Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fluvial Geomorphology Modeling below Watana Dam Study
Study Plan Section 6.6

Final Study Plan

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

July 2013

6.6. Fluvial Geomorphology Modeling below Watana Dam Study

On December 14, 2012, Alaska Energy Authority (AEA) filed with the Federal Energy Regulatory Commission (FERC or Commission) its Revised Study Plan (RSP), which included 58 individual study plans (AEA 2012). Included within the RSP was the Fluvial Geomorphology Modeling below Watana Dam Study, Section 6.6. RSP Section 6.6 focuses on the modeling planned for assessing the effects of the proposed Project and its operations on fluvial geomorphology in the Susitna River basin.

On February 1, 2013, FERC staff issued its study determination (February 1 SPD) for 44 of the 58 studies, approving 31 studies as filed and 13 with modifications. On April 1, 2013 FERC issued its study determination (April 1 SPD) for the remaining 14 studies; approving 1 study as filed and 13 with modifications. RSP Section 6.6 was one of the 13 approved with modifications. In its April 1 SPD, FERC recommended the following:

Modeling in Focus Areas

> *- We recommend that AEA file by June 30, 2013, the proposed technical memorandum related to the selection and application of the one- and two-dimensional models (proposed for development in the second quarter of 2013). We also recommend that the technical memorandum include the following information:*
>
> > *1) specification of the one- and two-dimensional models to be used in the fluvial geomorphology modeling pursuant to this study as well as the aquatic habitat models pursuant to Study 8.5 (fish and aquatics instream flow);*
> >
> > *2) location and extent of one- and two-dimensional geomorphology and aquatic habitat modeling in project reaches, focus areas, and other study sites;*
> >
> > *3) rationale and criteria for model selection including an overview of model development;*
> >
> > *4) for fluvial geomorphology modeling only, a detailed description of the processes and methods by which ice and LWD would be incorporated into the modeling approach (as described in our recommendations for Incorporating Large Woody Debris and Ice Processes into Fluvial Geomorphic Modeling); and*
> >
> > *5) documentation of consultation with the TWG, including how the TWG's comments were addressed.*
>
> *We expect additional detail on model parameterization, model calibration, model validation, and sensitivity analysis would be included in the initial and updated study reports.*

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.

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.

Operational Scenarios

- As discussed under the general comments section of this study plan determination, we recommend the study plan be modified to include run-of-river operation.

In accordance with the April 1 SPD, on May 3, 2013, AEA provided to the Technical Work Group participants for comment a Draft Fluvial Geomorphology Modeling Approach Technical Memorandum (Geomorphology Modeling TM) that was developed to provide responses to all April 1 SPD recommendations. The Draft Geomorphology Modeling TM was made available on the Project website (http://www.susitna-watanahydro.org). Consistent with the April 1 SPD, AEA allowed a minimum of 15 days for comment. NMFS submitted comments on May 18, 2013. AEA also received comments on the Draft Geomorphology Modeling TM from one individual and two non-government organizations.

Recommended modifications were addressed in detail in the Final Geomorphology Modeling TM filed with FERC on July 1, 2013. Information in the Final Geomorphology Modeling TM supersedes relevant details within this Final Study Plan.

6.6.1. General Description of the Proposed Study

The overall goal of the Fluvial Geomorphology Modeling below Watana Dam Study is to model the effects of the proposed Project on the fluvial geomorphology of the Susitna River to assist in predicting the trend and magnitude of geomorphic response. More specifically, the purpose of the modeling study, along with the Geomorphology Study (Section 6.5), is to assess the potential impact of the Project on the behavior of the river downstream of the proposed dam, with particular focus on potential changes in instream and riparian habitat. 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 (i.e., 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 two geomorphology studies:

- 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 in the absence of the project?
- Will and in what ways will the Project alter the equilibrium status of the downstream river (i.e., what is the expected morphologic evolution over the term of the license under with-Project conditions)?
- What will be the expected effect of the Project-induced changes on the geomorphic features that form the aquatic habitat and therefore are directly related to the quantity, distribution and quality of the habitat?

The methods and results from the Geomorphology Study and the Fluvial Geomorphology Modeling Study will address these questions.

Specific objectives of the Fluvial Geomorphology Modeling Study are as follows:

- Develop calibrated models to predict the magnitude and trend of geomorphic response to the Project.
- Apply the developed models to estimate the potential for channel change for with-Project operations compared to existing conditions.
- Coordinate with the Geomorphology Study to integrate model results with the understating of geomorphic processes and controls to identify potential Project effects that require interpretation of model results.
- Support the evaluation of Project effects by other studies in their resource areas providing channel output data and assessment of potential changes in the geomorphic features that help comprise the aquatic and riparian habitats of the Susitna River.

6.6.2. Existing Information and Need for Additional Information

Sediment transport issues downstream of Watana Dam are expected to stem from the influences of the regulated outflows and the deficit of sediment supply due to trapping of sediments in the reservoir. These issues are particularly important because fish resources have the greatest potential to be affected by the Project, and most of the potential impacts would occur downstream of the Project (AEA 2010). The effect of altered flows on anadromous and resident fish habitats and their associated populations was the major focus of studies conducted in the 1980s (APA 1984). The major fish habitats are located in the Susitna River, side channels, side sloughs, upland sloughs, and tributary mouths (APA 1984).

Modeling of the hydraulics of the Susitna River below the previously proposed project, a necessary step in developing a sediment transport model, was performed in the 1980s. This work included development and application of one-dimensional HEC-2 hydraulic models to support the calculation of water-surface profiles and channel hydraulics (Acres 1983). The models represented the reach between Devils Canyon (Susitna RM 186.8) and Talkeetna (RM 99), excluding Devils Canyon (Susitna RM 162.1 to RM 150.2). The Aquatic Resources Data Gap Analysis (HDR 2011) indicates that sediment transport modeling of a portion of the Susitna

River was also undertaken. Realizing the complexity of the sediment transport problem at the Chulitna River confluence, APA commissioned the Iowa Institute of Hydraulic Research to develop a quasi-steady, one-dimensional numerical model of sediment transport for the 14-mile reach of the Susitna River from the Chulitna confluence downstream to Sunshine Station (Holly et al. 1985). The model was based on sediment transport data from 1981 and 1982, as the following years of data collection had not yet been completed. The topography was derived from 28 cross-sections (approximately 1 every ½ mile) measured by R&M Consultants and aerial photography (Ashton and R&M 1985). The model was still in development as of the writing of the 1985 report; however, the companion report, referenced in Holly et al. (1985), was not found in the Susitna documentation.

The Aquatic Resources Data Gap Analysis (HDR 2011) indicates that channel equilibrium, an important macrohabitat variable, was not addressed in the APA Project instream flow study. The question of whether the existing channel morphology will remain the same, or at least be in "dynamic equilibrium" once the proposed action is implemented is a significant question in an instream flow study. Instream flow versus habitat relationships developed for today's river assume that similar relationships will persist for the duration of the project, within a reasonably defined range of variability. In the case of the proposed Project's instream flow study, the question is whether the river is currently in a state of equilibrium or disequilibrium. If it is in a state of disequilibrium, will the state be exacerbated or reversed as a result of the Project? If it is exacerbated or reversed, the impact of the Project cannot be assessed without estimating a post-Project channel configuration (Bovee et al. 1998). The same holds true if the river is currently in a state of equilibrium and shifts to disequilibrium for a significant period of time with the Project in place.

The AEA Susitna Water Quality and Sediment Transport Data Gap Analysis Report (URS 2011) concluded: "Numerical modeling of the sediment transport dynamics would provide a basis for comparing the changes in channel morphology and aquatic habitat associated with the proposed Project and the proposed operations." The Fluvial Geomorphology Modeling below Watana Dam Study addresses the need to develop a sediment transport model of the Susitna River. It was also indicated in the Data Gap Analysis Report (URS 2011) that further quantification of the sediment supply and transport capacity would help identify the sensitivity of the channel morphology (and associated aquatic habitats) to the effects of the proposed Project. The report indicated that information on sediment continuity could provide a basis for evaluating whether the Susitna River below the Chulitna confluence would be at risk of aggradation, and if so, whether the magnitude would alter aquatic habitats and hydraulic connectivity to these habitats. URS (2011) also pointed out that side channels and sloughs are of particular importance to fisheries, and changes to the relationships between flow and stage at which the habitats are accessible could affect the fisheries. These relationships can be affected by not only flow distribution, but also changes in the bed elevations due to sediment transport processes. Other impacts to the sediment transport regime could affect the cleaning of spawning gravels, hyporheic flows through redds, groundwater inflows, and hydraulic connectivity for out-migration to the main channel.

6.6.3. Study Area

The study area for the Fluvial Geomorphology Modeling below Watana Dam is the portion of the Susitna River from Watana Dam (RM 184) downstream to RM 75. This downstream limit has been set to extend the Study into the upper portion of the Lower Susitna River Segment. This limit extends this study nine miles downstream of the lower limit of Geomorphic Reach LR-1. Evaluation of information from the 1980s studies as well as current information indicates that it is unlikely that Project effects on the geomorphology of the Susitna River will extend downstream of Geomorphic Reach LR-1. This is initial assessment is based on the large introduction of sediment and water at the Three Rivers Confluence where both the Chulitna and Talkeetna rivers approximately double the flow in the Susitna River and increases the sediment supply by approximately a factor of five. In response to the increase in sediment supply as well as a reduction in gradient, the form of the Susitna River changes at the Three Rivers Confluence from a single channel to a braided channel. The 15 miles of braided channel is expected to buffer the downstream remaining portion of the Susitna River from the changes in flow regime and sediment supply caused by the Project.

