Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fluvial Geomorphology Modeling Approach
Draft Technical Memorandum

Prepared for

Alaska Energy Authority

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

Prepared by

Tetra Tech

May 3, 2013

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ACRONYMS AND ABBREVIATIONS

1-D	one dimensional
2-D	two dimensional
AEA	Alaska Energy Authority
AOW	additional open water
BEI	Bank Energy Index
BG	background
cfs	cubic feet per second
DHI	Danish Hydraulic Institute
FAs	Focus Areas
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
PRM	Project River Mile [
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
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

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:

   - *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);*
   - *Location and extent of one- and two-dimensional geomorphology and aquatic habitat modeling in project reaches, focus areas, and other study sites;*
   - *Rationale and criteria for model selection including an overview of model development;*
   - *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*
   - *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.

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. This draft technical memorandum is a planned topic for the May 21, 2013, TWG meeting and will be finalized for a June 30, 2013, submittal to FERC. 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. 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 will be performed using 1-D models, as they are well suited for long term simulations over long river reaches. The 1-D models will be used to assess reach-scale sediment transport conditions, potential changes in bed and water surface elevations, 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 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.

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, side channels, 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 and provide opportunity for other study team members and licensing participants to provide feedback on modeling approaches to ensure that the needs of all parties are being met, to the extent practical.

Specific objectives include:

- Identify the 1-D and 2-D sediment transport models that will be used for reach- and local-scale modeling.
  - Provide the rationale and criteria for model selection.
  - Specify the selected models.
  - Provide 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.

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2. OVERALL MODELING APPROACH

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 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 streamwise 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 side channel 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.

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:

- 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.
    - Locations of tributaries that will be modeled as reaches. Note: These will include the Chulitna and Talkeetna rivers based on agency comments and SPD recommendations.
    - 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.
- 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.
- 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.
- Develop bed-material gradation and layer information.
    - Surface sampling conducted throughout the channel network,
    - Subsurface sampling, and
    - Bank material samples.

- 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.
- Other considerations.
  - Bridge constrictions and geometries,
  - Ineffective flow areas around bridges and other rapid expansion and contraction areas, and
  - Use of depth- or flow-variable roughness input.
- 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 significant change or instability in hydraulic results.
- 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 side channels, and
    - High water marks reported from extreme flood events.
- Test the sediment transport model.
  - Conduct a sediment transport time-step sensitivity analysis to evaluate appropriate computational time steps for different flow magnitudes.
- 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:
    - Gage station measurements sediment loads, specific gage plots, flow area, width, depth, and velocity measurements,
    - Comparison cross sections, and
    - Longitudinal profiles.
- 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 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, limited number of sediment size classes (eight) to represent the range of sediments in the Susitna River and tributaries, 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, its broader range of project applications, and capability to simulate a larger number of sediment size classes. 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 significant 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, side channels, 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 significant 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:

- 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.

- 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.
- 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 significant change or areas of significant habitat interest.
  - Determine the node elevations from the geometric data. Note: It is important to refine the network prior to determining elevations in order to not simply refine the geometry from the coarser network.
  - Review mesh quality to assure that element size transitions and other modeling requirements are reasonably met.
- 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 are used to incorporate internal flow stresses and reasonable values depend on each model’s numerical representation of these stresses.
- Develop bed material gradation and layer information.
  - Surface sampling conducted throughout the channel network,
  - Subsurface sampling, and
  - Bank material samples.
- Develop inflow hydrographs and sediment inflows for existing and with-project conditions.
  - For fully unsteady model, 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.

- Other considerations.
  - Ice jam breakup hydrographs,
  - Ice jam blockage of main channel or side channels causing redistribution of flow,
  - LWD as obstructions or changes in roughness, and
  - Erodibility of floodplain areas.
- Test the hydraulic model over a range of flow conditions.
  - Evaluate mesh quality and the need for additional mesh refinement.
- Calibrate and validate the hydraulic model.
  - Adjust flow resistance input values (within reasonable limits) to calibrate the hydraulic results. 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. Calibration and validation will be performed using available data including:
    - Measured water-surface elevations throughout the focus areas during site survey.
    - 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 surface elevations collected at other flows.
    - Water level loggers.
    - Discharge distribution between main channel and side channels.
    - High water mark information if available.
- Test the sediment transport model.
  - Conduct a sediment transport time-step sensitivity analysis to evaluate appropriate computational time steps for different flow magnitudes.
- 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:
    - Main channel bed level changes observed in the 1-D modeling,
    - Comparison cross sections, and
    - Longitudinal profiles.
- 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 Susitna River. 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. 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 significantly 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 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 base 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. 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 hydraulic, 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, 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.

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 three 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, and (3) cross section locations on side 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 in-channel areas (similar to the 2012 cross sections) will be surveyed directly. The remaining extent will be developed using detailed LiDAR data.

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 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 will be surveyed in the downstream approximately four miles of these tributaries. 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 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.

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 below the top-of-bank. Some floodplain survey will also be performed, but the primary topographic data source for the floodplain areas will be the LiDAR data. 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 extend 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.

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, side channels, 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. 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. The rate of width adjustment may be greatest in the initial years after closure, so the time interval may be shorter during the initial periods of the simulation and, increase with time during the simulation.

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. Inclusion of at least one large, relatively rare (i.e., 50- to 100-year recurrence interval) event that does not occur in the selected model period will also be considered. 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.

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 the 1-D modeling results.

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 significant topographic or flow resistance variability. 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 4-24 shows and example of a fine mesh. 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. For the 2-D sediment transport models, the mesh sizes will be as large as possible, but with sufficient detail to represent variability in bathymetry, topography, roughness, and bed composition. An example of a coarse mesh is shown in Figure 4-25. These general guidelines represent starting values for the spatial resolution that will be refined and adjusted as necessary throughout the model development phase. These mesh examples do not fully meet the element size criteria outlined above because greater detail will be incorporated in the side channels and habitat areas.

4.3.1 Hydraulic and Bed Evolution Modeling

4.3.1.1 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. Based on discussions with the Fish and Aquatics Instream Flow team, it is anticipated that model output will be required for the range of flows from 10,000 cfs up to approximately 60,000 cubic feet per second (cfs) in approximate 5,000 cfs increments for the Focus Areas (W. Miller, pers. comm., 2013). This range can be adjusted, as necessary, during the modeling phase. From discussions with Miller, it is anticipated that 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 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 considers Project-related changes in the effective discharge analysis, riparian vegetation, and sediment supply. Projected changes in side channels and sloughs 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 up to 3 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 up to 3 operational scenarios to represent conditions 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.

4.3.1.2 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. 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 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 side channels and sloughs 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.

4.3.2 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. 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 side 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. 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 4-26, 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 4-27 through 4-33 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 maintenance of side channels and sloughs.
- 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, side channels, and floodplains.
- Hydraulic parameters to estimate Bank Energy Index and bank erosion rates.

4.4 Other Tributary Modeling

In the Lower River, local-scale sediment transport models will be developed for the mouth 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.

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.

5. CONSULTATION DOCUMENTATION

This section will be developed to document the review, consultation, and revision process.

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6. REFERENCES

AEA. 2012. Revised Study Plan. Susitna-Watana Hydroelectric Project FERC Project No. 14241. Alaska Energy Authority, Anchorage, Alaska.

Arneson, L.A., Zevenbergen, L.W., Lagasse, P.F., and Clopper, P.E. 2012. Evaluating Scour at Bridges, Fifth Edition, Federal Highway Administration Report No. FHWA-HIF-12-003 HEC-18. 340 p.

Assani. A.A., Petit, F., 1995. Log-jam effects and bed-load mobility from experiments conducted in a small gravel-bed forest ditch. Catena 25, 117-126.

Blackburn, J., Hicks, F., 2003. Suitability of Dynamic Modeling for Flood Forecasting during Ice Jam Release Surge Events. Journal of Cold Regions Engineering, 17(1), March 2003. ASCE.

Bovee, K.B., 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper No. 12. FWS/OBS-82/26. U.S. Fish and Wildlife Service, Office of Biological Services, Fort Collins, Colorado.

Brabets, T.P, 1997, Geomorphology of the Lower Copper River, Alaska: U.S. Geological Survey Professional Paper 1581, 89 p.

Buffington, J. M., and D. R. Montgomery. 1999. Effects of hydraulic roughness on surface textures of gravel-bed rivers. Water Resources Research 35, 3507-3521.

Conaway, J.S., and Moran, E.H., 2004, Development and calibration of two-dimensional hydrodynamic model of the Tanana River near Tok, Alaska: U.S. Geological Survey Open-File Report 2004-1225, 22 p.

DHI. 2011a. Danish Hydraulic Institute, Water and Environment. MIKE 11, A Modeling System for Rivers and Channels – User Guide.

DHI. 2011b. Danish Hydraulic Institute, Water and Environment. MIKE 21 Flow Model, Hydrodynamic Module User Guide, 90p.

Ettema, R. 2010. Ice Effects on Sediment Transport in Rivers. Chapter 10 of Sedimentation Engineering, 614-648, M.H. Garcia, Ed., American Society of Civil Engineers,

Greimann, B. and Y. Lai, 2008. Two-Dimensional Total Sediment Load Model Equations, ASCE Journal of the Hydraulics Division, 134(8): 1142–1146.

Huang, J.V. and Greimann, B.P., 2011. SRH-1D 2.8 User's Manual, Sedimentation and River Hydraulics – One Dimension, Version 2.8, U.S. Department of Interior, Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulics Group. 227p.

Hydronia. 2012. RiverFLO-2D V3, Two-Dimensional Finite-Element River Dynamics Model, User's Guide Release V3.0, Hydronia, LLC, Pembroke Pines, Florida, 39 p.

Hygelund, B. and Manga, M., 2003. Field measurements of drag coefficients for large woody debris. Geomorphology, 51 (2003) 175-185

Kwan, S. 2009. A Two Dimensional Hydrodynamic River Morphology and Gravel Transport Model. University of British Columbia, Vancouver, CA, 113p.

Lagasse, P.F., Ghosn, M., Johnson,. P.A., Zevenbergen, L.W., and Clopper. P.E. 2013. Risk-Based Approach for Bridge Scour Prediction, Draft Final Report, Transportation Research Board, National Academy of Science. Washington D.C.

Lai, Y.G., 2008. SRH-2D version 2: Theory and User's Manual, Sedimentation and River Hydraulics – Two-Dimensional River Flow Modeling, U.S. Department of Interior, Bureau of Reclamation, November, 113 p.

McAnally, W.H. 1989. STUDH: A Two-Dimensional Numerical Model for Sediment Transport, in Sediment Transport Modeling, Sam S. Y. Wang, Ed., ASCE, p. 659-664.

McDonald, R.R., Nelson, J.M., and Bennett, J.P., 2005, Multi-dimensional surface-water modeling system user's guide: U.S. Geological Survey Techniques and Methods, 6-B2, 136 p.

Miller, William. 2013. Personal communication. Ecological Consultants, Inc., Fort Collins, Colorado. April 23.

Mobile Boundary Hydraulics, 2010. Sedimentation in Stream Networks (HEC-6T) User Manual. 388 p.

Mussetter, R.A., Harvey, M.D. and Sing, E.F., 1995. Assessment of dam impacts on downstream channel morphology. In Lecture Series, U.S. Committee on Large Dams, San Francisco, California, May 13-18, pp. 283-298.

Mussetter, R.A. and Harvey, M.D., 1996. Geomorphic and hydraulic characteristics of the Colorado River, Moab, Utah: Potential impacts on a uranium tailings disposal site. Proc. Conference on Tailings and Mine Waste, '96, Colorado State University, January 16-19, 1996, Balkema, Rotterdam, pp. 405-414.

Nelson, Jonathon, 2012. Personal Communication. U.S. Geological Survey. June 18.

Nelson, J.M., Shimizu, Y., Takebayashi, H., and McDonald, R.R. 2010. The International River Interface Cooperative: Public Domain Software for River Modeling. In the 2nd Joint Federal Interagency Conference, Las Vegas, NV, June 27-July1, 2010.

Parker, G. 1990. Surface-based bedload transport relation for gravel rivers. Journal of Hydraulic Research, 28(4), 417-436.

R2 Resource Consultants, Inc. 2013a. Selection of Focus Areas and Study Sites in the Middle and Lower Susitna River for Instream Flow and Joint Resource Studies – 2013 and 2014, Technical Memorandum for Alaska Energy Authority Susitna-Watana Hydroelectric Project, FERC No. 14241.

