River will extend approximately 10 miles to a location of channel narrowing. Model topography for the upstream 6 miles of this reach will be developed from the LiDAR data that will be collected during low flow. The surveyed bathymetry from the lower 4 miles of the Chulitna River will be used to guide adjustments to the low flow channel to account for the missing topography below the water surface."</p> <p>What algorithms will be used to create the bare-earth model from the LiDAR data?</p>	<p>AEA will use a customized Terrascan ground classification algorithm to create the bare-earth model from the LiDAR data. The bare-earth class is developed from the set of returns classified as "Only" and "Last of Many" by an iterative method. First, a rectangular filter is passed over the "Unclassified" points and a set of local low points is selected to seed the bare-earth class. Then all the unclassified points are compared to the triangulated surface defined by the set of bare-earth points and those that are found be close enough to fall within a certain angle and distance of the surface are added to the bare-earth class (ASPRS Class 2). The process is repeated with the expanded bare-earth class until the number of points being added to the bare-earth class declines. In response to this comment, additional detail has been added to the TM at Section 4.1.1.</p>
12.1	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	<p>How will the topography be determined under water, conifers and dense trees from the LiDAR data?</p>	<p>Hydrographic survey will be used for the underwater portions of surveyed cross sections. See TM at Table 2.2 for model inputs that will be developed from hydrographic surveys. LiDAR will not be used directly for under water topography, but as described in the response to comment 12.2, below water portions of some cross sections will be developed for the Chulitna River. For the comment on vegetation, see AEA's response to Comment 12.</p>

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
12.2	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	What portion (percentage) of the channel is under water during low flow and how will the underwater portion of the channel be constructed? i.e. dropping the edge of water points by a pre-determined amount (normal depth for the flow in the river at the time of the LiDAR data collect) and then connecting them with a slightly lower point in the middle of the low flow channel.	AEA will target a low flow to have the least amount of wetted area. As described in the TM at Section 4.1.1, AEA will develop additional cross sections on the Chulitna River outside the area of hydrographic survey using the surveyed cross sections as a guide and infer the flow area based on normal depth calculations and the observed water surface slope. The channel bed will be developed for the below-water areas using a shape that is consistent with the surveyed cross sections.
13	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	<p>Page 27: "Each of the tributary mouths and a nominal reach length will be included in the Focus Area models to simulate delta processes and tributary bed response. The length of the reaches will be determined in the field, but are anticipated to be between 0.2 and 0.7 miles. Approximately 5 cross sections will be surveyed in each tributary to develop sediment input rating curves to the Focus Area models."</p> <p>It is difficult to say if 5 cross sections would provide enough detail in these tributaries based on various lengths. It would better to identify the number of cross sections as a function of channel/trib width (ie. XSs will be spaced at a minimum of X-channel widths apart and no more than X-channel widths).</p>	There may be more or fewer cross sections depending on local conditions (channel slope, geometric variability, and controls). The number and locations will be determined in the field to best represent sediment transport and supply.

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
14	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	<p>Page 28: "Data from the Riparian Instream Flow Study, the Fish and Aquatics Instream Flow Study analysis of changes in hydrology operational scenarios, and 1-D sediment transport analysis provide a basis for adjusting the channel width in the 1-D model throughout the simulation. It is anticipated that adjustments will be made to the width in the with-Project scenario runs at up to five times during each simulation."</p> <p>What criteria will be used to determine when/how/why channel width adjustments are needed and how will that ultimately change the results of the modeling?</p>	<p>Channel width is anticipated to change due to changes in hydrologic regime (~2-yr recurrence interval flows, effective discharge) and will be influenced by sediment supply and riparian vegetation. AEA will review hydraulic geometry for current conditions as a first step in relating hydrologic regime to channel width, though constrained reaches are not expected to have consistent hydraulic geometry relationships. We anticipate that we will need to differentiate between Middle and Lower Susitna River as a minimum and probably between specific geomorphic reaches. The Middle River, especially the area above Devils Canyon, will have an immediate hydrologic and sediment change and throughout the 50 years of operation. The Lower River will experience the hydrologic change immediately but will have a delayed sediment supply change. We anticipate using Rate Law (exponential decay) with rapid initial change approaching an asymptotic long-term value. The difficulties in predicting the rate of width change will require AEA with the input of Technical Workgroup (TWG) participants to arrive on an acceptable target. Width change will affect hydraulics and sediment transport just as bed elevation change will. See TM at Section 4.2.1 for further discussion on width-change.</p>