Further review of information developed during the 1980s studies and study efforts initiated in 2012, such as sediment transport analyses, hydrologic analysis, assessment of channel change and comparison of habitat mapping from the 1980s with current 2012 conditions in the Geomorphology Study (Section 6.5), and additional 2012 habitat mapping (Section 9.9) operations modeling and the Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3) will be used to determine the extent to which Project operations influence habitats in the Lower River Segment. An initial assessment of the downstream extent of Project effects will be developed in Q2 2013 in collaboration with the TWG. This assessment will guide the need to extend studies into the Lower River and which geomorphic reaches will subject to Reach and Focus Area level modeling of the fluvial geomorphology of the Susitna River in 2013. Results of the 2013 studies will be used to determine the extent to which Lower Susitna River Segment studies will be adjusted in 2014. Further discussion of the process and schedule for further assessing the downstream limit for the Fluvial Geomorphology Modeling Study, additional information becomes available, is provided in section 6.6.3.2.

The study area includes the entire Middle Susitna River Segment from the Watana Dam site (RM 184) downstream to the Three Rivers Confluence area (RM 98). (Note: Modeling of Devils Canyon will not be performed because this reach is considered too dangerous to perform cross-section and other surveys needed to develop the model. Devils Canyon will be assumed to be a stable, pass-through reach in terms of sediment transport due to the high level of bedrock control and steep gradient present in this reach.)

6.6.3.1. Focus Areas

The bed evolution modeling approach calls for the application of a 1-D bed evolution model to predict the geomorphic response of the Susitna River to the Project for the entire study area (excluding Devils Canyon). To provide a higher level of detail and to model physical processes not adequately represented in a 1-D bed evolution model, a 2-D bed evolution model will be applied in to some or all of the “Focus Areas” (in some instances, it may be appropriate to apply a more detailed 1-D bed evolution model or series of 1-D models than a 2-D bed evolution model). Focus Areas will involve portions of the Susitna River and its floodplain where detailed study efforts will be jointly conducted by several study teams including the Fish and Aquatics Instream Flow (Section 8.5), Riparian Instream Flow (Section 8.6), Geomorphology (Section 6.5), Ice Processes (Section 7.6), Groundwater (Section 7.5), and Characterization and Mapping of Aquatic Habitats (Section 9.9) studies. The Focus Areas will allow for a highly integrated, multidisciplinary effort to be conducted, evaluating potential Project effects for key resource areas across a range of representative sites.

The 2-D models will be used to evaluate the detailed hydraulic and sediment transport characteristics on smaller, more local scales where it is necessary to consider the more complex flow patterns to understand and quantify the issue(s). The 2-D models may be applied to specific Focus Areas, within the selected 1-D modeling study area, that are representative of important habitat conditions and the various geomorphic reach types. If site conditions at a particular Focus Area do not warrant 2-D bed evolution and associated hydraulic modeling, 1-D modeling will be applied at that focus site. The decision on what type of modeling to apply to each Focus Area will be made as part of the site selection process conducted in collaboration with the licensing participants. In addition, the Focus Areas will be chosen jointly by the Fish and Aquatics Instream Flow (Section 8.5), Riparian Instream Flow (Section 8.6), Geomorphology (Section 8.5), Ice Processes (Section 7.6), and Characterization and Mapping of Aquatic Habitats Study (Section 9.9) studies to facilitate maximum integration of available information among the studies. Sites will be chosen such that there is at least one Focus Area for each geomorphic reach (except reaches MR-3 and MR-4 where there are safety concerns associated with Devils Canyon due to the extreme whitewater conditions) and the sites will cover the range of riverine aquatic habitat types. At least one unstable site, likely representative of a braided channel reach, will be included in the Focus Areas. If focus sites involve primary tributary deltas, 2-D modeling will also be considered based on screening that considers the importance to the existing fishery and the potential for adverse project effects. The 2-D hydraulic modeling could include the Three Rivers Confluence area, though application of a 2-D bed evolution model would likely be infeasible. (The distribution of the 2-D sites is based on the study requests submitted by NOAA-NMFS and USFWS on May 31, 2012, and discussions during the June 14, 2012 Water Resources TWG meeting.)

6.6.3.2. Determination of Downstream Study Limit

The downstream extent of the Lower Susitna River Segment modeling effort has been identified as RM 75. The 1-D modeling will be continued downstream to this limit which is approximately nine miles downstream of Sunshine Station (RM 84) (NOAA-NMFS and USFWS requested the 1-D modeling extend to Sunshine Station [study requests dated May 31, 2012]). The downstream extent of the impacts of a dam on the geomorphic and physical habitat characteristics of a river is fundamentally dependent on the rate of downstream tributary mitigation of the reduced flows and sediment loads below the dam (Williams and Wolman 1984; Grant et al. 2003). Under existing conditions, it is clear based on the change in morphology of the Susitna River from a relatively confined single channel to extensively braided (Smith and Smith 1984) that the Chulitna and Talkeetna Rivers, in combination, significantly increase both the volumes of flow and sediment supply to the Susitna River, and thus potentially mitigate the proposed Project impacts on the geomorphology of the river below the confluence. Because of the geologically-controlled valley floor constriction at RM 84, there is extensive sediment storage within the reach between the Susitna-Chulitna-Talkeetna Rivers confluence at RM 97 and RM 84 that is likely to mitigate any sediment impacts below the dam and thus make it unlikely that Project geomorphic and related physical habitat impacts will extend below RM 84 (LR1). Sediment loads estimated by the USGS for Water Year 1985 (October 1984 through September 1985) are presented in Table 6.5-2. This information suggests that the Chulitna River contributes the majority of the sediment load at the Three Rivers Confluence. The relative contributions are 61 percent for the Chulitna River, 25 percent for the Susitna River, and 14 percent for the Talkeetna River. Of note is the relatively small amount of the gravel load contributed by the Susitna River to the Three Rivers Confluence (about 4 percent, compared to 83 percent from the Chulitna River and 13 percent from the Talkeetna River, based on the 1985 data). The bedload component of the total sediment load typically has the most influence on the form and behavior of the river channel. Based on the relatively small contribution of the Susitna River to the bedload downstream from the Three Rivers Confluence and the indication from the 1985 data that the portion of the study reach between the Three Rivers Confluence and Sunshine is a net sediment accumulation zone, it appears that changes in bedload associated with the Project may not have a significant impact on channel form and process in the Lower River.

The hypothesis suggested by the above preliminary conclusion that changes in bedload due to the Project will not affect channel form and process in the Lower River will be carefully tested with an initial assessment of potential Project effects on channel morphology that will be completed in early Q1 of 2013 as part of the Geomorphology Study (Section 6.5.4.6, Reconnaissance-Level Assessment of Project Effects on the Lower and Middle Susitna River Segments). The technical memorandum detailing the results of the Reconnaissance-Level Assessment of Project Effects on the Lower Susitna River Segment will be presented to and reviewed by the agencies and licensing participants as part of the first check-in on the downstream study limit of RM 75. Discussions of the results and conclusions regarding the extent of Project effects on the geomorphology of the Lower Susitna River Segment and the decision on adjusting the downstream study limit for the 2013 efforts will occur at Technical Workgroup Meetings to be held in February and/or March 2013. These discussions will include establishing the criteria for identifying whether Project effects potentially extend downstream of RM 75. It is an objective of the process to finalize the decision on the downstream study limit by the early Q2 of 2013 to allow for planning of the 2013 field season.

The second check-in on the downstream study limit to be provided by the geomorphology studies will be based on the results of the 1-D bed evolution model. If the results of the 1-D modeling effort show differences between the modeled existing and the modeled with-Project conditions that are beyond the range of natural variability below Geomorphic Reach LR-1 (RM 98 to RM 84), the 1-D modeling will be continued farther downstream in the Lower Susitna River Segment in 2014. The criteria for determining what constitutes natural variability will be made in collaboration with the licensing participants. As part of the process, a technical memorandum documenting the 1-D modeling effort and its results will be prepared and distributed for review by the licensing participants in January 2014. A Technical Workgroup meeting(s) will be held in February and/or March 2014. If it is determined that the results of the 1-D modeling warrant extending the study limits farther downstream, the need for adding Focus Areas in the Lower Susitna River Segment will also be determined through consultation with the licensing participants and pertinent study leads at the February and March 2014 Technical Workgroup meetings. Table 6.6-1 provides a summary of the steps and dates involved in the process that will be used to assess and if necessary, adjust the downstream study limit for the Fluvial Geomorphology Modeling Study.