R2 Resource Consultants, Inc. 2013b. Adjustments to Middle River Focus Areas, Technical Memorandum for Alaska Energy Authority Susitna-Watana Hydroelectric Project, FERC No. 14241.

Ruark, M., Niemann, J., Greimann, B., and Arabi, 2011. Method for Assessing Impacts of Parameter Uncertainty in Sediment Transport Modeling Applications, Journal of Hydraulic Engineering, 137(6): 623–636.

Shields, F.D. and Gippel, C.J., 1995. Prediction of effects of woody debris removal on flow resistance. Journal of Hydraulic Engineering 121, 341-354.

Smiarowski, A., 2010. The evaluation of a two-dimensional sediment transport and bed morphology model based on the Seymour River. University of British Columbia, Vancouver, CA. 111 p.

Smith, R.D., Sidle, R.C., Porter, P.E., Noel, F.R., 1993. Effects of experimental removal of woody debris on the channel morphology of a forest, gravel-bed stream. Journal of Hydrology 151, 153-178.

Steffler, P. and Blackburn, J. 2002. Two-Dimensional Depth Averaged Model for River Hydrodynamics and Fish Habitat – Introduction to Depth Averaged Modeling and User's Manual, University of Alberta, CA, 120 p.

Tetra Tech Inc. 2012. Fluvial Geomorphology Modeling. Technical Memorandum for Alaska Energy Authority Susitna-Watana Hydroelectric Project, FERC No. 14241.

U.S. Army Corps of Engineers (USACE), 1992. Guidelines for the Calibration and Application of Computer Program HEC-6. Training Document No. 13, Hydrologic Engineering Center, Davis, California

U.S. Army Corps of Engineers (USACE), 1993. HEC-6, Scour and Deposition in Rivers and Reservoirs, User's Manual, Hydrologic Engineering Center, Davis, California.

USACE, 2010. HEC-RAS, River Analysis System, User's Manual, Version 4.1.0, Hydrologic Engineering Center, Davis, California.

USACE, 2013. Adaptive Hydraulics User Manual Version 4.3. U.S. Army Corps of Engineers, Engineering Research and Development Center.

Wilcock, P.R., and Crowe, J.C. 2003. "Surface-based transport model for mixed-size sediment." Journal of Hydraulic Engineering. 129(2), 120-128.

Zabilansky, L.J., Ettema, R, Wuebben, J., and Yankielun, N., 2002. Survey of River Ice Influences on Channel Bathymetry Along the Fort Peck Reach of the Missouri River, Winter 1998-1999. ERDC/CRREL TR-02-14, Cold Regions Research and Engineering Laboratory, USACE, 151 p.

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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 3-1. Evaluation of 1-D models

Model Characteristics and Evaluation Criteria	Models			
	HEC-RAS	**SRH-1D**	**MIKE 11**	**HEC-6T**
General				
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	○[1]	●	●	●
Experience with model: High (H); Moderate (M); Low (L)	H	L	M	H
Model Size Limitations				
# of cross sections	NL	NL	NL	5,000
# of hydrograph ordinates	40,000	NL	NL	NL
# of sediment sizes	20	8	NL	20
Sediment Sizes Supported				
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
[1] 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**
General						
Commercial/cost (if applicable)	○	○	○	● / $20k	○	● / $5k
Unsteady flow capability	●	●	●	●	●	●
Ice for fixed bed	○	●	○	●	●	○
Ice for moveable bed	○	●	○	●	●	○
Number of transport equations supported	4	2	○[1]	10	2	8
Supports user defined transport equation	○	●	○[1]	●	○	●
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_s), drag coefficient (C_d, $C_d \alpha 1/C^2$)	n	n, K_s	C_d, K_s	n, C	K_s	n
Moveable boundary simulation	●	●	○[1]	●	●	●
Grid Structure/Model Formulation						
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
Model Size Limitations						
# of grid elements for sediment routing, (U = unlimited)	16k[2]	U	○[1,3]	U	>100k	>100k
Sediment Sizes Supported						
Wash load (silts, clays)	○	●	○[1]	●	○	○
Considers settling	○	●	○[1]	●	○	○
Sand	●	●	○[1]	●	●	●
Gravel and cobble (P = Parker, W = Wilcock & Crowe)	● P,W	●	○[1]	●	● W	●
Sediment Gradation/Multiple Layers/Armoring	●	●	○[1]	●	●	○

Notes: ● = Yes; ○ = No;

[1] Not currently available, but in development.

[2] >100k elements for hydraulic modeling,

[3] 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

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[1]
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

[1] 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.

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8. FIGURES

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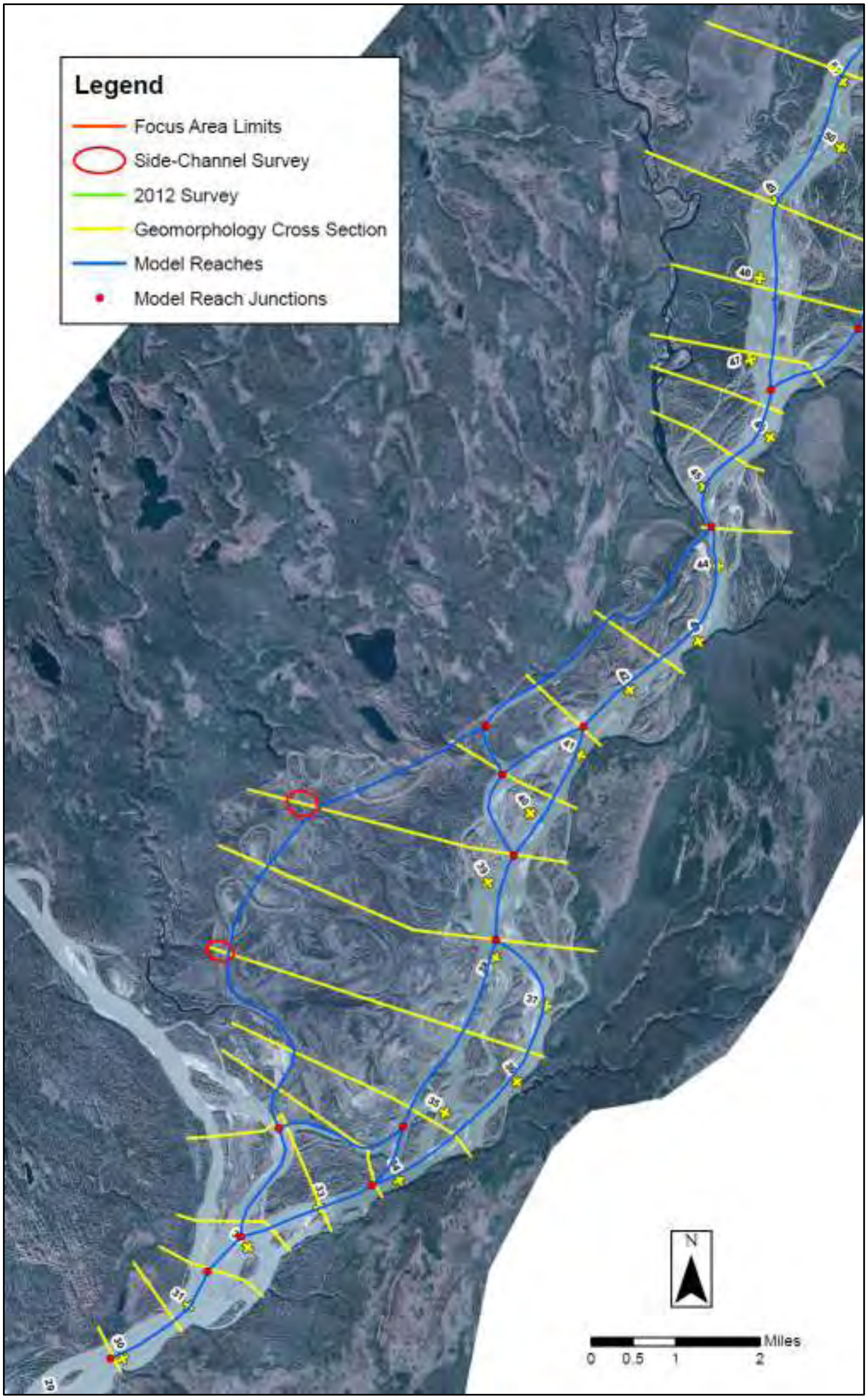