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
15	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	Page 30 – Large Woody Debris Modeling  How will LWD be represented in the 2D models and how will flow in, under and through be accounted for?	See AEA's response to Comment 9 and TM at Section 4.3.2 for a description of modeling Large Woody Debris and RSP Section 6.6.4.1.2.7.
16	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	Page 32 – "Boundary conditions for all of the 2-D model simulations, including downstream water surface elevations, and upstream flow and sediment supply, will be obtained from the 1-D modeling results."  Is this the case for both the fixed bed and mobile bed models?	Yes, with the exception that the fixed-bed models will not have a sediment supply.
16.1	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	For the fixed bed case (current conditions), why not use field collected discharge and wse for inputs to the 2D models, vs, 1D model outputs for boundary conditions?	AEA has not included these inputs because the 1-D models will have a more complete and greater range of flows than the field measurements. The 1-D model will be calibrated using discharge and water surface elevation data collected in the field.
16.2	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	For the mobile bed modeling, it is unclear how changes in channel geometry and associated WSE in the 1D model output could be used to provide boundary condition input for the focus area 2D modeling when the channel geometries are different?	AEA will adjust channel geometry of the year-25 and year-50 2-D morphology models based on changes in geometry at those dates in the 1-D modeling. The boundary conditions will also correspond to year-25 and year-50 conditions. Therefore, it is intended that the geometry and boundary condition information will be consistent. See TM at Sections 2.2 and 4.3.

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
17	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	<p>Page 32: "The output values for the required hydraulic variables that include depth, velocity, and water-surface elevation, will be provided at each node along with the associated geo-referenced horizontal coordinates and elevations."</p> <p>Consider Froude number as a model output, as it is may be an important habitat metric for some species (benthic fish and macroinvertebrates).</p>	<p>AEA will coordinate the selection of habitat metrics with other studies and seek the input of the TWG participants. See TM at Section 4.3.1.2 and RSP Section 6.6.4.1.2.1, and RSP Section 8.5.4.6.1.4. The Froude number can be calculated as a post-processing step based on depth and velocity. Similarly, shear stress can be computed using velocity, depth and bed roughness as a post processing step or as direct model output. See TM at Sections 4.2.3 and 4.3.3.</p>
17.1	Transmittal Email (attachment)	5/18/2013	Eric Rothwell	NMFS	<p>Pages 56-58 – Figures 4-5, 4-6, 4-7: Focus Areas 104, 138, 141, 144, 128 boundaries should be adjusted to incorporate geomorphology cross sections, in order to maximize the usability of collected field data in modeling Focus Areas.</p>	<p>Geomorphology cross sections were placed outside, but near the Focus Areas (FA) to define the model boundary conditions somewhat away from the areas of interest. AEA's goal is to reasonably represent flow conditions within the FA limits for habitat analysis. AEA would strongly discourage including the area between the FA limit and the model boundary in any habitat analysis due to boundary condition effects.</p>

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
<b>NMFS COMMENTS cont.</b>						
18	Transmittal Email (body of email)	5/18/2013	Eric Rothwell	NMFS	<p>During the conversations there were several fluvial geomorph related comments that came up. It may be useful to bring these up again next Tuesday at the geomorph meeting.</p> <p>Study integration - how will the mobile bed model be incorporated into assessment of changes in habitats (will they be reclassified - Greg Auble asked about this) at FA's?</p>	<p>The 1-D mobile bed modeling will address channel change (aggradation, degradation, depth, and width) and potential changes in substrate for the main channel and major secondary channels on a reach-scale over the 50-year license period. The 2-D morphology modeling will be conducted for &lt;1-year periods at years 0, 25 and 50, and will incorporate bed change consistent with the 1-D results. The 2-D morphology modeling will provide additional information to the 2-D hydraulic modeling used to develop input to the habitat analysis. Specifically, changes in the connectivity or breaching flows will be determined and if reclassification of the lateral habitats results from changes in the breaching flows, these changes will be identified. See TM at Section 2 for a description of the overall modeling approach.</p>