The results of the Open-water Flow Routing Model (see Section 8.5.4.3), which is scheduled to be completed in Q1 2013, as well as results of the operations model (Section 8.5.4.3.2), are an important part of the determination of the downstream study extent for a variety of resource areas. The results of the Open-water Flow Routing Model completed in Q1 2013 will be used to determine whether, and the extent to which, Project operations related to load-following as well as seasonal flow changes occur within a section of the Lower Susitna River Segment that includes all of Geomorphic Reach L-1 and a portion of L-2 (down to RM 75). Thus, an initial assessment of the downstream extent of Project effects will be developed in Q1 2013 with review and input of the TWG. This assessment will include a review of information developed during the 1980s studies and study efforts initiated in 2012, such as sediment transport (Section 6.5), habitat mapping (Sections 6.5 and 9.9), operations modeling (Section 8.5.4.3.2), and the Mainstem Open-water Flow Routing Model (Section 8.5.4.3). The assessment and the following six criteria will be used to evaluate the need to extend studies into the Lower River Segment, and if studies are needed, will identify which geomorphic reaches require instream flow analysis in 2013. The criteria include (1) Magnitude of daily stage change due to load-following operations relative to the range of variability for a given location and time under existing conditions (i.e., unregulated flows); (2) Magnitude of monthly and seasonal stage change under Project operations relative to the range of variability under unregulated flow conditions; (3) Changes in surface area (as estimated from relationships derived from LiDAR and comparative evaluations of habitat unit area depicted in aerial digital imagery under different flow conditions) due to Project operations; (4) Anticipated changes in flow and stage to Lower River off-channel habitats; (5) Anticipated Project effects resulting from changes in flow, stage and surface area on habitat use and function, and fish distribution (based on historical and current information concerning fish distribution and use) by geomorphic reaches in the Lower River Segment; and (6) Initial assessment of potential changes in channel morphology of the Lower River (Section 6.5.4.6) based on Project-related changes to hydrology and sediment supply in the Lower River. Results of the 2013 studies will then be used to determine the extent to which Lower River Segment studies should be adjusted in 2014.

It is noted that a variety of resource areas require determination of their downstream study limits. Although both Middle and Lower Susitna River segments are under consideration as part of the IFS, the majority of detailed study elements for the IFS described in the RSP (Sections 8.5 and 8.6) are concentrated within the Middle River Segment. This is because Project operations related to load-following and variable flow regulation will likely have the greatest potential effects on this segment of the river. These effects tend to attenuate in a downstream direction as channel morphologies change, and flows change due to tributary inflow and flow accretion. The diversity of habitat types and the information from previous and current studies that indicate substantial fish use of a number of slough and side channel complexes within this segment also support the need to develop a strong understanding of habitat–flow response relationships in the Middle Susitna River Segment. The determination for downstream study limits may also depend on the outcome of 2013 efforts being conducted for the Water Quality Modeling Study (Section 5.6), Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3), and the winter flow routing model (Section 7.6). Whether there is need to integrate Fluvial Geomorphology Modeling Study results with certain studies also depends on the final downstream limit for the modeling effort. Specifically, the Eulachon Study (Section 9.16) is limited to the downstream-most portions of the Lower Susitna River Segment and will not require detailed sediment transport modeling input from the Fluvial Geomorphology Modeling Study if the modeling effort is not extended downstream of RM 75.

6.6.4. Study Methods

The Fluvial Geomorphology Modeling below Watana Dam is divided into three study components:

- Bed Evolution Model Development, Coordination, and Calibration
- Model Existing and with-Project Conditions
- Coordination on Model Output

Each of these components is explained further in the following subsections.

6.6.4.1. Study Component: Bed Evolution Model Development, Coordination, and Calibration

The overall goal of the Bed Evolution Model Development, Coordination, and Calibration study component is to develop a model that can simulate channel formation processes in the Susitna River downstream of Watana Dam.

6.6.4.1.1. Existing Information and Need for Additional Information

Modeling of hydraulics of the Susitna River below the proposed Project, a necessary step in developing a sediment transport model, was performed in the 1980s. One-dimensional HEC-2 hydraulic models were developed in the 1980s to support the calculation of water-surface profiles and channel hydraulics (Acres 1983). However, the 1980s effort did not include sediment transport modeling. Both 1-D and 2-D sediment transport models are required to characterize the bed evolution for both the existing and with-Project conditions in the Susitna River. This study component involves selection and development of the sediment transport models.

6.6.4.1.2. Methods

The Bed Evolution Model Development, Coordination, and Calibration study component is divided into three tasks:

- Development of Bed Evolution Modeling Approach and Model
- Coordination with other Studies on Processes Modeled
- Calibration/Validation of the Model

6.6.4.1.2.1. Development of Bed Evolution Model Approach and Model Selection

Development of the bed evolution model for a dynamic system such as the Susitna River is a complex undertaking that requires considerable investigation and coordination. The work in the Middle and Lower Susitna River Segments contained in the Geomorphology Study provides a considerable part of the required investigation. Based on the study results and input from the Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3), Fish and Aquatics Instream Flow (Section 8.5), Riparian Instream Flow (Section 8.6), Ice Processes (Section 7.6), and Characterization and Mapping of Aquatic Habitats Study (Section 9.9) studies, models will be developed that represent the physical processes that control the dynamic nature of the Susitna River, and that will provide other studies with the required information on the potential changes in the channel and floodplain for their analyses.

Some of the important steps in the development of the modeling approach and model are as follows:

- Review and understand available data.
- Develop an understanding of the dominant physical processes and governing physical conditions in the study reach.
- Coordinate with other studies to understand their perspective on system dynamics, and the physical features and processes that are important to their studies.
- Identify an overall modeling approach that is consistent with the study goals, the constraints on information that is currently available or can practically be obtained, and the needs of the other studies.
- Identify a modeling approach that is consistent with the spatial and temporal scale of the area to be investigated.
- Determine the spatial limits of the modeling effort.
- Determine the time scales for the various models.
- Review potential models and select a model(s) that meets the previously-determined needs and conditions.
- Identify data needs and data gaps for the specific model and study area being investigated.
- Collect the required data to fill data gaps.
- Develop the model input.
- Identify information to be used to calibrate and validate the model.
- Perform initial runs and check basic information such as continuity for water and sediment, hydraulic conditions, magnitude of sediment transport, and flow distributions.
- Collaborate with other studies on initial model results.
- Refine model inputs.
- Perform calibration and validation efforts, to include comparison of modeled water-surface elevations, in-channel hydraulic conditions (e.g., velocity and depth), sediment transport rates, and aggradation/degradation rates with available measured data.
- Perform model runs for existing conditions to provide a baseline for comparison of with-Project scenarios.
- Work with other studies to develop scenarios to evaluate the potential Project effects, and apply the model to those scenarios.
- Coordinate with other studies to evaluate and define the appropriate format for presentation of the model results.
- Develop and run additional scenarios, as necessary, based on results from the initial scenarios and identified Project needs.

The following subsections outline the identified issues to be considered and summarize the development of the modeling approach, the model selection, and the model development.

Issues to be Considered: To develop the modeling approach, specific issues that need to be addressed have been identified. These specific issues have been further differentiated into reach-scale and local-scale issues because the scale influences the proposed approach.

<u>Reach-Scale Issues:</u> 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 the following:

- Historical changes in the system and the existing status with respect to dynamic equilibrium.
- 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 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 bed profile, channel dimensions, and potentially hydraulic roughness.

<u>Local-Scale Issues:</u> 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 specific geomorphic and habitat features. Local-scale issues are addressed using a more detailed assessment over a finer Focus Area scale; however, these analyses must draw from and build upon the understanding and characterization of the system behavior as determined at the reach scale. Local-scale issues include the following:

- 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 off-channel habitat units.
- Changes in upstream connectivity (breaching) of off-channel habitats due to alteration of flow regime and possibly channel aggradation/degradation. These changes may induce further changes in the morphology of off-channel habitats, including the following:

  - Potential for accumulation of sediments at the mouth.
  - Potential for accumulation of fines supplied during backwater connection with the mainstem.
  - Potential for changes in riparian vegetation that could alter the width of off-channel 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, as discussed below.

Tributary confluences are areas of interest for determining the potential Project effects on sediment transport and morphology. Modeling of tributary deltas is discussed as a topic separate from the mainstem.

<u>Synthesis of Reach-Scale and Local-Scale Analyses:</u> The final step in the effort will be the synthesis of the reach-scale and local-scale analyses to identify potential Project-induced changes in the relative occurrence of aquatic habitat types and associated surface area versus flow relationships. In addition to the results of the hydraulic and sediment transport modeling, this synthesis will require application of fluvial geomorphic relationships to develop a comprehensive and defensible assessment of potential Project effects. This type of integrated analysis has been performed in the past by the study team on several projects including: instream flow, habitat, and recreation flow assessments to support relicensing of Slab Creek Dam in California; a broad range of integrated geomorphic assessments and modeling to assist the Platte River Recovery Implementation Program in Central Nebraska; and ongoing work to support the California Department of Water Resources and Bureau of Reclamation to design restoration measures for the San Joaquin River in the Central Valley of California downstream of Friant Dam.

Development of Modeling Approach: The proposed modeling approach considers the need to address both reach-scale and local-scale assessments 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 is proposed. Considering the broad physical expanse of the Susitna River system, the general hydraulic and sediment transport characteristics of the various sub-reaches that make up the overall study area will be evaluated using 1-D computer models and/or established hydraulic relationships. The 2-D models will be used to evaluate the detailed hydraulic and sediment transport characteristics on smaller, more local scales where it is necessary to consider the more complex flow patterns to understand and quantify the issues. The 2-D models will be applied to specific Focus Areas that are representative of important habitat conditions—the various channel classification types and selected primary tributaries. These sites will be chosen in coordination with the licensing participants and the Fish and Aquatics Instream Flow (Section 8.5), Riparian Instream Flow (Section 8.6), Ice Processes (Section 7.6), and Characterization and Mapping of Aquatic Habitats (Section 9.9) studies to facilitate maximum integration of available information between the studies.