Figure 4-1. Survey and Model Cross Sections from PRM 30 to PRM 47

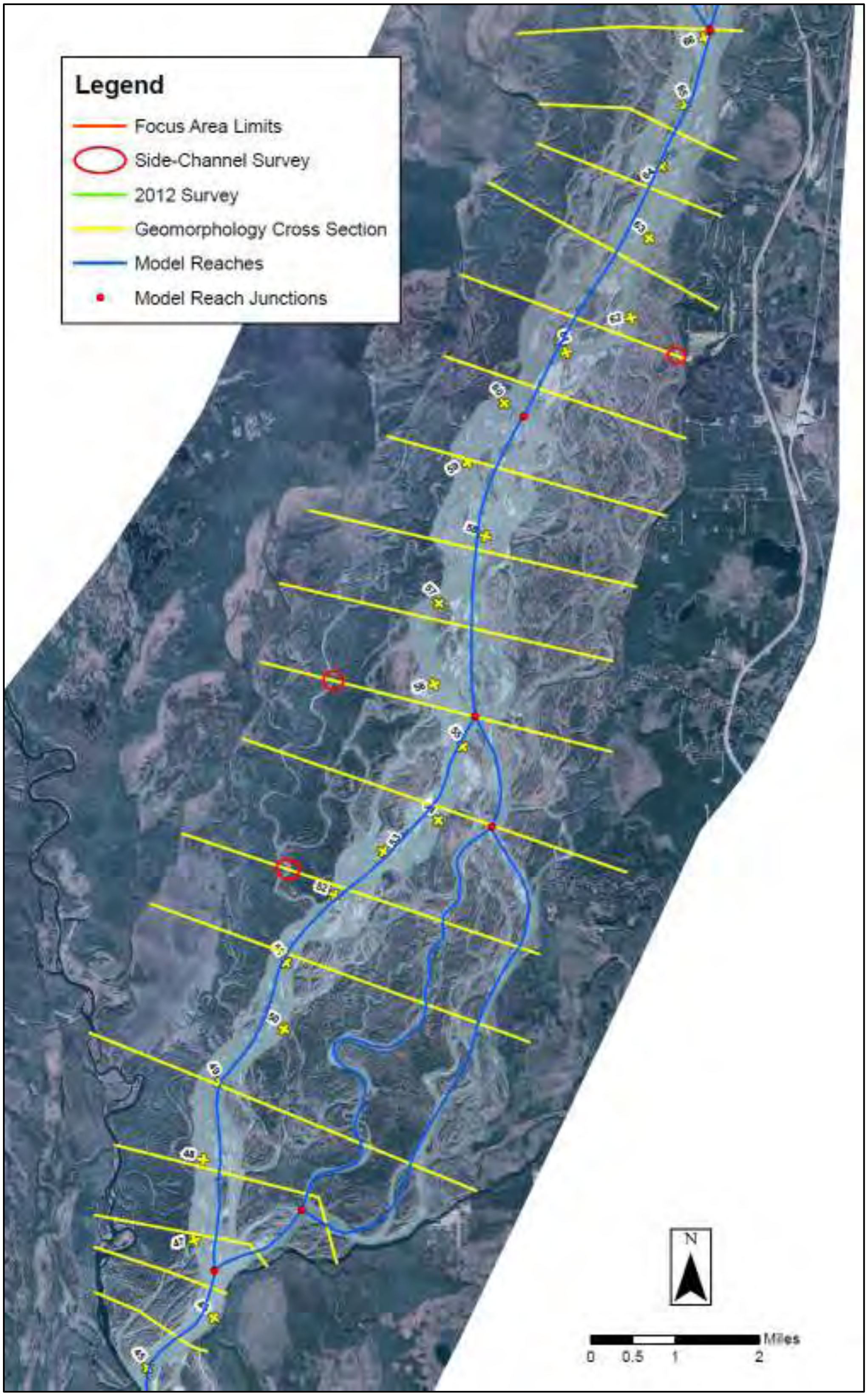

Figure 4-2. Survey and Model Cross Sections from PRM 45 to PRM 66

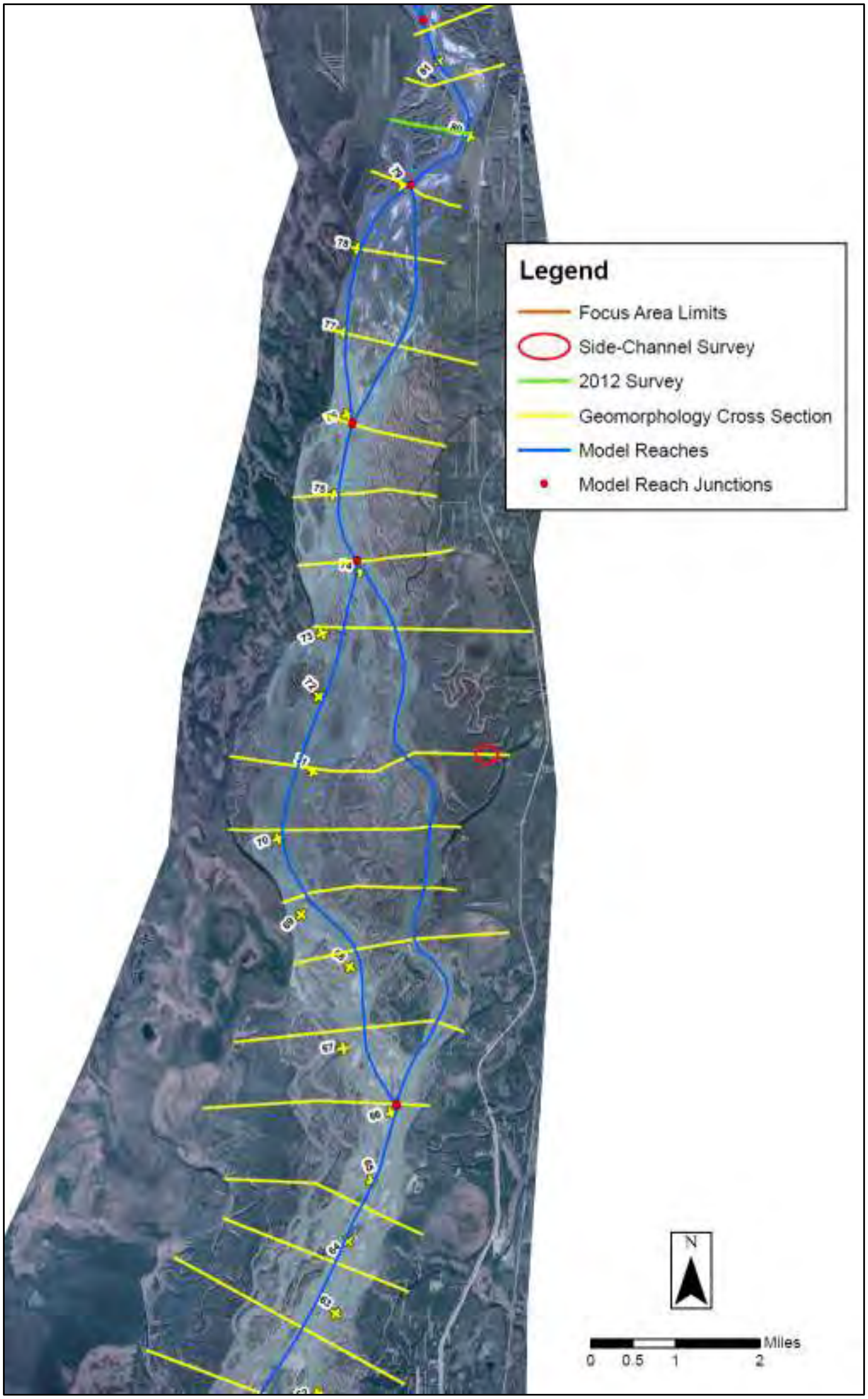

Figure 4-3. Survey and Model Cross Sections from PRM 63 to PRM 81

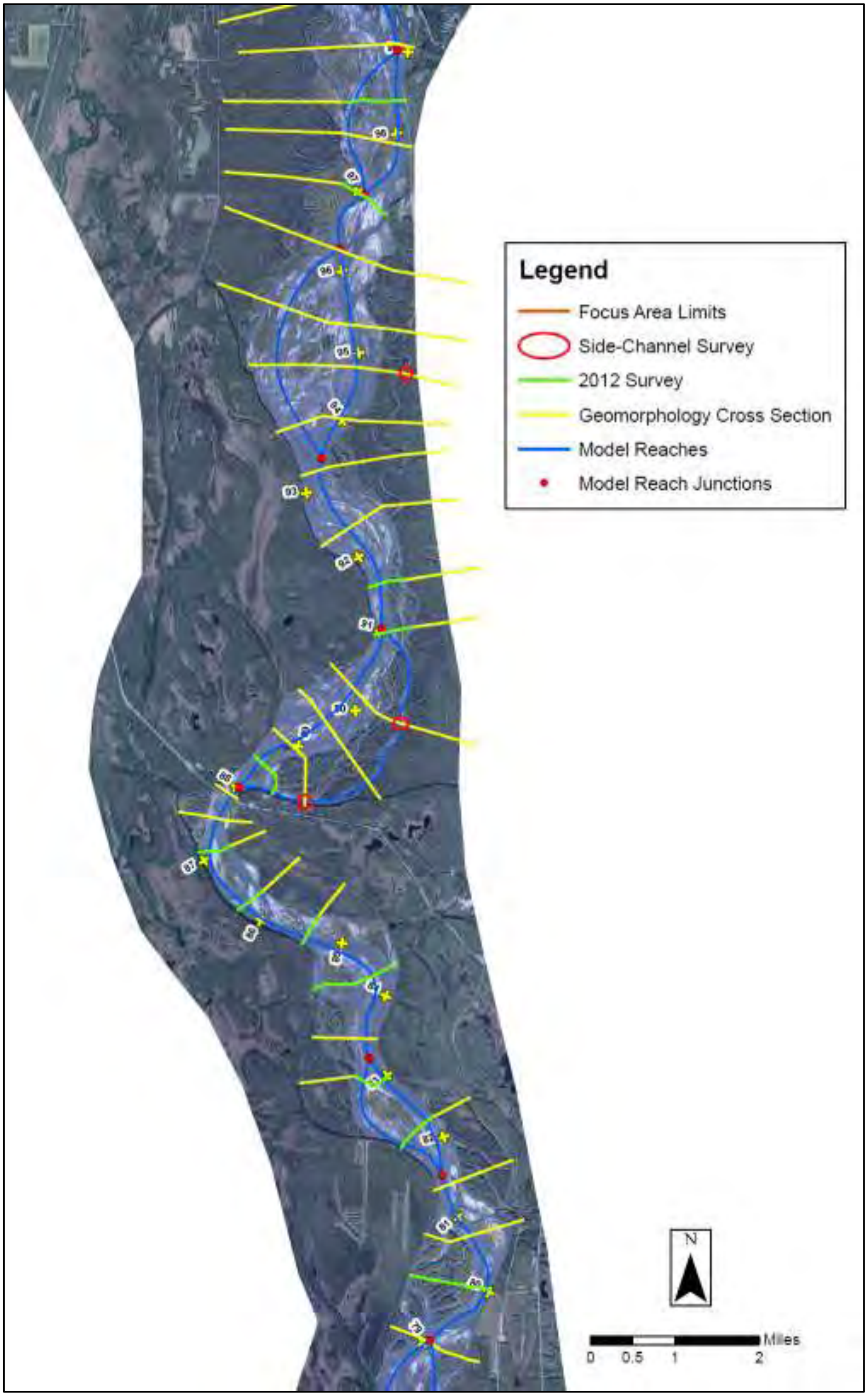

Figure 4-4. Survey and Model Cross Sections from PRM 79 to PRM 99

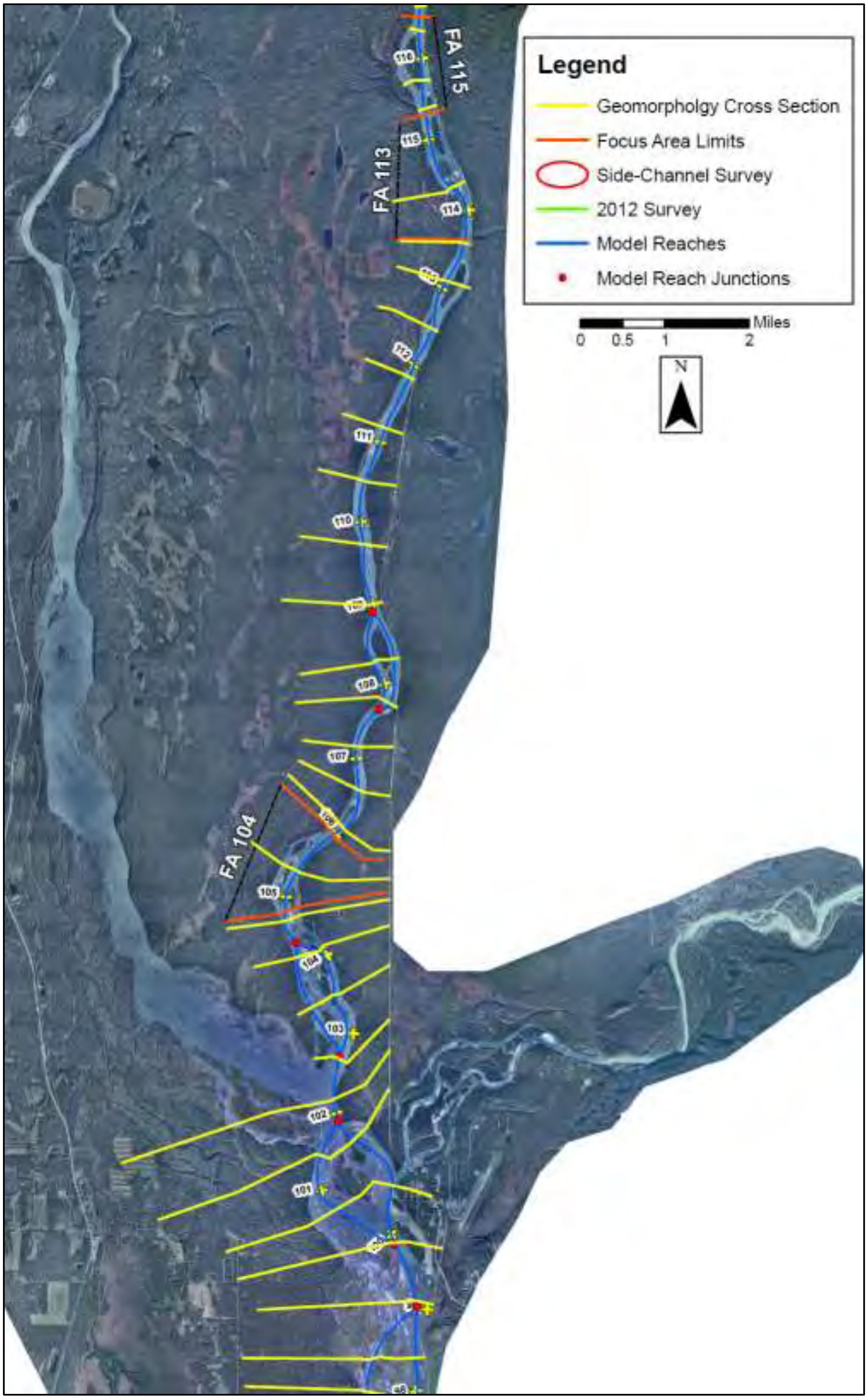

Figure 4-5. Survey and Model Cross Sections from PRM 98 to PRM 116