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
19	Transmittal Email (body of email)	5/18/2013	Eric Rothwell	NMFS	Study integration - a discussion of fish access to off-channel habitats, how will the FA bed models be used to assess future changes to fish access of tributaries, sloughs, side-channels, etc? Also a review of how the 1D model would be used to address this same question outside of the FA's. Bill called in today and addressed this, but it would be beneficial to me to revisit.	Sediment supply will be estimated for the tributaries. This supply will be used directly in the FA 2-D models to evaluate delta formation and fish access. In the 1-D models the supply will be used to manually adjust delta geometry and encroachment into the main channel. See TM at Section 2.2 and RSP Section 6.6.4.1.2.6 for further discussion on tributary modeling. For other types of side channels, the FA models will include detailed representation of side-channel entrances and exits to evaluate potential for morphologic change affecting fish access.
<b>Individual Comments</b>						
20	Email	6/4/13	Becky Long	Individual	Under Comprehensive Modeling Approach, the draft TM has shown 4 operation scenarios for modeling purposes: existing, load following, base load and intermediate. This was for the 1 D Reach-Scale Morphology Models for sediment input, geometry and d's rating curves; 2 D Morphology for Unsteady Models at Focus Areas for sediment inflow, substrate and lateral feature geometry and d's rating curve; 2 D Hydraulic (habitat) Steady Models at Focus Areas for hydraulic data to habitat models for range of flows. There needs to be a RoR operation scenario for these models.	AEA will include a run of river scenario in the Fluvial Geomorphology Modeling effort. See TM at Section 1.1.

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
21	Email	6/4/13	Becky Long	Individual	For ungaged tributary modeling, 3 operation scenarios will be run: no dam, load following and baseload. A RoR operation scenario needs to be added to these scenarios. The RoR scenario will pinpoint dam effects on the tributaries and represents a project operation scenario that could be run during sensitive natural ecosystem processes such as salmon spawning, redd incubation periods, post-hatching and pre-emergence periods and salmon migration.	AEA will include a run of river scenario in the Fluvial Geomorphology Modeling effort. See TM at Section 1.1.
22	Email	6/4/13	Becky Long	Individual	The draft TM mentioned "In addition to simulating long term continuous period of flows, will be possible to include rare flood events associated with unusual climactic conditions or ice jam break up." I support this. I also support that reach scale models should include at least 1 large relatively rare (i.e. 50-100 year recurrence interval) event that does not occur in the selected model 50 year period. I would like to request that these models could be run to simulate cumulative impacts from future climate change conditions and post project impacts.	AEA anticipates including an extreme event in the continuous 50-year flow record if one does not occur within that record. There is a reasonable chance (64%) that a 50-year or greater event would occur during a 50 year period. See TM at Section 4.2.1. Climate change is not included in the fluvial geomorphic modeling because using the historic record provides a better comparison of Existing conditions to the operational scenarios without introducing hypothetical and uncertain modifications to the flow record.

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23	Email	6/4/13	Becky Long	Individual	I am concerned about the 1 year snapshots of short term looks at patterns of degradation and aggradation. Judgment and interpretation of results will have to be used due to the short time frame. Therefore, I am concerned about the scientific validity.	The 50-year continuous simulation using the 1-D model will provide useful information on system-side channel response including aggradation and degradation. The 2-D models will be run for year-0, -25, and -50 for a range of hydrologic conditions (dry, average, and wet seasonal conditions). The 2-D models will include channel changes consistent with the 1-D models for the three time periods. Therefore, AEA anticipates that the modeling approach will provide the information needed to evaluate potential Project effects on geomorphology and habitat. See TM at Section 2.2.
24	Email	6/4/13	Becky Long	Individual	The AEA team will have to pick a 50 year record out of the 61 year USGS record, a significant portion of which is based on modeling itself. I heard a National Weather Service person state in a radio report that there is not much confidence in the Sunshine Gage. I have not been able to find out what is meant by that. But this concerns me.	AEA will evaluate the data from each of the gages. It may be that the gage has variable rating curves (stage-discharge relationships). AEA will perform specific-gage analyses using historic flow measurements at the gages. Variability of the rating curves will be useful information during model development. See TM at Section 4.2.1.