The proposed approach to integrating 1-D modeling at the reach-scale and 2-D modeling at the local-scale will provide the following advantages:

- 1-D modeling will allow for efficient assessment of the hydraulic conditions and sediment transport balance over the length of the study reach downstream of Watana Dam.
- The 1-D model uses cross-sectional data that are being obtained as part of the Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3). (Note that some supplemental cross-sections may be required for the 1-D sediment transport model.)
- The 1-D model will provide the boundary conditions for the 2-D model, including starting water-surface elevations and upstream sediment supply.
- 2-D modeling applied at the Focus Areas that are also chosen for the Ice Processes (Section 7.6) and Riparian Instream Flow (Section 8.6) 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 for this study.
- 2-D modeling at the Focus Area will provide an understanding of the hydraulic conditions and sediment transport processes that contribute to formation of individual habitat types.
- 2-D modeling provides a much more detailed and accurate representation of the complex hydraulic interaction between the main channel and the off-channel habitats than is possible with a 1-D model.

Model Selection: 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 project objective(s); (2) the class, type, and regime of flows that are expected to be modeled; and (3) the availability of necessary data for model development and calibration. While 2-D modeling would provide the most comprehensive assessment of hydraulic and sediment transport conditions in the study reach, the extent of required data, effort required for model development, and computational time required for execution to model the entire system make this impractical. Considering the very broad physical expanse of the overall Susitna River system, a one-dimensional (1-D) computer model and/or engineering relationships that can be applied in a spreadsheet application is the most practical approach to modeling overall system behavior at the scale of the study reach. 2-D modeling will then be used for evaluating the detailed hydraulic and sediment-transport characteristics that control the complex geomorphic features and habitat at the local scale. A variety of candidate models will be evaluated for application on the Susitna River. Potential candidate models for the 1-D and 2-D portions of the study are discussed below.

<u>General Discussion of 1-D Models:</u> 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-section control volume (i.e., the sub-channel concept), and the shape of the cross-section is adjusted accordingly. Because the sediment-transport calculations are performed by size fraction, the models are capable of simulating bed material sorting and armoring. The computations proceed from time-step to time-step, using the updated cross-sectional and bed material gradations from the previous time-step.

1-D sediment-transport models should not be applied to situations where 2- and 3-dimensional flow conditions control the sediment-transport characteristics because they do not consider secondary currents, transverse movement and variation, turbulence, and lateral diffusion; thus, the models cannot simulate such phenomena as point bar formation, pool-riffle formation, and planform changes such as river meandering or local bank erosion. 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 also not directly considered. 1-D models are, however, useful in evaluating the general sediment-transport characteristics and overall sediment balance of a given reach, and they are also useful in providing boundary conditions for localized 2-D models.

Potential 1-D Models: One-dimensional models that are being considered for this study include the U.S. Army Corps of Engineers HEC-RAS (version 4.1; USACE 2010a), the U.S. Bureau of Reclamation's SRH-1D (version 2.8; Huang and Greimann 2011), DHI's MIKE 11 (version 2011; DHI 2011a), and Mobile Boundary Hydraulics' HEC-6T (version 5.13.22_08; MBH 2008). Each of these models, including potential benefits and limitations, is summarized in the following sections.

- **HEC-RAS:** HEC-RAS, version 4.1.0 (USACE 2010a) is a publicly available software package developed by the U.S. Army Corps of Engineers (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.

- **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 under a broad range of conditions outside the U.S. Bureau of Reclamation and the lack of graphical user interface that complicates data input and manipulation and display of output.
- **MIKE 11:** Danish Hydraulic Institute's (DHI) MIKE 11 is a proprietary 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 the reporting and presentation capabilities. Disadvantages primarily stem from the proprietary nature of this model and high cost of the software license.
- **HEC-6T:** HEC-6T was written by William A. Thomas, former Chief of the Research Branch at the USACE Hydrologic Engineering Center (HEC). Mr. Thomas planned, designed, wrote, and applied the publically available version of HEC-6; HEC-6T is a proprietary 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. This software is relatively inexpensive; the fact that it is proprietary is not a significant limitation.

<u>One-Dimensional Model Selection Process and Initial Evaluation:</u> Based on the information provided above and experience with these models, the Geomorphology Study team tentatively proposes to use HEC-6T for the reach-scale sediment transport analysis. This proposal is based on confidence gained that HEC-6T is capable of effectively and efficiently modeling the processes that are important for this scale of geomorphic analysis. The selection of the 1-D (as well as the 2-D) model will be coordinated with the other pertinent studies and the licensing participants. As part of the coordination process, a technical memorandum titled *Fluvial Geomorphology Modeling* (Tetra Tech 2012) was posted on the AEA website in May 2012. Specific model-selection criteria are identified in Table 6.6-2 along with an evaluation of each candidate model relative to the criteria.

<u>Potential 2-D Models:</u> Potential 2-D models that are being considered for this study include the U.S. Bureau of Reclamation's SRH2-D version 3 (Lai 2008; Greimann and Lai 2008), USACE's Adaptive Hydraulics ADH version 3.3 (USACE 2010b), the U.S. Geological Survey's (USGS)

MD_SWMS suite (McDonald et al. 2005; Nelson et al. 2010), DHI's MIKE 21 version 2011 (DHI 2011b), and the River2D modeling suite (University of Alberta 2002; University of British Columbia 2009).

- **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 unstructured arbitrarily-shaped 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. Preliminary contact with the model developers indicates that permission would be granted for use in this study. This 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. 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.
- **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, 3D 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. 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 model is publically available.
- **MD_SWMS Modeling Suite (FaSTMECH/SToRM):** The USGS Multi-Dimensional Surface-Water Modeling System (MD_SWMS; 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 iRIC, 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 (GUI) that allows the modeler to build and edit data sets, and provides a framework that links the GUI with a range of modeling applications. The GUI 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 include FaSTMECH (Flow and Sediment Transport with Morphologic Evolution of Channels) and SToRM (System for Transport and River Modeling) that were 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 appears to be 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 structured, 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 (pers. Comm., Jonathon Nelson, USGS, June 18, 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.

- **MIKE 21:** Developed by DHI, MIKE 21 is a proprietary 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 GUI 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 primary limitation to MIKE-21 is that it is proprietary software and is relatively expensive compared to other available software.

- **River2D Modeling Suite:** River2D is a two-dimensional, depth-averaged finite-element hydrodynamic model developed at the University of Alberta and is publically available from the university. The River2D suite consists of four programs: R2D_Mesh, R2D_Bed, River2D, and R2D_Ice, each of which contains a GUI. 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 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. 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).

<u>Two-Dimensional Model Selection Process and Initial Evaluation:</u> The selection of the 2-D model will be coordinated with the other pertinent studies and the licensing participants. Specific model selection criteria are identified in Table 6.6-3, along with an evaluation of each candidate model relative to the criteria.

Model Development: The manner in which the models are developed will depend on the model software programs that are ultimately selected for use. Regardless of the selected modeling software, the models will be developed in accordance with the software developers' guidance and recommendations.

6.6.4.1.2.2. Coordination with other Studies

As previously discussed, it is envisioned that a combination of 1-D and 2-D sediment transport models will be used to assess potential changes in the aggradation/degradation behavior and related processes in the Susitna River downstream from Watana Dam due to the potential size and complexity of the system to be modeled. As a result, the current vision for the modeling approach is to use a reach-scale 1-D model to evaluate the potential effects of the Project on the overall aggradation/degradation behavior of the study reach, and then use a series of representative, local-scale 2-D models at key locations where the dynamic behavior of the channel and habitat cannot be adequately assessed using the 1-D modeling approach. The 1-D model will provide boundary conditions for the individual 2-D models. Because of this modeling approach, it will be very important to coordinate with other studies because results from the detailed 2-D model will only be available at specified locations that will be selected from the key locations (e.g. Focus Areas) identified by the Fish and Aquatics Instream Flow (Section 8.5), Riparian Instream Flow (Section 8.6), Ice Processes (Section 7.6), and Characterization and Mapping of Aquatic Habitats (Section 9.9) study teams and in consultation with the licensing participants. Ten proposed Focus Areas have been identified, with each representing a length of river on the order of one to several miles that includes a representation of each geomorphic reach (excluding Devils Canyon) and one unstable reach (likely a braided reach). The 2-D modeling will be applied at the vast majority if not all of the Focus Areas (selection of modeling approach at each Focus Area will be determined during the Q1 2013 TWG meetings concerning the confirmation or adjustment of the proposed Focus Areas). The Focus Areas also include selected primary tributary confluences. Coordination among the studies will also be necessary to ensure efficient collection of field data, because it is likely that a considerable amount of the data necessary for development and calibration of the 1-D and 2-D models will either be required for the other studies, or will be easily obtained along with data that will be required for those studies. For example, the Fish and Aquatics Instream Flow Study (Section 8.5) will obtain velocity magnitude and direction, flow depth, and discharge measurements, the data from which would be very useful for calibration of the 2-D models. It may also be possible to obtain subaqueous bed material data for the modeling by lowering a laser/video through the ice thickness transect holes that will be bored as part of the Ice Study when turbidity levels are expected to be low.

The temporal resolution for model execution will be selected to ensure model stability and proper representation of important variability in flow conditions (e.g., daily fluctuations associated with load-following). The overall time-scale for model execution will also be an important factor. Because a key purpose of the 1-D model will be to assess the long-term sediment balance in the study reach, this model will likely be executed for a continuous period of 50 years to represent the length of a FERC license. On the other hand, due to the computational requirements of the 2-D model, much shorter time-periods will be evaluated.