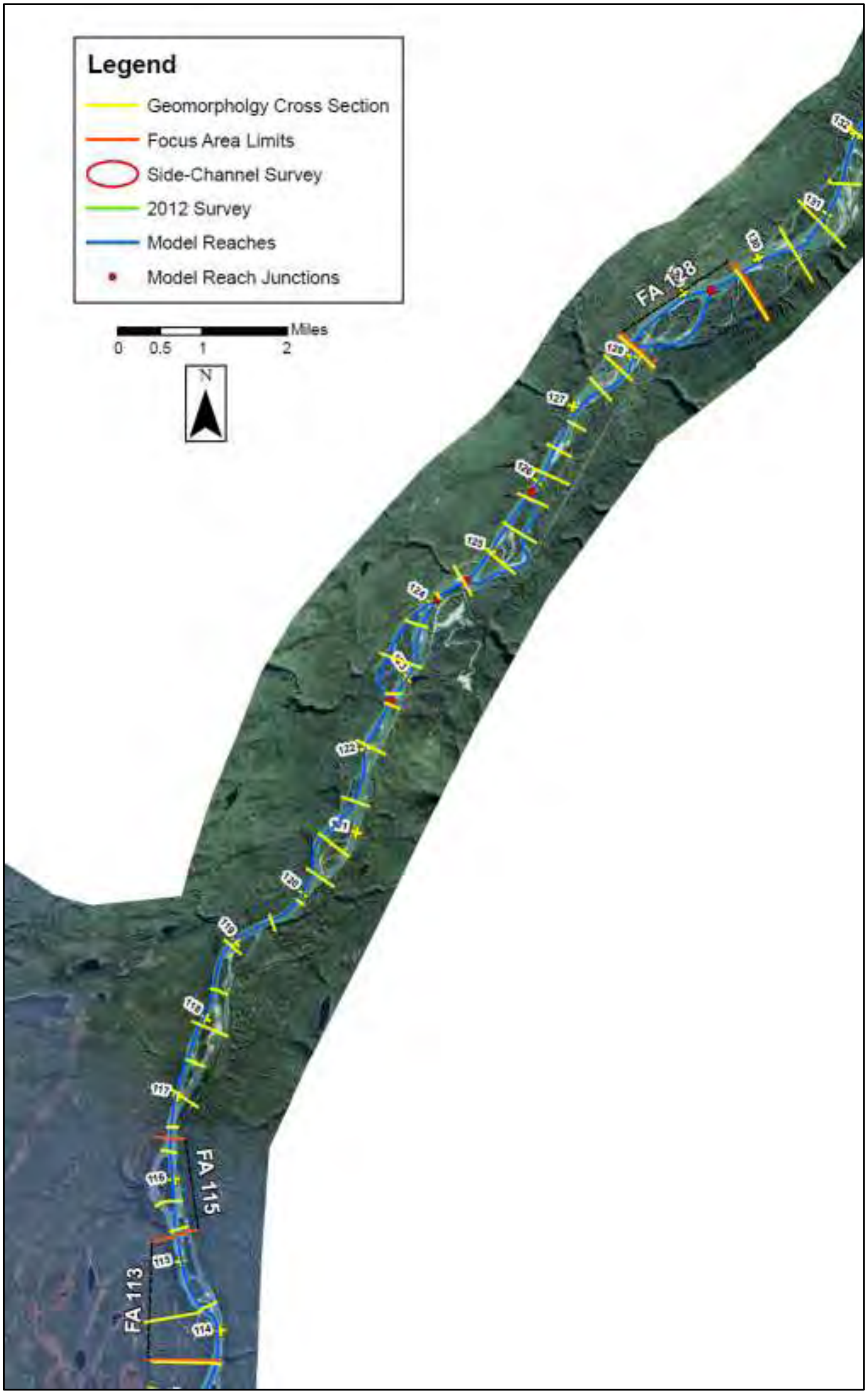

Figure 4-6. Survey and Model Cross Sections from PRM 114 to PRM 131

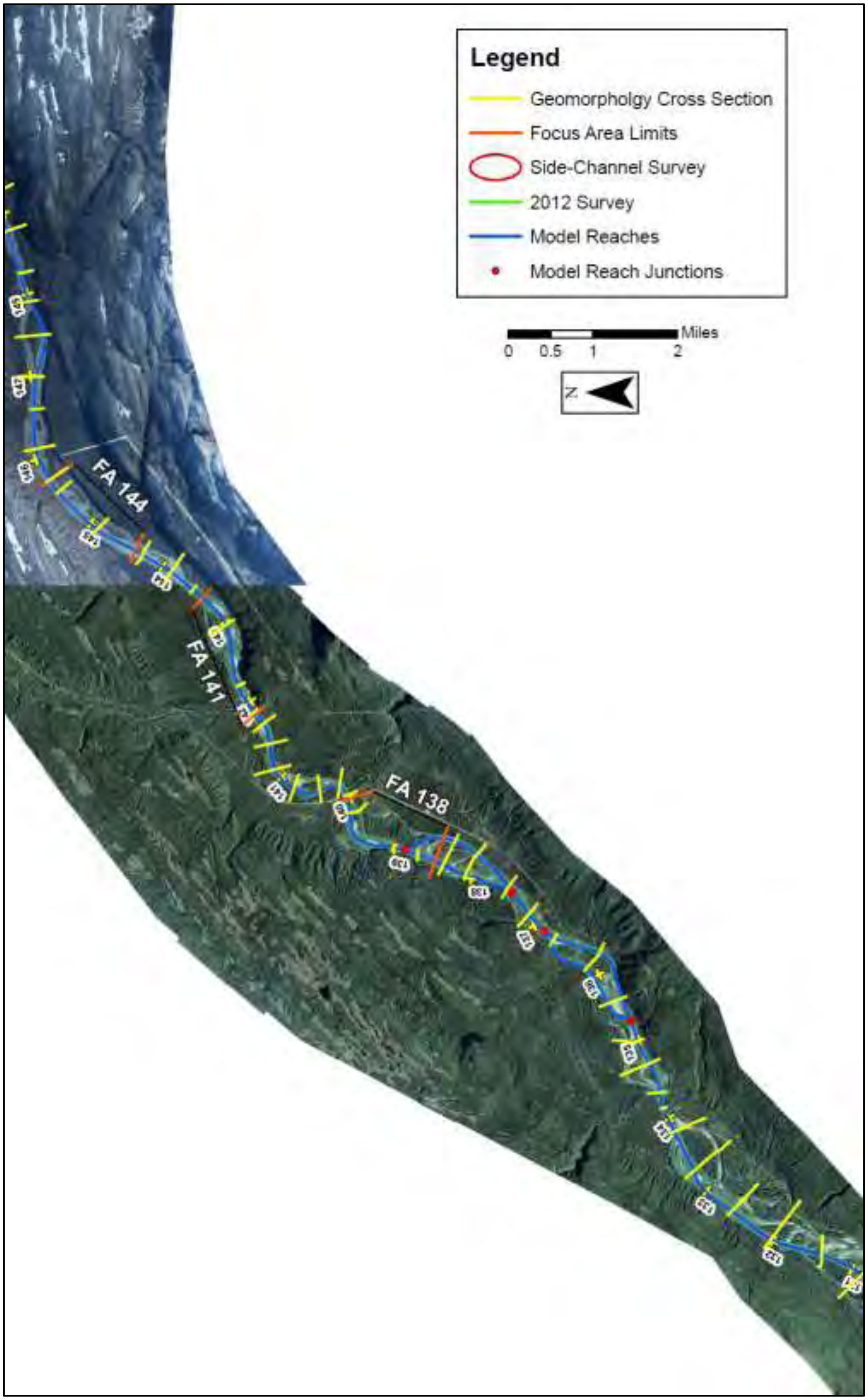

Figure 4-7. Survey and Model Cross Sections from PRM 131 to PRM 148

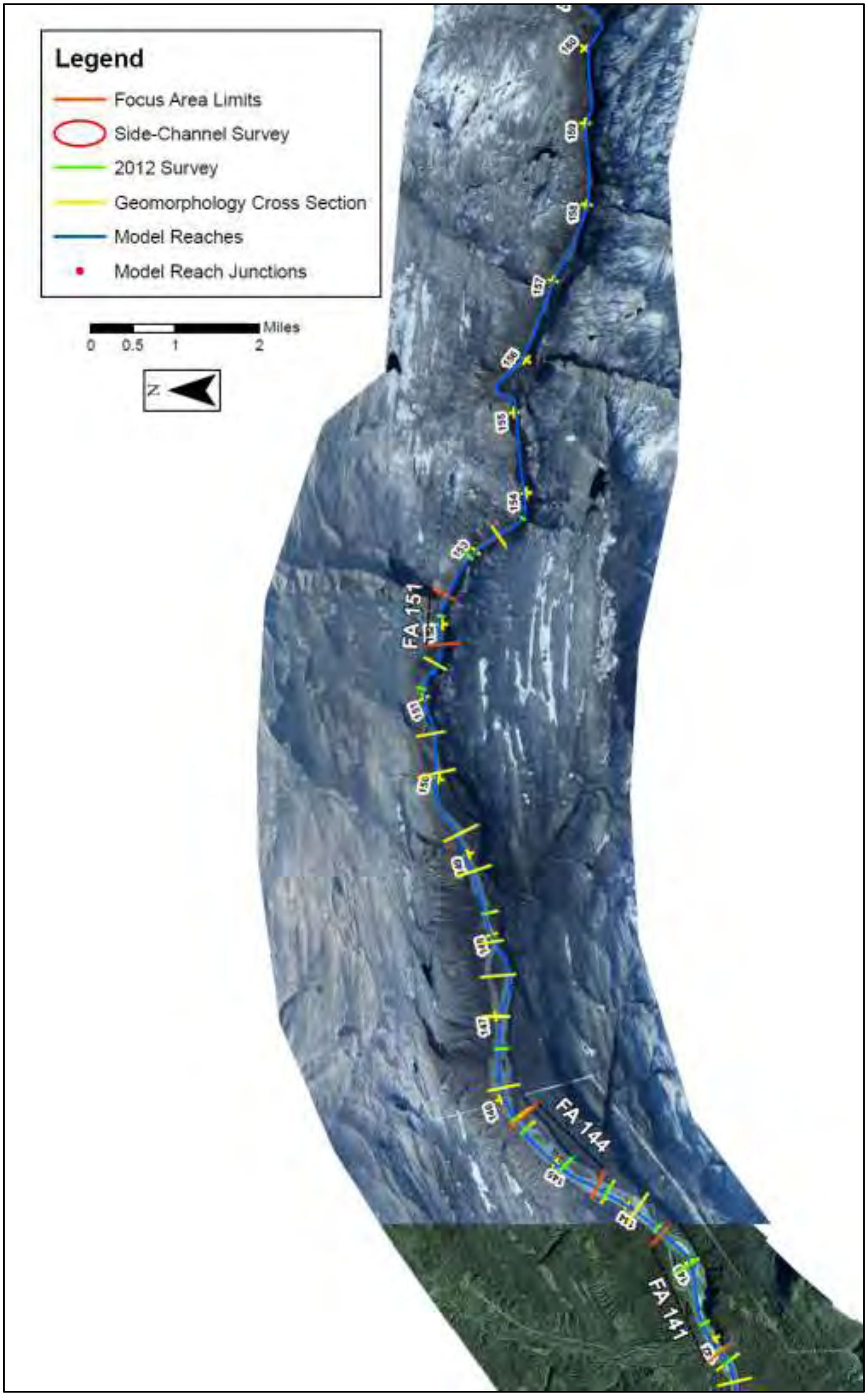

Figure 4-8. Survey and Model Cross Sections from PRM 142 to PRM 154

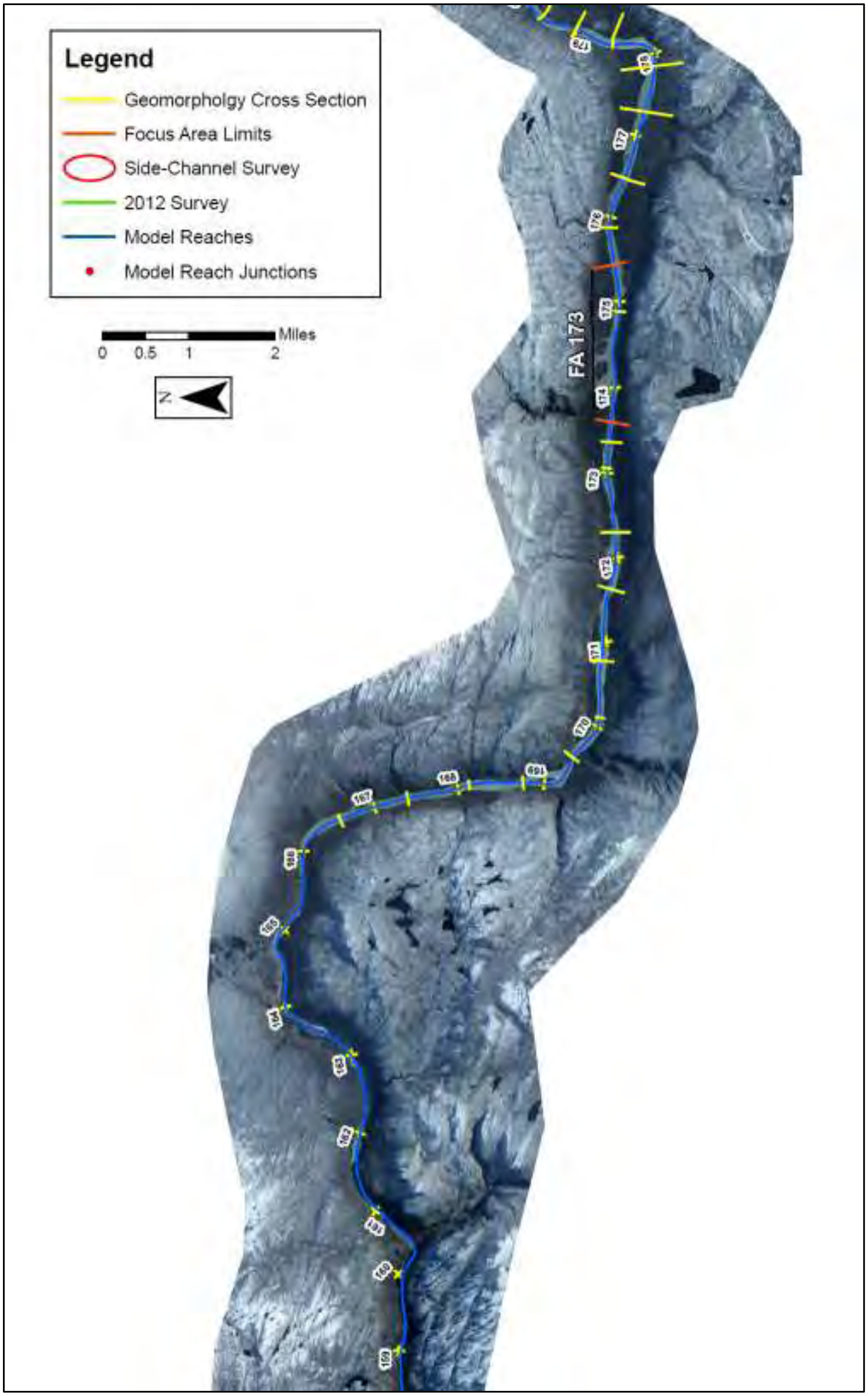

Figure 4-9. Survey and Model Cross Sections from PRM 166 to PRM 179