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25	Email	6/4/13	Becky Long	Individual	I support looking closely at the Talkeetna and Chulitna Rivers for post- project geomorphologic impacts. Specifically it is important to answer the question will the elevation of the main tributary beds change due to the mainstream changes of lower water surface elevations? What does this mean for those tributaries? The aggradation simulation is important. As a long time resident of the Talkeetna River watershed dependent on the Talkeetna River salmon resources, I appreciate this effort.	Thank you for the comment. The modeling approach was amended to include the Chulitna and Talkeetna Rivers as tributary reaches rather than sediment/water sources only. See TM at Section 4.1.1. This will allow AEA to evaluate potential channel and water surface change on these tributaries.
26	Email	6/4/13	Becky Long	Individual	4.3.3 Ice Effects - the "tentative assumption" that the river bed will be "stable due to low flows and ice cover" seems incorrect. Proposed 10,000 cfs winter flows are far from low. The ice transport capacity of the river this fall left 6-8' ice sheets far into lateral brush habitat and close to the end of Main Street, Talkeetna. The potential for winter ice jamming should be seriously addressed, as should general winter sediment transport.	As stated by the Ice Processes Study (RSP Section 7.6.4.7), "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." Although flows will be higher for winter operation conditions, the discharges may not be high enough to cause general sediment transport and the potential for general sediment transport will be assessed from the model results. Ice jamming will also be evaluated related to formation and localized sediment transport from ice jam breakup. See TM at Section 4.3.3.
TCCI						

Com #	Comment Format	Comment Date	Licensing Participant Name	Licensing Participant Affiliation	Comment	Response
27	Letter	6/5/13	Whitney Wolff	Talkeetna Community Council, Inc. Susitna Dam Committee	1.) How will 1D sediment transport analysis be incorporated into the Chulitna (10 mile reach from mouth) and Talkeetna (5 mile reach from mouth) without "upstream sediment supply" data to assess sediment capacity?	The 1-D sediment transport analysis will include sediment rating curves at the upstream model limits of the Chulitna and Talkeetna River tributary reaches (Section 4.2.1). These rating curves have been developed using data collected by the USGS at the gaging station locations. The locations of the upstream reach limits were selected so the gage sediment transport rates would be applicable. See RSP Section 6.5.4.3 and Section 4.2 ( <i>Sediment Load Rating Curves</i> ) of AEA's 2012 Study Report, <i>Development of Sediment-Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments</i> .
28	Letter	6/5/13	Whitney Wolff	Talkeetna Community Council, Inc. Susitna Dam Committee	2.) Bank erosion rates are calculated through BEI which requires both 1D and 2D modeling. How will AEA achieve a "defined approach" without 2D modeling? The approach currently depends on LIDAR for the upper 6 miles of the Chulitna; will there be study site work on the cross sections during the 2013 season?	Bank Energy Index can be calculated with either 1- or 2-D results and is calibrated by comparing historic flow energy with observed bank erosion. LiDAR will be used to develop the channel geometry data for the Chulitna River because it is a braided reach that will be relatively shallow during the low flow conditions when the LiDAR data is collected. Field work on the Chulitna River in 2013 includes survey of two cross sections, bed material sampling, bank material characterization, and LWD characterization. See TM at Section 4.1.1 and 4.2.2.2.

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29	Letter	6/5/13	Whitney Wolff	Talkeetna Community Council, Inc. Susitna Dam Committee	3.) How will such a dynamic study year be representative of base line conditions?	Base line conditions are flow and sediment supplies unaffected by Watana Dam and operational scenarios include dam operations. Base line conditions will simulate a continuous 50 year hydrologic record to represent the license period in the 1-D modeling and will include a range of hydrologic conditions (dry, average, and wet) for open-water periods at years-0, -25, and -50. AEA will coordinate with the other study team members and review agencies to select suitable hydrologic conditions, which need to include a wide range of flow conditions to develop representative results, but may not necessarily include 2012 or 2013. See TM at Section 2.2.
30	Letter	6/5/13	Whitney Wolff	Talkeetna Community Council, Inc. Susitna Dam Committee	TCCI supports FERC's recent inclusion of a ROR operations model for examining base line flows. This TM should be updated to include this necessary addition.	AEA will run of river scenario in the Fluvial Geomorphology Modeling effort See RSP Section 6.6 and TM at Section 1.1.