Close coordination between the study leads and key study team members will be required throughout the model development process. It is important that all the study teams have an understanding of the capabilities and limitations of the models, the information that will be provided by the model, and the selection of the Focus Areas. This will be accomplished through frequent informal communication and more formal Technical Workgroup meetings. The study leads and other key participants will spend time together in the field to develop a practical understanding of each study's needs.

An important aspect of coordination between other studies is to establish which models will be the source for what type of information. There are a number of hydraulic models being applied to various aspects of this study. In order to avoid inconsistencies in reported information such as flows and stage, the model that will take precedence for reporting of information has been established. Table 6.6-4 provides the model precedence as it has currently been established. This table will be distributed to all study leads. In the event that the precedence established in the table changes, a revised table will be provided to all study leads.

Due to application of several hydraulic models, there will be opportunities to perform cross-checking between models. For instance, water surface elevations and stage can be checked between the mainstem open-water flow routing model, 1-D bed evolution model, and the water quality model. If there are significant discrepancies, then parameters within the models will be checked and adjusted if necessary. In some case, the discrepancies may be explained by the formulation of the models or the resolution of the data used by each model.

6.6.4.1.2.3. Model Resolution and Mesh Size Considerations

Selection of the appropriate mesh size for the 2-D bed evolution model is dictated by several factors including the following:

1. The size and complexity of the site features of primary interest.
2. The overall area of the site.
3. The desired resolution of output information such as velocity, depth, and bed material gradation.

Factors that can also influence mesh resolution, subject to meeting the needs indicated by the above critical factors include:

4. Limitations on the maximum number of elements that the model can simulate.
5. Model execution time.

In general, the mesh resolution in any particular portion of the model should be consistent with the dimension of the scale of the processes that are being analyzed (Pasternack, 2011; Horritt, et al, 2006). For example, bed evolution modeling to predict aggradation/degradation in the mainstem can typically be performed using a relatively coarse mesh because the topographic and hydraulic variability is less pronounced that in smaller habitat features where a relatively high resolution mesh is necessary to describe the hydraulic variability that is important to habitat quality and processes. The need to provide a high level of spatial resolution to satisfy items 1, 2, and 3 to develop and accurate model can push the limitations imposed by items 4 and 5. One approach to avoid trade-offs between model complexity and physical limitations of the model is to use a variable mesh (also referred to as flexible mesh) that allows a finer mesh to be applied in areas where either the information desired or the condition being modeled requires higher spatial resolution (i.e., a finer mesh). The 2-D models being considered for this study allow the use of a variable mesh. Figure 6.6-1 and Figure 6.6-2 provide examples of a relatively coarse and relatively fine mesh applied to the potential Focus Area at Whiskers Slough in the Middle Susitna River Segment Geomorphic Reach MR-8.

Areas that will require finer mesh sizes include the following:

- Side sloughs
- Upland sloughs
- Smaller side channels
- Spawning areas

- Tributary mouths
- Locations where circulation is of interest such as eddies between the main channel and backwater areas
- Other specific habitat features of interest

Areas where lower spatial resolution may be appropriate include the following:

- Main channel
- Floodplains
- Large side channels

In the areas of higher resolution such as side sloughs, spawning areas, and critical eddies, the mesh size will be on the order of several feet to 25 feet. In areas where lower spatial resolution is acceptable, the mesh size may be in the range of 25 to 100 feet.

At some Focus Areas, two model meshes may need to be developed. In these cases, a higher-resolution mesh will be used to evaluate detailed hydraulic conditions for use in assessing factors such as mobilization of spawning gravels in the side sloughs and side channels where channel widths and depths are small relative to the main channel and connections between side channels and side sloughs and at the tributary mouths where circulation plays a key role. Where necessary due to model size limitations, the coarser mesh will be used for the bed evolution model because issues related to bed evolution associated with sediment transport processes can be adequately addressed at a coarser scale.

6.6.4.1.2.4. Focus Area Selection

The use of "Focus Areas" to conduct concentrated interdisciplinary studies at selected areas within the study area was introduced in Section 6.6.3.1. Such areas represent specific sections of the river that will be investigated across resource disciplines and will provide for an overall understanding of interrelationships of river flow dynamics on the physical, chemical, and biological factors that influence fish habitat. Focus Areas will involve portions of the Susitna River and its floodplain where detailed study efforts will be jointly conducted by the Fish and Aquatics Instream Flow (Section 8.5), Riparian Instream Flow (Section 8.6), Geomorphology (Section 6.5), Ice Processes (Section 7.6), Groundwater (Section 7.5), and Characterization and Mapping of Aquatic Habitats (Section 9.9) studies. The Focus Areas will allow for a highly integrated, multidisciplinary effort to be conducted evaluating potential Project effects on key resource areas across a range of representative sites.

The entire process for identifying candidate Focus Areas and selecting the specific portions of the study area to conduct the Focus Area studies is detailed in Section 8.5.4.2 of the Fish and Aquatics Instream Flow Study. This section describes the involvement of the geomorphology studies in the selection of the proposed Focus Areas.

The Geomorphology Study has provided input on the selection of proposed Focus Areas. The geomorphic reach classification system and resulting reach delineation were utilized in the selection process. A total of 10 proposed Focus Areas were selected. A primary criterion was to select at least one Focus Area for each geomorphic reach (except reaches MR-3 and MR-4 where there are safety concerns associated with Devils Canyon due to the extreme whitewater conditions). Since several of the geomorphic reach types are represented by multiple reaches in the study area, there is duplication of reach types within the candidate sites. Table 6.6-5 lists the proposed Focus Areas, the upstream and downstream limits, the associated geomorphic reach, and the geomorphic reach type. The proposed Focus Areas represent five areas within the SC2 reach type, four within the SC3 reach type, and one within the transitional MC1/SC2 reach type. The locations of the Middle Susitna River Segment proposed Focus Areas are shown on Figure 6.6-3. More detailed maps that show individual proposed Focus Areas on recent (2011) color aerial photographs are provided in the FA-IFS (Section 8.5.4.2). The areas selected were those deemed representative of the major features in the geomorphic reach and included mainstem habitat types of known biological significance (i.e., where fish have been observed based on previous and/or contemporary studies), as well as some locations (e.g., Slough 17) where previous sampling revealed few/no fish. The proposed Focus Areas include representative side channels, side sloughs, upland sloughs, and tributary mouths.

The Geomorphology Study also helped establish the upstream and downstream limits of the focus study areas. The upstream and downstream boundaries as well as the lateral extents of the Focus Areas have been chosen so that appropriate boundary conditions, upstream inflow and downstream water surface elevation on the main channel, as well as the off-channel features, can be established for the hydraulic and bed evolution modeling. Considerations included encompassing potential inflow and outflow points to preserve the mass balance and minimize difficulties and assumptions associated with inflow points. Potential upstream connections for side channels, side sloughs, and upland sloughs were also identified and included in the modeling domain. The upstream and downstream limits on the main channel were identified to either provide relatively uniform flow conditions or sufficient distance upstream and downstream from areas of interest so that flow conditions in the area of interest are not significantly affected by the flow directions at the boundary.

The Geomorphology Study is also collaborating on the selection of the modeling approach for each Focus Area. In some instances, it may be appropriate to utilize a 1-D model rather than a 2-D model. The 1-D model could be appropriate when there are not numerous flow splits and junctions, flow paths are primarily linear, and specific habitat features do not have the streamwise and lateral resolution of the 2-D model. The determination of modeling approach will be made in Q1 2013 as part of the TWG meetings involving confirmation or adjustment of the Focus Areas selected.

6.6.4.1.2.5. Model Calibration and Validation

Calibration and validation of the models will be a stepwise process. First, the hydraulic components of the models will be calibrated by adjusting roughness and loss coefficients to achieve reasonable agreement between measured and modeled water-surface elevations, and to measured and modeled velocities. Discharges along the study reach will be obtained from the three USGS gages. These gages will also provide a continuous record of stages and water-surface elevations at the gage locations. These data will be supplemented with stage data from at least 10 pressure-transducer type water-level loggers that have been or will be installed as part of various studies being conducted in the Middle and Lower Susitna River Segments. Water-levels measured during the cross-section and bathymetric surveys will also be used to calibrate the models. In addition to water-surface elevations, the depths and velocities predicted by the 2-D model should be compared with measured data from ADCP measurements at the Focus Areas.

Depending on the range of conditions and spatial coverage of the depth and velocity data from the Fish and Aquatics Instream Flow Study, additional data may be needed for calibration specifically for this study. Specific calibration criteria will be established for both the 1-D and 2-D models during the model selection phase. The 2-D water surface elevations will also be compared against water surface elevations generated by the 1-D model and the Mainstem (Open-water) Flow Routing Model to ensure that the models are producing consistent results.

Calibration of the velocities and depth are critical to the FA-IFS. Calibration of the flow depths is achieved directly through calibration of the water surface elevations. Calibration of the local flow velocities will be achieved by comparing predicted velocities from the 2-D models with measured velocities at the key locations from the field data collection, including ADCP and current meter data. PHABSIM studies have typically required measurements at at least three flows levels (low, medium, and high discharges). Calibration activities for this study will include all available flow data. Pasternack (2011) provides guidelines for evaluating 2-D model performance with respect to the velocity magnitude. These guidelines suggest that the calibration is reasonable when the following criteria are met:

- Variance (r^2) between the predicted and corresponding measured values is in the range of 0.4 to 0.8.
- Median and mean error of individual points is in the range of 15 to 30 percent. Pasternak (2011) also notes that the relative error for low velocity conditions is typically much greater than for normal to high velocity conditions.