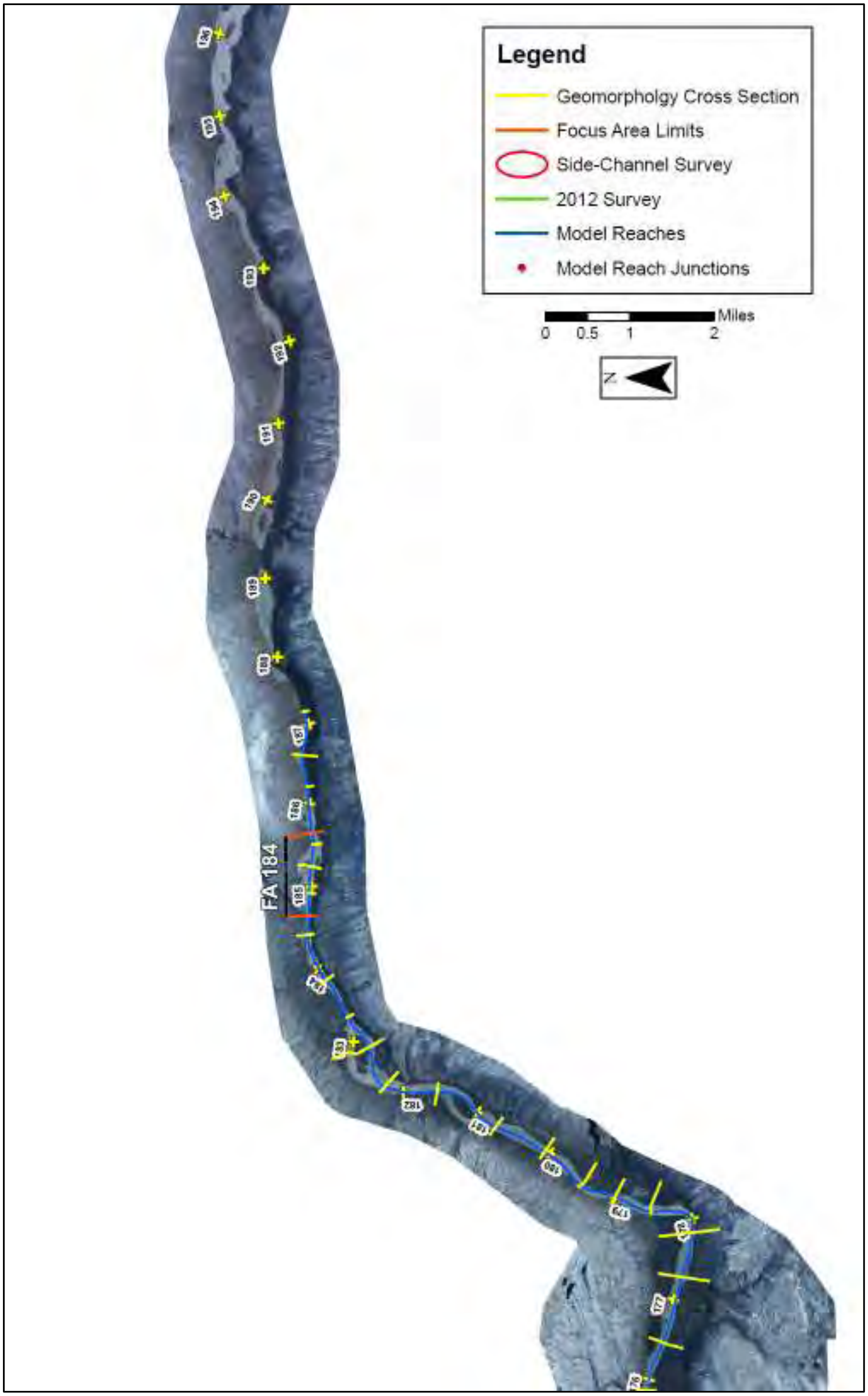

Figure 4-10. Survey and Model Cross Sections from PRM 176 to PRM 188

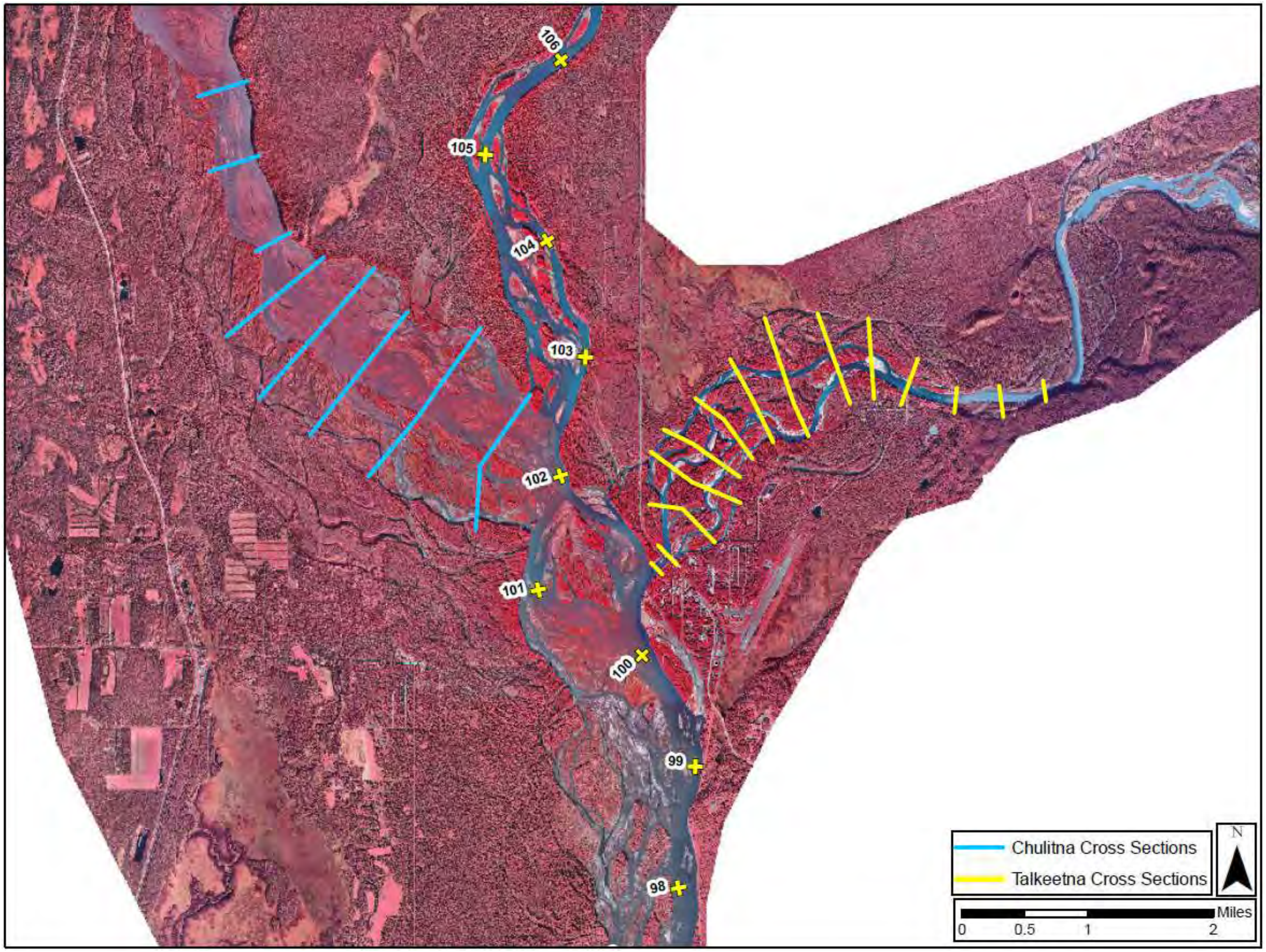

Figure 4-11. Proposed Cross Section Layout for Chulitna and Talkeetna Rivers, 1-D Model Tributary Reaches

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

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

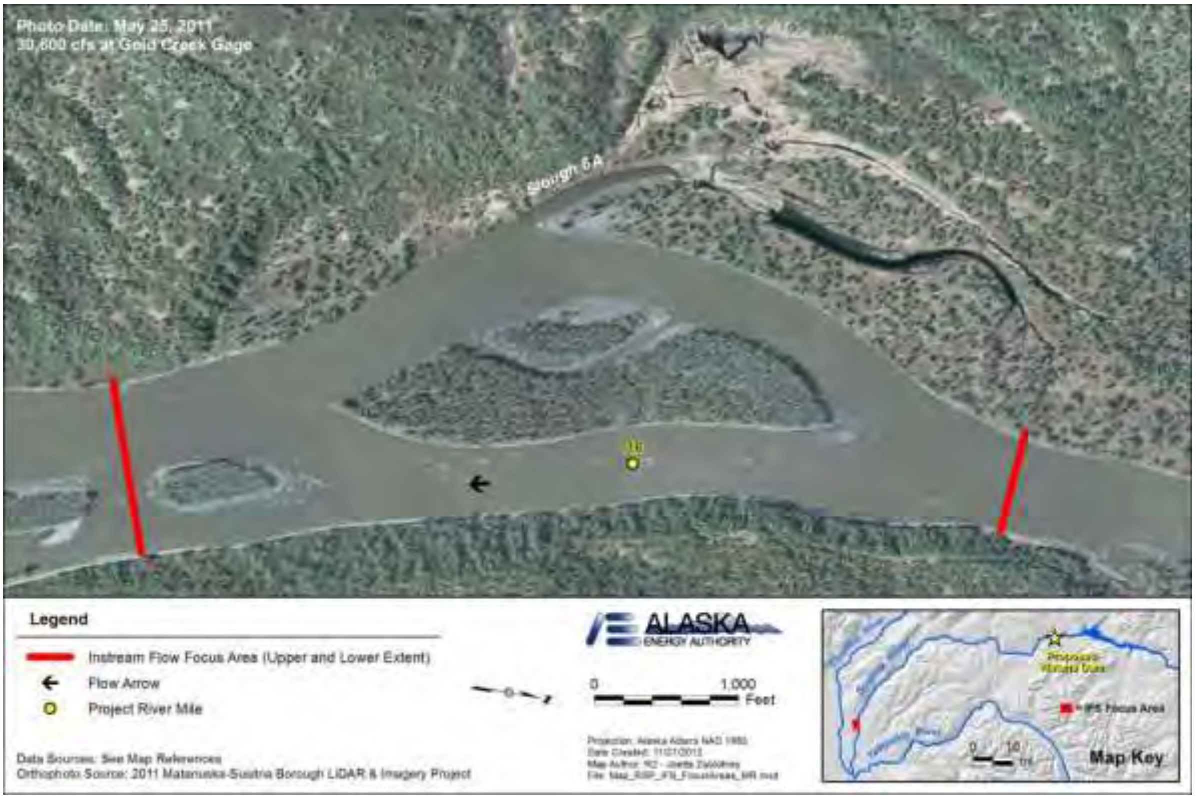

Figure 4-14. FA115 (From R2 Resource Consultants Inc. 2013)