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CWA						
31	Letter	6/5/13	Harold Shepherd	Center for Water Advocacy	The Draft Memo does not mention FERC's directive to AEA in the SPD that AEA include a run-of-river alternative in the operating scenario evaluations for Study 6.6 (geomorphology modeling) and Study 7.6 (ice processes). This is a significant oversight because although AEA filed a request for reconsideration of the run of river requirement in the SPD due to its contention that such a scenario did not have a nexus to the proposed Project alternative and would have been too expensive, ultimately, FERC concluded "that we have insufficient basis for dismissing consideration of a run-of-river alternative at this early stage in the pre-filing licensing process. Accordingly, staff will not alter the requirement that AEA evaluate a run-of-river operating scenario."2	AEA will include a run of river scenario in the Fluvial Geomorphology Modeling effort. See RSP Section 6.6 and TM at Section 1.1.

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32	Letter	6/5/13	Harold Shepherd	Center for Water Advocacy	The Technical Memo, therefore, should include floodplain modeling that incorporates the use of two-dimensional hydraulic models, to compare the unimpaired and current frequency, magnitude and duration of floodplain inundation. AEA should use a two-dimensional model of the middle Susitna River, from RM 184 downstream to the confluence with the Chulitna River at RM 98, to determine how much floodplain area is currently accessible. It should then use current and unimpaired hydrology to determine the frequency, duration, and magnitude of floodplain inundation under both scenarios as well as the total area and depth of inundation during the ecologically important spring snowmelt season. Finally, AEA should work collaboratively with ILP participants to define additional, specific ecologically important time periods for floodplain inundation modeling.	The reach-scale 1-D modeling incorporates channel and floodplain features from Watana Dam site down to Susitna Station gage at PRM 30. See TM at Section 4.1.1. Therefore, information on floodplain inundation frequency, duration and magnitude will be available throughout the potentially affected downstream areas for existing and alternative operational scenarios. In addition, each of the focus area models will include main channel, side channels, other lateral features, islands and floodplain areas. The FAs will be simulated for Year-0, -25, and -50 conditions for a range of hydrologic conditions (dry, average, & wet). From the 1-D and 2-D analyses we anticipate having sufficient information in both the channel and floodplain areas. See TM at Section 2.2.

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33	Letter	6/5/13	Harold Shepherd	Center for Water Advocacy	In the Susitna River, year-to-year differences in the timing and quantity of flow result in substantial variability around any average flow condition. Accordingly, as in the case of the Draft Memo, modeling for the "average" condition can be misguided.....In addition, the Technical Memo should include modeling that develops quantitative, river-specific standards, based on the reconstruction of the natural flow regime. <sup>5</sup> Restoration actions based on such guidelines should be viewed as experiments to be monitored and evaluated—that is, adaptive management—to provide critical new knowledge for creative management of natural ecosystem variability.	The comment is beyond the scope of the issues addressed in this technical memorandum. AEA will include an alternative analysis in its License Application, and FERC's environmental analysis will include analysis of Project alternatives. The existing information and the studies approved by FERC will provide sufficient information to support alternative analyses.
34	Letter	6/5/13	Harold Shepherd	Center for Water Advocacy	The Technical Memo, therefore, should incorporate modeling efforts that describes how experimental high and steady flows during a specific time period, could help and assess the long-term benefits to aquatic habitat salmon and fine sediment along the Susitna River downstream of Project Dam site. This would allow for an adaptive management approach, wherein the relationship between dam operations and downstream resources was recognized as uncertain and an active experimental approach was adopted	The comment is beyond the scope of the issues addressed in this technical memorandum. AEA will include an alternative analysis in its License Application, and FERC's environmental analysis will include analysis of Project alternatives. The existing information and the studies approved by FERC will provide sufficient information to support alternative analyses.

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35	Letter	6/5/13	Harold Shepherd	Center for Water Advocacy	To this end AEA should continue to use Watana reservoir inflows developed directly from USGS records as the basic hydrologic input dataset for the reservoir operation and power studies. However, it should also consider alternative hydrologic input datasets, which account for potential future hydrologic change.	Using the historic flow record is considered as a sound approach for making comparisons between existing conditions and the operational scenarios. Introducing other variables, especially variables with high levels of uncertainty, may make it very difficult to separate potential project effects from other influences.