The sediment transport portions of both the 1-D and 2-D model will be first calibrated based on the available measured sediment transport data and the associated sediment rating curves for both bedload and suspended load. For coarse-grained rivers such as the Susitna River, the bed material load transport is dominant with respect to channel forming processes; however, the fine-grained suspended load (i.e., wash load) may be important in evaluating the changes to other features including turbidity, instream habitat, side channels, sloughs and floodplains. The sediment transport model will also be validated, to the extent that available information allows, by comparing modeled and measured (or if necessary, qualitatively observed) changes in bed elevations and bed material gradations from the Geomorphology Study, by making model runs for specific time-periods. This effort will include comparison of 1980s and current 2012 transect data if sufficient data are available.

6.6.4.1.2.6. Tributary Delta Modeling

Tributary confluences are areas of interest for determining the potential Project effects on sediment transport and morphology. Alteration of the mainstem flow regime has the potential to change the elevation at which tributary sediments are initially deposited because the mainstem may be at a different stage when the tributaries are at peak flow. Additionally, the ability to mobilize and transport bedload delivered by tributaries may also be altered. Changes in the configuration of sediments deposited at the tributary confluences can affect the ability of fish to access the tributaries and the extent of clear water habitat associated with some tributary confluences. Modeling sediment transport and deposition processes at select tributary mouths will therefore be necessary.

The tributaries to be modeled will be determined in conjunction with the instream flow and fish and aquatic resources studies and the licensing participants based on fish use and the potential for Project effects. The Geomorphology Study will model a subset of tributary confluences with the Susitna River that represent the range of conditions among all the tributaries. The selection of primary tributary deltas for 2-D modeling will be based on screening that considers the importance of the existing fishery and potential adverse Project effects. Based on the discussion at the June 14, 2012 Water Resources TWG meeting, it is possible that the effort will include the Three Rivers Confluence area (Susitna, Talkeetna, and Chulitna confluence), though bed evolution modeling in this area may not be feasible. The selection of the tributary delta sites for 2-D modeling will be coordinated with the other pertinent studies and in consultation with the licensing participants.

It is currently proposed that a model will be created for the tributary deltas that uses estimated bedload transport from the tributary, the topography and the bathymetry of the confluence, measurements of the characteristics of the tributary deposits, and the ability of the mainstem in the area of the confluence to mobilize and transport those deposits. The approach will include field observations to characterize the sediment transport regime that will be used to identify appropriate methods of estimating bedload transport. Surveys of tributary channel geometry and sampling of bed material gradations will be coupled with an appropriate bed material transport function to calculate sediment yield rating curves. Hydrology synthesized for ungaged tributaries will be needed from other studies for each of the selected tributaries for this purpose as well as for the purpose of the flow routing models (summer ice-free model and winter ice-covered model). The yield and topography in the area of the expected delta, along with the ability of the mainstem to mobilize and transport the bed material, will provide a basis for characterizing how Project operations would affect the formation of tributary deposits. At this time, it is envisioned that a relatively detailed 1-D hydraulic model of the mainstem in the vicinity of each tributary will provide sufficient hydraulic information to evaluate the potential for, and likely extent of, additional growth of the tributary deposits into the mainstem. For complex tributary confluences that are of particular interest to the Fish and Aquatics Instream Flow Study, local-scale 2-D models can be developed and applied to support the analysis.

6.6.4.1.2.7. Large Woody Debris Modeling

The assessment of the Project effects on the large woody debris processes within the Middle Susitna River will be assisted by the Fluvial Geomorphology Modeling Study, recognizing that bank erosion is a key process in large woody debris recruitment. Both the 1-D hydraulic and 2-D model results will be used to estimate changes in bank erosion rates by using the model output, along with the long-term pre- and post-Project flow records and measurements of the channel planform, to estimate pre- and post-Project Bank Energy Indices (BEI) (Mussetter et al. 1995; Mussetter and Harvey 1996). The BEI values for relevant periods will be correlated with historic bank erosion rates determined from the available aerial photography. Anticipated changes in the erosion rates, and thus, this aspect of large woody debris recruitment, under Project conditions will then be estimated based on the correlation results and the Project-conditions BEI values. A similar approach will be used to evaluate large woody debris recruitment at the local scale at the Focus Areas using output from the 2-D model where various levels of large woody debris are present based on the localized hydraulic and scour conditions. This information will be provided to the Fish and Aquatics Instream Flow Study for quantification of the change in habitat resulting from Project-induced changes in large woody debris. Review of the overall role of large woody debris in formation and maintenance of the geomorphic features and the potential impacts of changes in the large woody debris supply on these features will be identified using model results and the analysis described in Section 6.5.4.9.

In developing the change in large woody debris supply under the post-Project condition, the primary questions are the sources of the large woody debris, the current rate of large woody debris loading to the river, and the impact of the Project on the large woody debris loading rate. The existing supply of large woody debris from recruitment within the Middle Susitna River Segment and from upstream of the Watana Dam site (RM 184) will be estimated in the Geomorphology Study (Section 6.5.4.9). The Project will change the upstream supply of large woody debris by retention in the reservoir. Project operations may also change large woody debris recruitment from bank erosion. Changes in bank erosion can be addressed by an assessment of the pre- and post-Project rates of erosion of vegetated geomorphic surfaces (vegetated islands and floodplain segments) that deliver large woody debris to the river. The rates of bank erosion and thus large woody debris loading can be ascertained by comparison of time sequential aerial photography, the turnover analysis in the Geomorphology Study (Section 6.5.4.4) in conjunction with an estimate of the density of the vegetation (volume and sizes of the trees) growing on the geomorphic surfaces from the Riparian Instream Flow Study (Section 8.6) and the Riparian Botanical Resources Study (Section11.6).

The impacts of the Project on the rates of bank erosion and large woody debris recruitment can be semi-quantitatively addressed with a comparison of pre- and post-Project Bank Erosion Index (BEI) (Mussetter et al. 1995; Mussetter and Harvey 1996) values at specific sites along the river where the output from both 1-D and 2-D models can be used to compute the pre- and post-Project BEI values. The BEI is an index of the total energy applied to the banks at specific locations, and is computed based on the hydraulic characteristics of the channel, the channel planform, and the magnitude and duration of flows (Mussetter and Harvey 1996). The BEI values will be calibrated with site-specific bank erosion rates determined from the aerial photography-based turnover analysis. The pre-Project rate of large woody debris recruitment from bank erosion along the mainstem Susitna River will be scaled using the ratio of the pre- and Post-Project BEI based erosion rate estimates to develop the post-Project rate of large woody debris recruitment. These data will be incorporated into the analysis of pre- and post-Project large woody debris loading from all mechanisms as described in Section 6.5.4.9.

A detailed survey of large woody debris within the Focus Areas will be also performed as part of the fieldwork in 2013 as described in Section 6.5.4.9. This information will be used to incorporate large woody debris within the 2-D bed evolution model mesh. This will permit determination of the influence on flow patterns, local hydraulics, and scour that accumulations of large woody debris have. At selected Focus Areas, adjustment of the amount of large woody debris at the site will be performed and the 2-D bed evolution model executed again for a range of hydrologic conditions. The resulting comparison of flow patterns, local hydraulics, and scour between the various large woody debris densities will assist in determining the potential influences the change in density of large woody debris at the site may have on the geomorphic features associated with the aquatic habitats. These results will be provided to the Fish and Aquatics Instream Flow Study (Section 8.5) to develop estimated changes in the aquatic habitat indicators.

6.6.4.1.2.8. Wintertime Modeling and Load-Following Operations

It is currently not proposed to execute the sediment transport models—either 1-D or 2-D—during the winter period when flows are low and the bed material is not mobilized. However, if the Characterization of Bed Material Mobility component of the Geomorphology Study indicates that the bed material is mobilized during winter-time flows, including higher than existing flows due to load-following, the sediment transport modeling will be extended to include the winter flow period. One winter operational issue of potential importance is the resuspension of fine sediments during load-following that could result in increased turbidity during the early portion of the otherwise clear water conditions during the winter months. To address this, an effort to model the resuspension of fines can be undertaken for the 1-D model and the 2-D model for the early portion of the winter period. This effort would include investigation of a controlled release to flush the fines from the system prior to commencement of winter load-following operations. Decisions on continuing the 1-D and 2-D modeling into the winter period will be made in consultation with the licensing participants and in coordination with the Fish and Aquatics Instream Flow (Section 8.5), Instream Riparian Flow (Section 8.6), Ice Processes (Section 7.6), and Characterization and Mapping of Aquatic Habitats (Section 9.9) studies. (This section on Wintertime Modeling and Load-Following Operations was added based on a study comment supplied by NOAA-NMFS in its May 31, 2012, study request; the Natural Resources Defense Council May 30, 2012, study request; and discussions on load-following and turbidity during the June 14, 2012 Water Resources TWG meeting.