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

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

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

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

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

Figure 4-20. FA128 (From R2 Resource Consultants Inc. 2013)

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

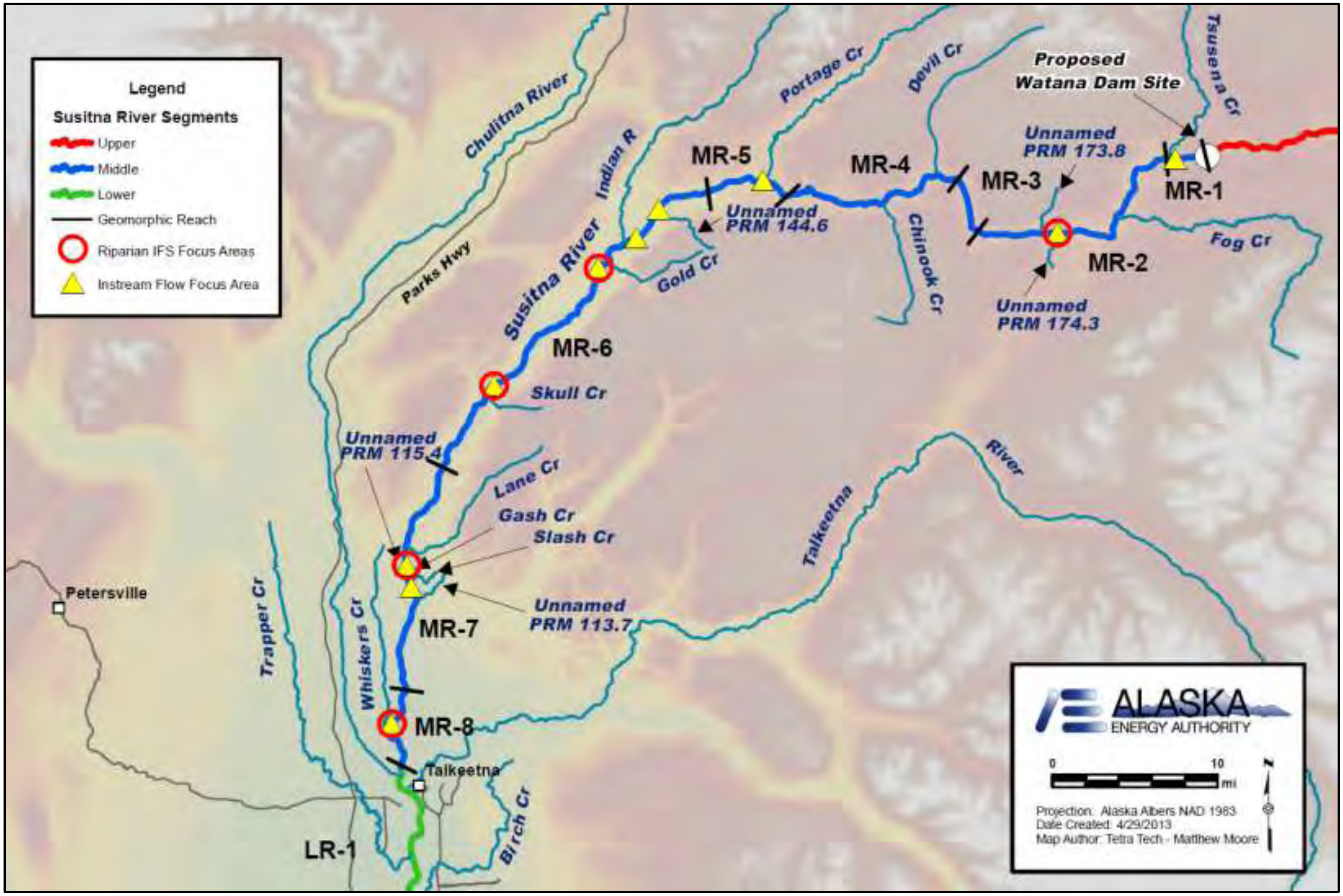

Figure 4-22. Middle River Tributary Locations Relative to Geomorphic Reach and Focus Areas

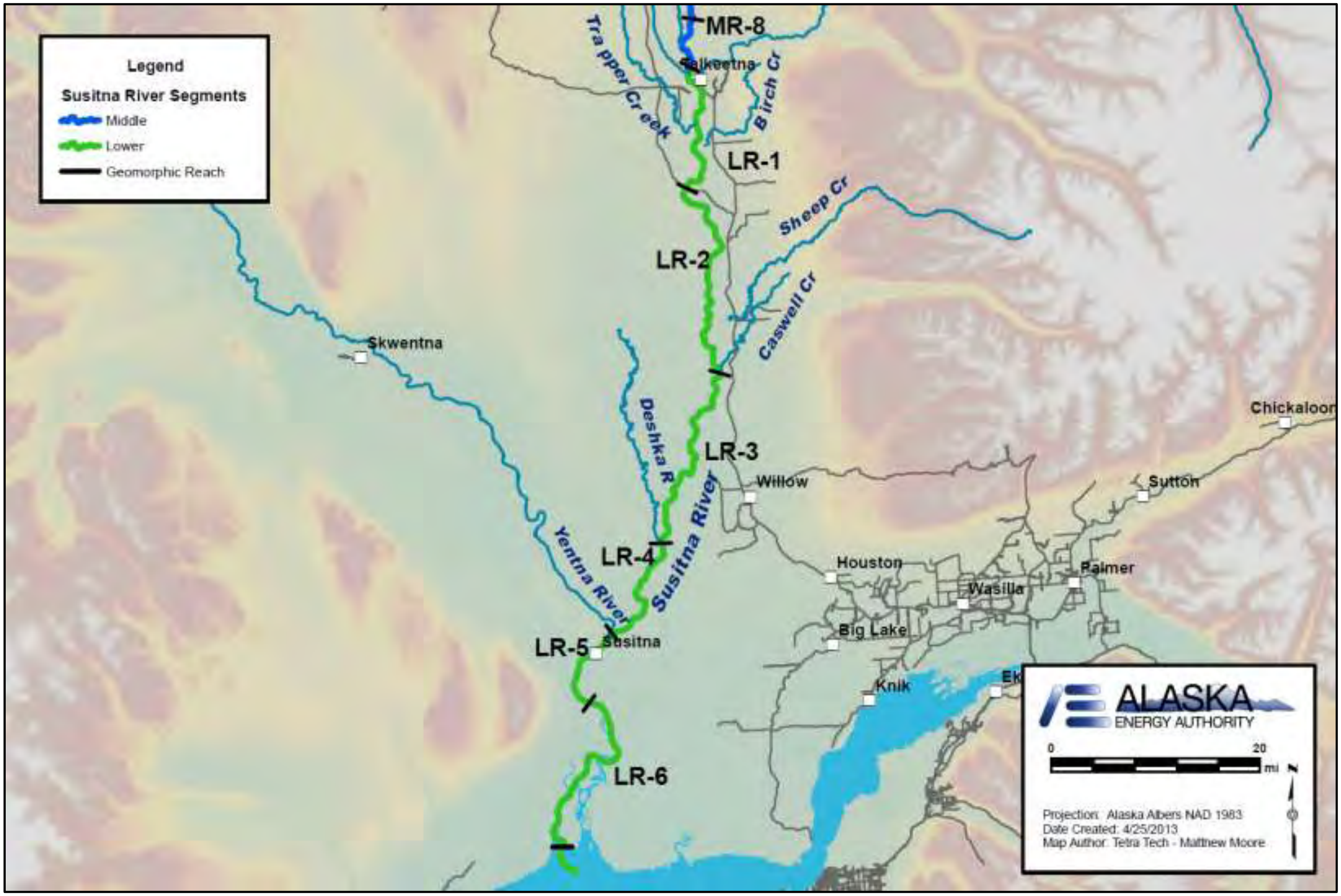

Figure 4-23. Lower River Tributary Locations Relative to Geomorphic Reach

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

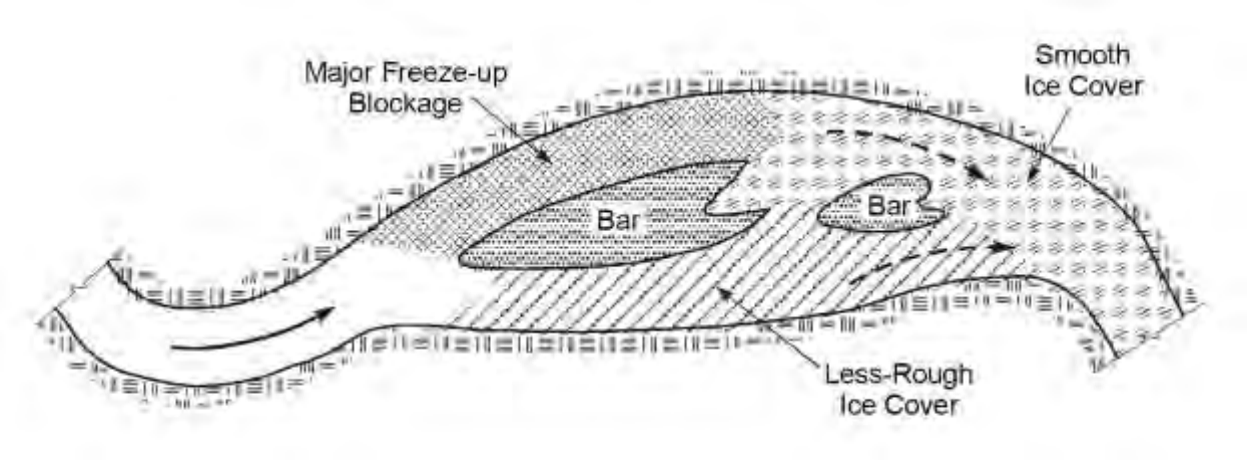

Figure 4-26. Example of Ice Blockage Altering Flow Distribution in Multiple Channel Reaches (Zabilansky et al. 2003)