6.6.4.1.2.9. Field Data Collection Efforts

The field data collection effort to support both the Geomorphology Study and the Fluvial Geomorphology Modeling Study are presented in this section. The majority of this effort will be conducted in the 2013 field season. If the subsequent need for additional data is identified during the model development process, more Focus Areas are added, or the downstream limit of the 1-D model is extended, additional data will be collected during the 2014 field season.

Much of the data collection performed in this task will be shared with and used by other studies including Fish and Aquatics Instream Flow (Section 8.5), Riparian Instream Flow (Section 8.6), Groundwater (Section 7.5), and Ice Processes (Section 7.6) studies. The exchange of data between these studies will be highest at the Focus Areas.

At the start of the summer 2013 field season, a reconnaissance of the entire Fluvial Geomorphology Modeling study area (RM 184 to RM 75) as well as the remainder of the Lower Susitna River Segment (RM 75 to RM 0) will be conducted. This site reconnaissance will be carried out to observe and characterize the following:

- Hydraulic and geomorphic controls (natural and man-made) that will influence sediment-transport conditions.
- Verification of mapping of geologic and geomorphic features performed in the Geomorphology Study.
- Hydraulic roughness conditions along the main channel and in the overbanks.
- Variations in bed material size.
- The sediment-transport regime, and areas that appear to be in equilibrium, or are aggradational or degradational.

- In areas that are not in equilibrium, qualitative assessment of the degree of erosion or deposition.

To support the site reconnaissance as well as all other field data collection activities, maps of the study area will be developed to assist crews during field activities. The mapping will include topography (from available LiDAR), aerial photo base layer, geologic units and controls, geomorphic features, aquatic habitat types, geomorphic reach boundaries, existing cross-section locations, proposed supplemental cross-section locations, survey control points, focus site locations, location of installed instrumentation, and safety related information.

Beyond the general site reconnaissance, detailed information will be collected to support the development of the 1-D model for the entire study area and the Focus Areas where 2-D and possibly 1-D modeling will be applied. Additional data will also be collected for the tributary confluences that are identified for modeling. The field data to be collected for each of these study components are provided below.

6.6.4.1.2.9.1. 1-D Bed Evolution Model

The primary field data to be collected in support of the 1-D bed evolution model include the following:

1. Supplemental cross-sections
2. Bed material samples
    a. Surface pebble count (Wolman count) or photo grid
    b. Subsurface bulk or photo grid samples
3. Bank material samples
4. Spot elevations to verify LiDAR in the area of the supplemental cross-sections (LiDAR will be used to provide the floodplain portion of the cross-sections)
5. Estimation of n-values at supplemental cross-sections
6. Observations on depositional or erosional features at the supplemental cross-sections

Supplemental cross-sections will be required to provide the level of detail in the hydraulic model necessary to properly model sediment transport conditions. The cross-sections collected in 2012 for the Mainstem (Open-water) Flow Routing Model will be used in development of the 1-D model; however, their spacing is such that additional cross-sections will need to be collected in 2013 to complete the 1-D sediment transport model. There were 88 cross-sections collected between RM 75 and 184 (excluding the 12-mile length of river in the Devils Canyon area) with an average spacing of just over 1 mile. The minimum and maximum spacing between the cross-sections was 0.1 and 3 miles, respectively. It is estimated that on the order of 80 to 100 supplemental cross-sections will need to be surveyed to complete the cross-sectional database for the 1-D sediment transport model. The transects and bathymetric data to be collected at the focus sites will meet a portion of this requirement, likely reducing the number of supplemental sections to be surveyed by 20 to 25 percent. Supplemental cross-sections collected for the Fish and Aquatics Instream Flow Study may also fulfill part of the 1-D model supplemental cross-section needs.

Bed material samples will be collected using pebble count, photographic grid, or bulk sampling procedures. Approximately 50 bed material samples will be collected to support the 1-D model development. A similar number of subsurface and bank material samples will be obtained. These samples will be supplemented by similar samples collected at the Focus Areas. The sampling will be performed at low flow to allow as much of the bed to be sampled as possible. In addition, the Geomorphology Study (Section 6.5) will work with the Ice Processes Study (Section 7.6) in the winter of 2013 to determine whether video bed material samples can be collected using a camera equipped with two lasers to provide scale. The winter period is when the Susitna River is sufficiently clear to support this type of effort.

6.6.4.1.2.9.2. Focus Areas

The primary field data to be collected at the Focus Areas by the Geomorphology Study include the following:

1. A combination of bathymetry (single and multi-beam), cross-section data, and spot elevations necessary to develop a digital terrain model for the portion of the site for which LiDAR is not available. (These will be the main channel, side channels, side sloughs, upland sloughs, tributaries, and open water areas that were inundated at the time the LiDAR was acquired.)
2. All obstructions in the off-channel habitats such as beaver dams and debris jams will be surveyed.
3. Large woody debris survey and characterization of its influence on the geomorphology of the channels, side channels and sloughs.
4. Bed material samples in the main channel, sloughs, and side channels
   a. Surface pebble count (Wolman count) or photo grid
   b. Subsurface bulk or photo grid samples
   c. Possible winter sampling in conjunction with the Ice Processes Study (Section7.6) (see 1-D Bed Evolution Model field data section and description of geomorphic mapping below)
5. Bank material samples.
6. Spot elevations to verify LiDAR in the Focus Area (LiDAR will be used to provide the floodplain portion of the cross-sections).
7. Estimation of n-values in the channels, side channels, sloughs, and tributaries.
8. Observations on depositional or erosional features at the supplemental cross-sections.
9. Field verification, and correction and/or mapping if necessary, of the geomorphic features, geologic controls, and terraces previously identified from available information for the Focus Area.
10. ADCP measurements to calibrate and determine the accuracy of the 2-D hydraulic model velocities.
11. Installation of level loggers and associated readings to support calibration of water surface elevations produced by the 2-D model.
12. Current meter measurements of velocity for areas where the ADCP cannot be used.
13. Mapping of depositional and erosional features.
14. Identification and mapping of evidence of ice processes at the site along with observations of their potential influence on the geomorphology of the Focus Area.
15. Any evidence of past extreme events.
16. Overall narrative description and assessment of the geomorphology of the Focus Area including identification of key physical processes and controls.

If it is determined that 1-D modeling is appropriate for a Focus Area, rather than collecting bathymetric, cross-sectional and topographic information required to build a digital terrain model

(DTM) to support 2-D mesh development, cross-sectional data will be collected on the hydraulic features to be modeled.

Geomorphic mapping of the Focus Area sites will be prepared during the field data collection at an appropriate level of resolution to delineate the key geomorphic features that control the dynamics and the availability of habitat at the site. This mapping will identify features at the scale of the individual habitat units that include riffles, pools, runs, meso-scale bars (i.e., dimensions on the order of the channel width in side channels and sloughs), banklines, large LWD clusters, and similar features. Characteristics of the substrate making up these features will be measured using techniques appropriate to the size range of the material in each unit. In coarse-grained areas (i.e., gravel and cobbles), surface samples will be taken using the pebble count method (Wolman 1954). In areas where the material is sufficiently fine (i.e., sand and fine- to medium-gravel), bulk samples will be collected for laboratory grain size analysis. Considering the generally coarse-grained nature of the substrate in the Focus Areas, subsurface sampling that will be conducted on the bars will most likely be done using a combination of the two techniques. After completion the surface sampling in each area, the surface layer over an appropriately-sized area will be removed and a sufficient quantity of material will be exhumed and placed on a tarp. The sample will then be weighed in increments with a field scale to determine the total bulk weight and the relative weights of the fine and coarse fractions. The coarse fraction will then be segregated into size classes and individual classes weighed to determine the gradation. A suitably-sized bulk sample of fine fraction will then be collected for laboratory sieve analysis. The overall gradation will then be determined by recombining the field-measured coarse fraction and laboratory-analyzed fine fraction into a single gradation based on the relative weights of each in the original field sample. The minimum size of the bulk samples will be determined based on the maximum particle size in the sample using guidelines in ASTM D75-71.

Surveys to develop the topography and bathymetry will be conducted at each Focus Area to provide the level of feature definition required for accurate 2-D modeling and to provide data at sufficient resolution to meet the needs to the FA-IFS. Surveys will be tied to the control network established along the Susitna River during the 2012 cross-section surveys performed to collect data for the Mainstem Open-water Flow Routing model. A single beam fathometer linked to survey grade RTK-GPS will be used to collect cross-sections at sufficient intervals to properly define the grids and define geomorphic features. In addition to the cross-sections, longitudinal stream-wise profiles will be run with the fathometer to define the channel thalweg and the transition from the channel bed to banks. These profiles will serve as break-lines when developing the digital terrain model (DTM). In areas where the river is shallow or dry, then the cross-sections will be completed with RTK-GPS or by total station.

In side channels and other off-channel features where the width and depth is sufficient for the use of the fathometer, these areas will be surveyed similar to the mainstem In areas where the channels are too small to utilize the boat-mounted survey equipment, the survey will be performed using RTK GPS or total station (in areas where vegetation may preclude the use of GPS). Since these areas will require fine mesh for both the 2-D modeling and for development of hydraulic conditions for the FA-IFS, care will be taken to survey the longitudinal break lines, in addition to the cross-sections, that will be needed to develop the detailed DTM. This survey will be combined with the geomorphic mapping.

It is anticipated that the upper portions of channels and the overbank or floodplain areas will be represented in the DTM by the Mat-Su LiDAR. However, points will be taken in these areas with the RTK-GPS to verify the accuracy of the LiDAR. In some cases, this information may be used to adjust the LiDAR data.