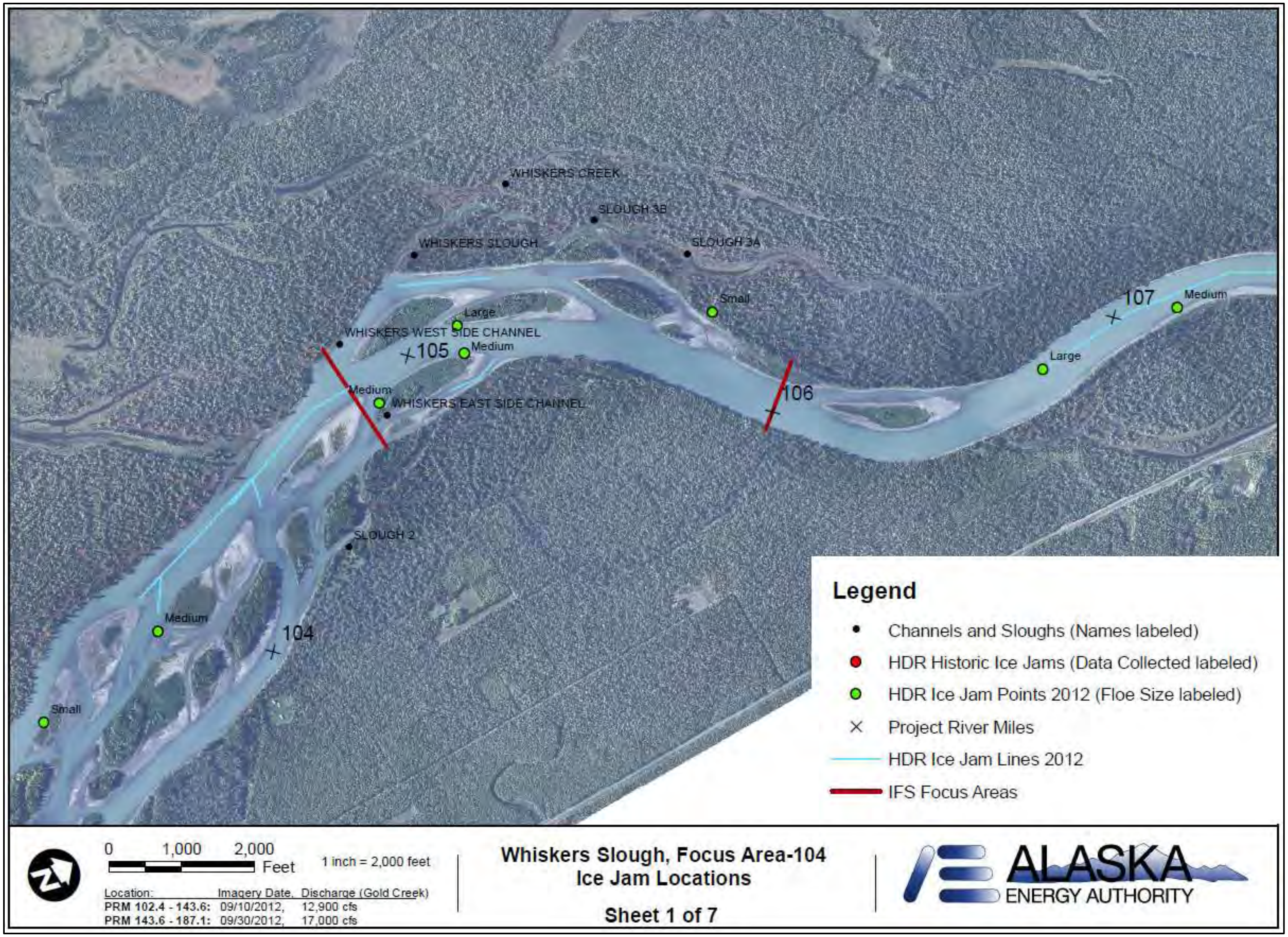

Figure 4-27. Ice Jam Locations at FA104

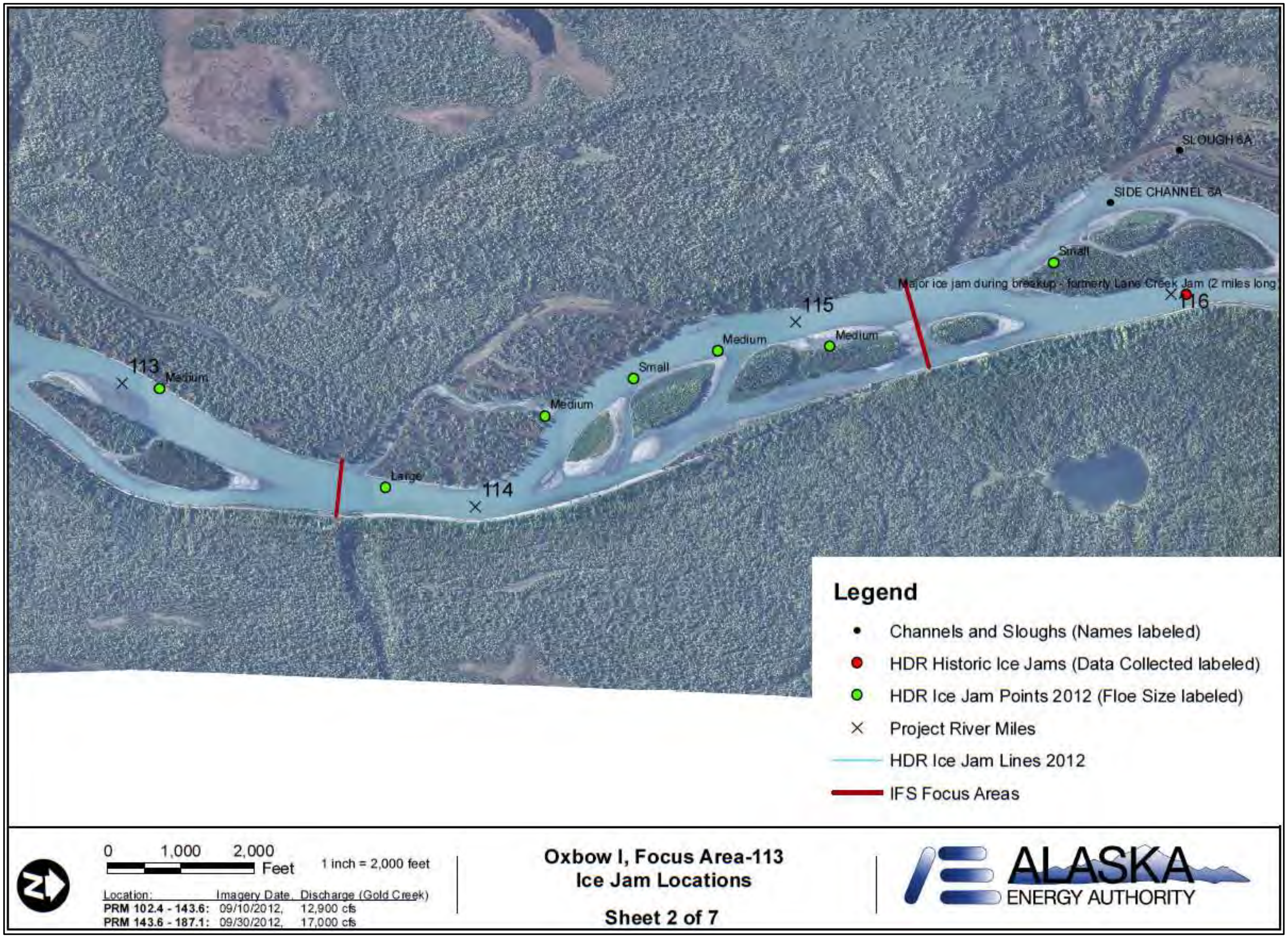

Figure 4-28. Ice Jam Locations at FA113

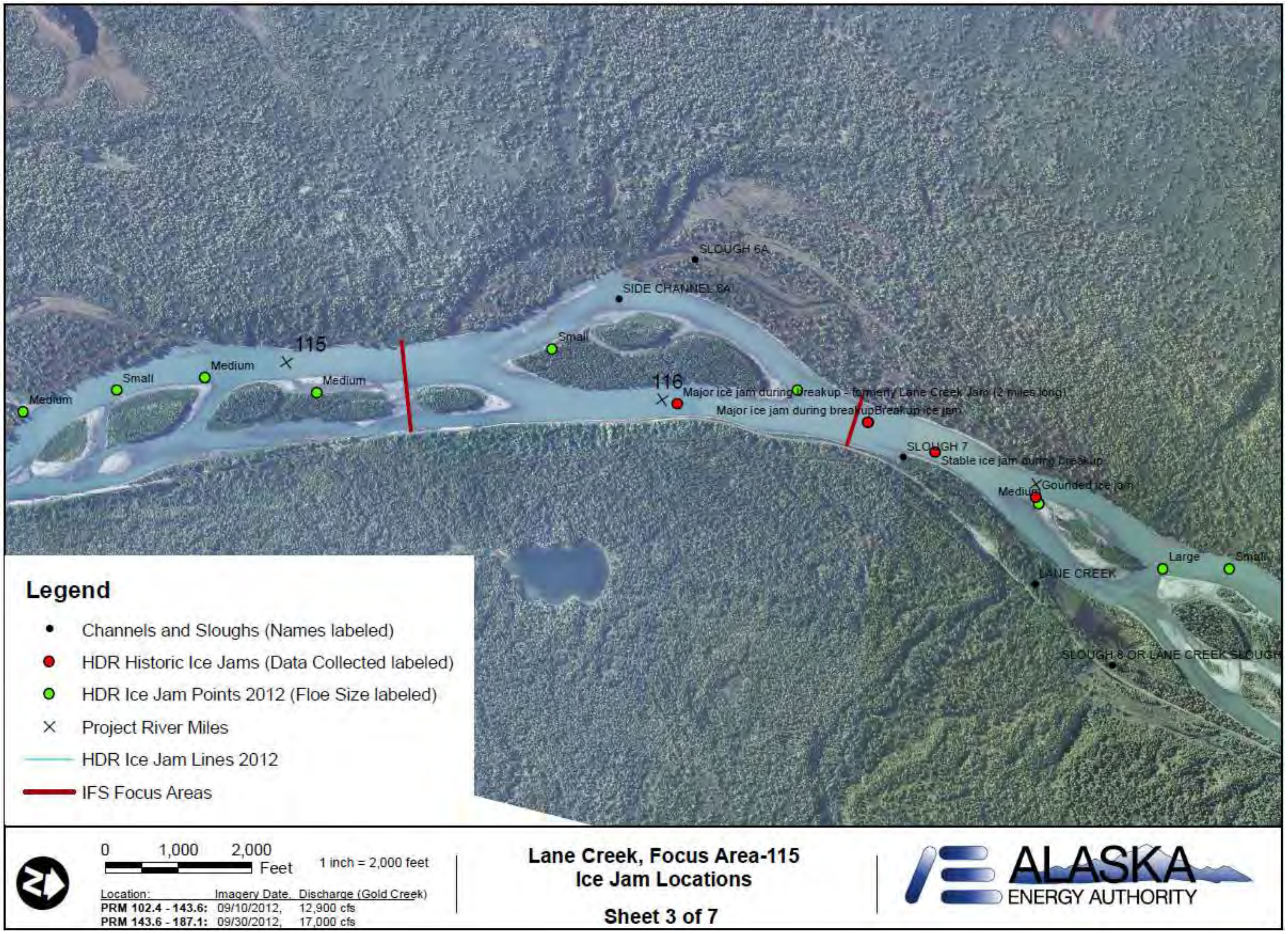

Figure 4-29. Ice Jam Locations at FA115

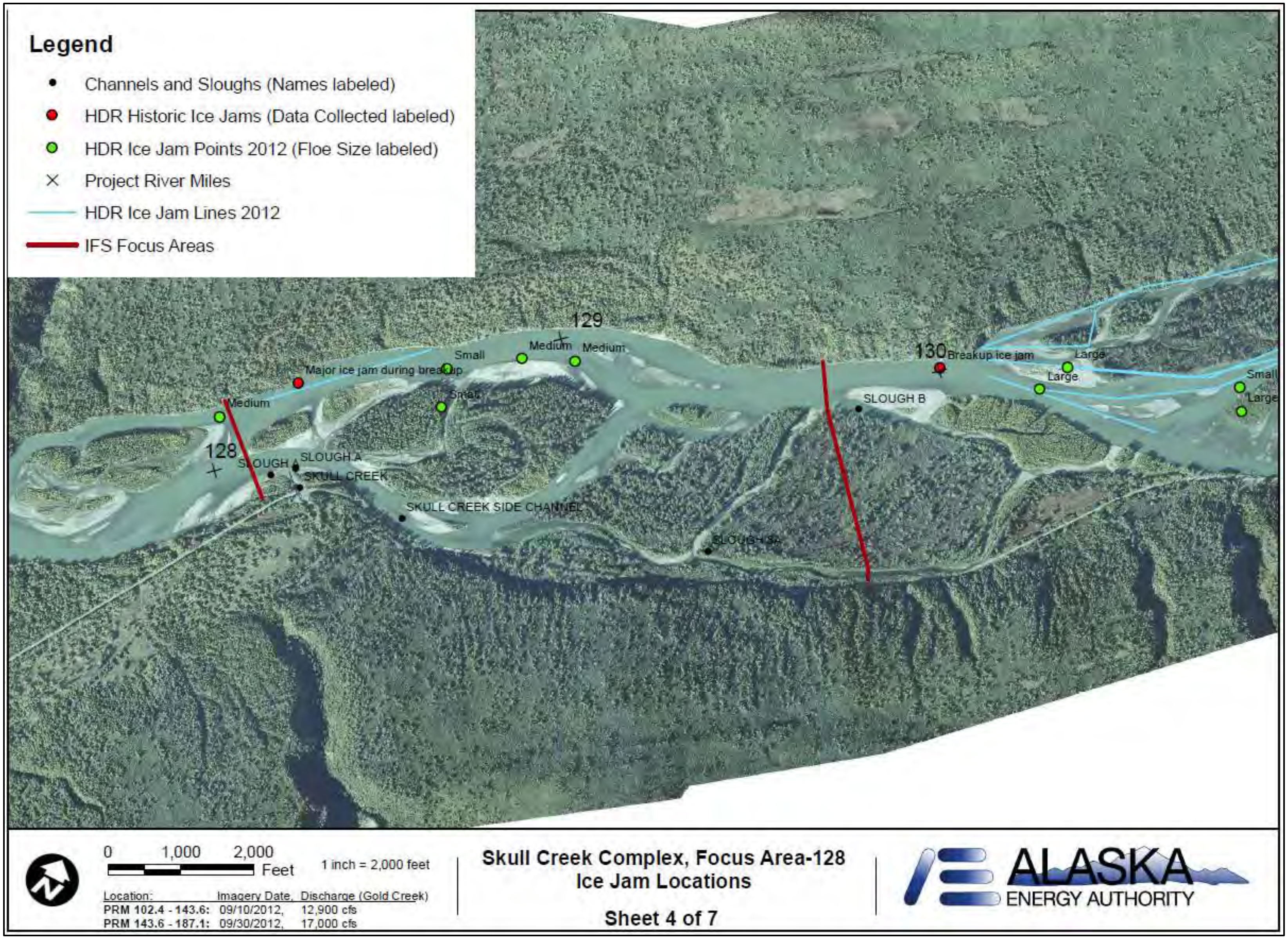

Figure 4-30. Ice Jam Locations at FA128

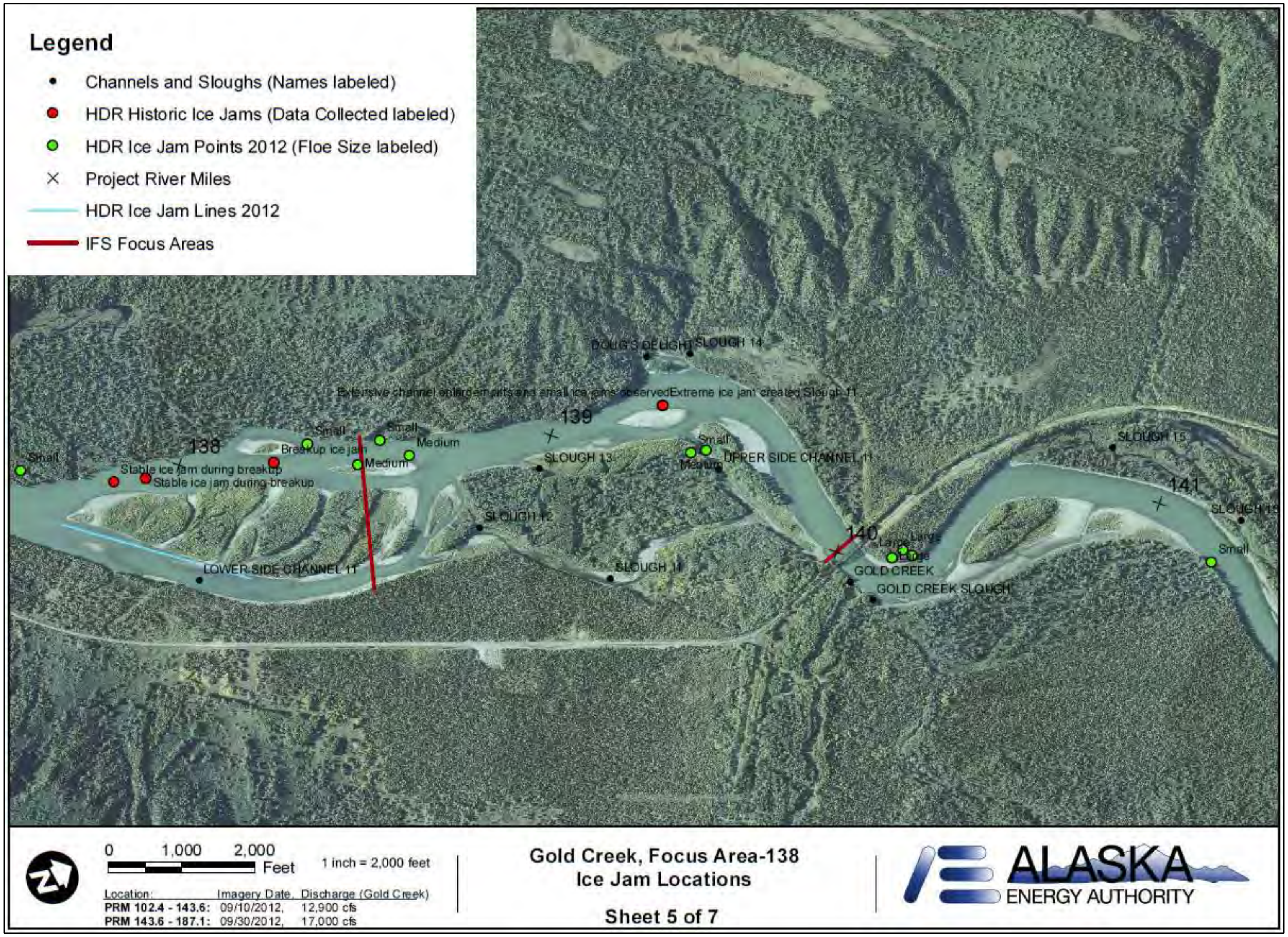

Figure 4-31. Ice Jam Locations at FA138

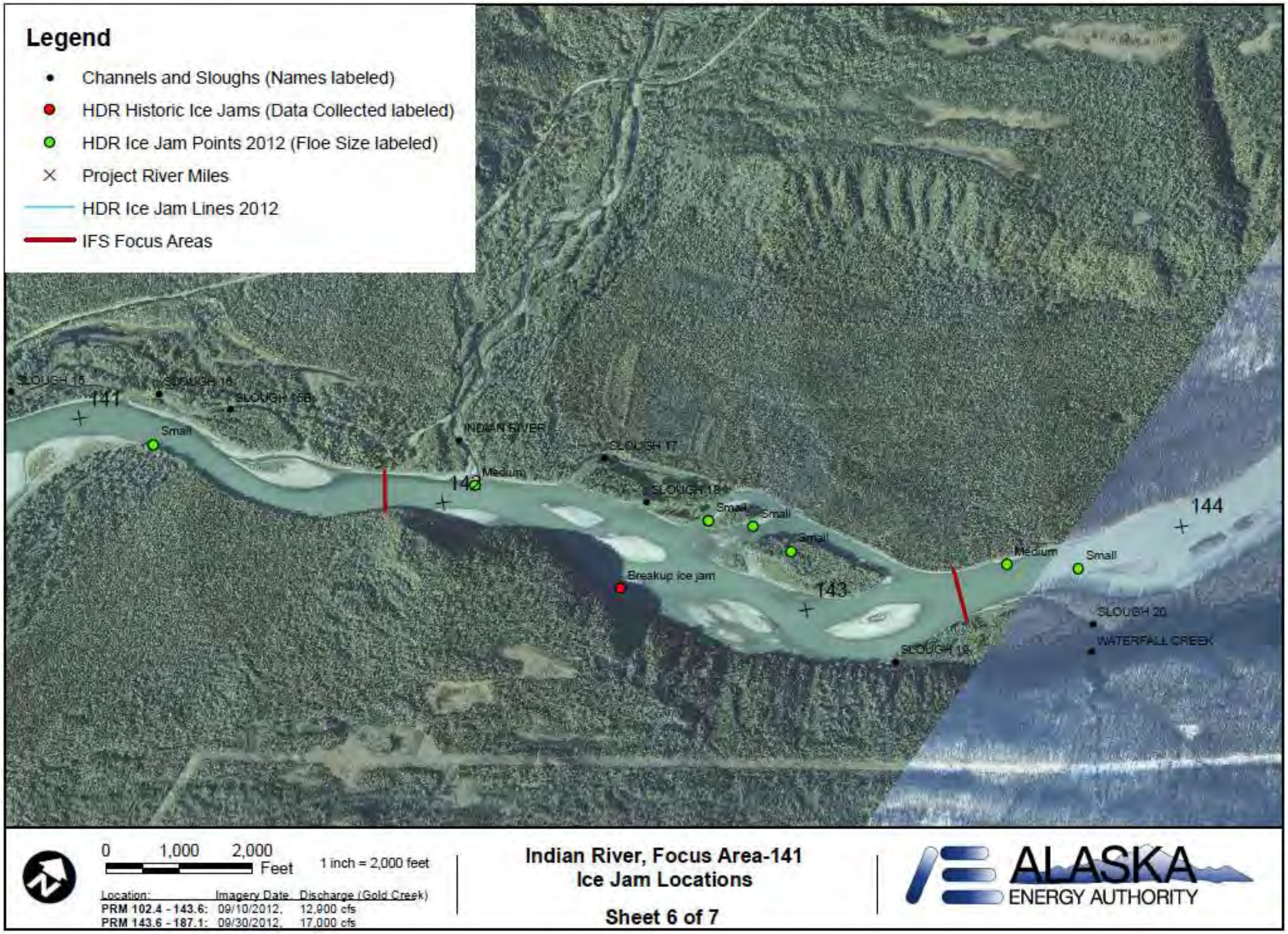

Figure 4-32. Ice Jam Locations at FA141

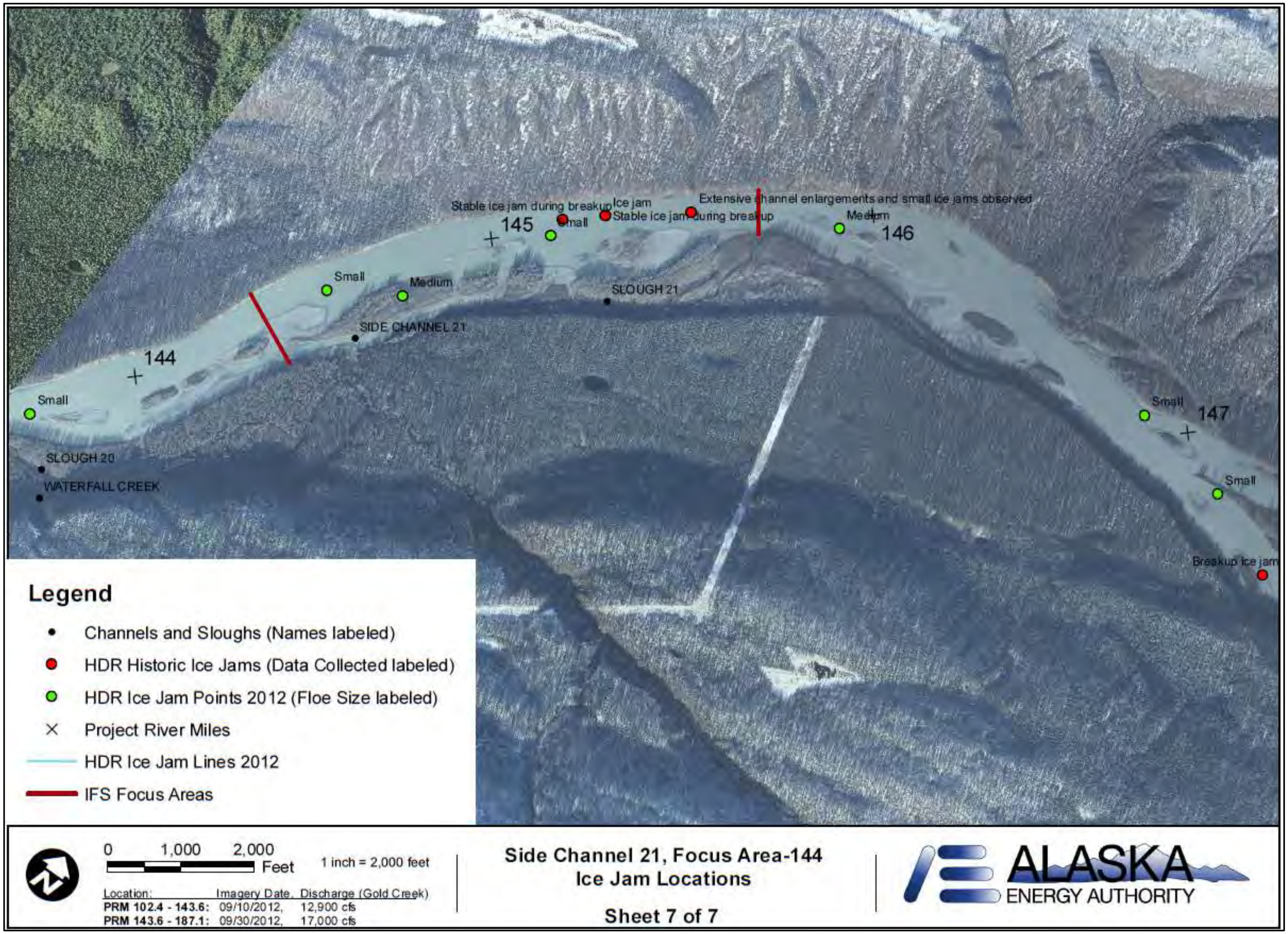

Figure 4-33. Ice Jam Locations at FA144