6.6.4.1.2.9.3. Tributary Deltas

A site reconnaissance and data collection effort will also be necessary for each of the key tributaries that have the potential to deliver significant quantities of sediment to the reach and/or are important to other study teams. The reconnaissance to these sites will be relatively detailed, because specific data will need to be collected, in addition to the general observations, to facilitate the modeling at the tributary mouths. Cross-sectional surveys of approximately six transects over a representative reach above the confluence will be necessary, with a spacing of about three- to five-times the active channel width. Surface and sub-surface bed material samples will be collected to characterize the gradation of the sediments along the reach, and will include at least two representative samples of the surface material on the fan. Observations and photographs of erosional and depositional features will be taken.

6.6.4.1.2.9.4. Field Data from Other Studies

In addition to the above field data collected as part of the Geomorphology Study (Section 6.5), the following data collected by the Fish and Aquatics Instream Flow (Section 8.5), Riparian Instream Flow (Section 8.6), Ice Processes (Section 7.6), and Groundwater (Section 7.5) studies will need to be obtained to support the Geomorphology Study:

- Mainstem (Open-water) Flow Routing Model cross-sections collected in 2012.
- Fish and Aquatics Instream Flow Study supplemental transects collected in 2013.
- Hydraulic calibration information used in the development of the Mainstem (Open-water) Flow Routing Model (water surface elevations and associated discharges).
- Information describing the influence of ice processes on channel and floodplain morphology.
- Information describing the influence of riparian vegetation on channel and floodplain morphology.
- Soil classification and gradation from Riparian Instream Flow Study test pits in the floodplain and on island.
- Thickness and aging of floodplain and island deposits from the Riparian Instream Flow Study.
- Mapping of vegetation and associated age classes from the Riparian Instream Flow Study.
- Information developed in the Geomorphology Study on channel changes that have occurred since the 1980s.
- Information developed in the Geomorphology Study on the physical processes most important to accurately modeling the study reach.
- The velocity and depth measurements collected by the Fish and Aquatics Instream Flow Study to characterize habitat for calibrating the hydraulic model(s).
- Data collected on the distribution of flow between the main channel and off-channel habitat to help calibrate the hydraulic portion of the 2-D model.

6.6.4.1.2.10. Information Required

In addition to the field data collection effort described in the previous section, the following existing information will be needed to conduct this study:

- Historical and current aerial photographs.
- Historical channel cross-sections.
- LiDAR to develop sub-aerial topography and extend surveyed transects across the floodplain.
- Extended flow records from USGS mainstem and tributary gages.
- Estimated flows from key ungaged tributaries that will be accounted for in the water and sediment inflows, and where potential development of tributary fans is to be evaluated.
- Historical bed material sample data.
- List of key indicators from the other studies (FA-IFS, R-IFS, Ice Process, Groundwater) to ensure that the models are structured to either directly quantify the indicators or provide quantitative data from which the indicators can be quantified using other relationships outside the context of the model.

6.6.4.1.3. Study Products

The products of this component of the modeling study will include the following:

- 1-D hydraulic models that will be used to estimate sediment loading from each of the tributaries that supply significant volumes of bedload along the modeled reach.
- A single, calibrated, 1-D bed evolution sediment-transport model, or a series of models, that extend from the proposed dam to a yet-to-be determined downstream limit.
- A number of calibrated 2-D sediment-transport models for proposed Focus Areas.
- Model calibration data and documentation.
- A report describing model calibration and application to existing conditions.

6.6.4.2. Study Component: Model Existing and with-Project Conditions

The goal of the Model Existing and with-Project Conditions study component is to provide a baseline and series of with-Project scenarios of future channel conditions for assessing channel change. The extent of the study area is the Susitna River downstream of Watana Dam, the specific downstream boundary of which will be determined in study component Bed Evolution Model Development, Coordination, and Calibration.

6.6.4.2.1. Existing Information and Need for Additional Information

Once the 1-D and 2-D bed evolution models are developed in the previous study component, the model will be run for the existing condition (the Susitna River without Watana Dam in place) in order to establish a baseline for comparison with Project model runs. The model will also be run for various Project scenarios to determine the potential effects of the Project on the fluvial geomorphology of the Susitna River.

6.6.4.2.2. Methods

6.6.4.2.2.1. Existing Conditions – Base Case Modeling

The RSP includes four operation scenarios. The first is the existing conditions or without-Project scenarios. This scenario provides the baseline against which all other with-Project scenarios are compared against to identify Project effects.

The time period and representative hydrologic conditions to be assessed with the bed evolution model will be determined through coordination with the Technical Workgroup, based on the availability of data, study objectives, and model limitations. The hydrologic inputs for the various with-Project scenarios will be obtained from the Reservoir Operations (Engineering) and Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3) and the model run for flows representative of each scenario. It is currently envisioned that a 50-year, continuous period of record that represents the length of the FERC licensing period will be used for the 1-D modeling, and shorter modeling periods will be used for the 2-D model due to computational limitations. The 50-year period will be divided into three points in time to provide comparison: year-0, year-25, and year-50. As previously indicated, the 1-D model will be applied to address the analysis of reach-scale issues and the 2-D model to address local-scale issues.

The shorter periods for the 2-D model will include specific years or portions of annual hydrographs for selected years of wet, average, and dry hydrologic conditions and warm and cold Pacific Decadal Oscillation (PDO) phases. Therefore, up to six annual hydrologic conditions will be considered. (The inclusion of the warm and cold PDO phases was requested by NOAA-NMFS and USFWS in the May 31, 2012, study requests; the rationale for the request was discussed at the June 14, 2012 Water Resources TWG meeting and it was agreed that the PDO phases would be included in the suite of representative annual hydrologic conditions.) Other scenarios might include rapid release of flows from an ice jam or larger flood events that are not contained in the period of the hydrologic record chosen for simulation.

Each run will be subjected to a quality control process to ensure that the appropriate data were used and model outputs are reasonable. Naming conventions for the model input and output files for the various scenario files will be applied so that files can be easily archived and retrieved in the future.

6.6.4.2.2.2. Future Conditions – with-Project Scenarios

The three with-Project scenarios will represent a maximum load-following, an intermediate load-following, and a base-load scenario. The three with-Project scenarios will provide bookends and an intermediate assessment of potential Project effects. These will provide an understanding of the range of potential Project effects. Similar to the existing conditions, the with-Project scenarios will be modeled with both the 1-D model to determine the reach-scale Project effect and the 2-D model to determine the local-scale Project effects. The with-Project scenarios will be evaluated over the same time periods as the existing conditions base case.

6.6.4.2.2.3. Uncertainty

To assist in identifying and understanding uncertainties, sensitivity analysis will be performed for the 1-D and 2-D bed evolution modeling efforts by varying key input parameters within the range of physically reasonable values. Additionally, the 50-year simulation period to be used for the 1-D bed evolution model includes a broad range of hydrologic conditions, and will be used to assess the sensitivity of the study reach to hydrologic variability. Variation in response to the six representative years (wet, average, and dry for wet and cold PDO) based on both the 1-D and 2-D bed evolution model results will also provide an understanding of the uncertainty associated with hydrologic conditions. Specific parameters that will be varied in the uncertainty analysis include hydraulic roughness coefficients, magnitude and gradations of inflowing sediment loads, substrate size gradations, and dimensionless critical shear (i.e., Shields) values.

6.6.4.2.2.4. Synthesis of Reach-Scale and Local-Scale Analyses

In general, based on the spatial resolution of the input and output data, the 1-D model results are used to facilitate analysis of processes at the reach-scale, while the 2-D model is used for local-scale analysis. It is important to recognize that the downstream stage and upstream discharge boundary conditions for the local-scale 2-D models will be taken from the 1-D Mainstem (Open-water) Flow Routing Model, and the inflowing sediment loads will be taken from the 1-D bed-evolution model, ensuring consistency at the model boundaries. (Although this is not anticipated, it may be necessary to take downstream stage boundary conditions from the 1-D bed evolution model for purposes of analyzing future conditions if this model shows sufficient change over the duration of the model runs.) In addition, results from the models are compared within the 2-D model domain to further ensure consistency. This comparison often leads to important adjustments to one or both of the models to improve consistency and predictive quality.

As described in the Section 6.6.4.1.2.4, the Focus Areas have been selected to represent the range of geomorphic and habitat conditions that occur within the study area. The detailed analysis at these sites that relies on the 2-D model results will be extrapolated to the overall study reach using the 1-D model results and other relevant information from the Geomorphology, FA-IFS, R-IFS, Ice Process studies, where appropriate, to quantify anticipated Project impacts at the Study Reach Scale.

6.6.4.2.2.5. Information Required

The following available existing information will be needed to conduct this study:

- The calibrated existing conditions model(s) developed in the previous tasks, including the data used to develop them.
- Extended flow records for mainstem gages and major tributaries for existing conditions.
- With-Project mainstem flows corresponding to the periods and locations in the extended flow record.
- The with-Project sediment outflow rating curve from Watana Dam.
- List of key indicators from the other studies (FA-IFS, R-IFS, Ice Process, Groundwater) to ensure that the models are structured to either directly quantify the indicators or provide quantitative data from which the indicators can be quantified using other relationships outside the context of the Fluvial Geomorphology Modeling Study.

6.6.4.2.3. Study Products

The products of this component of the modeling study will include the following:

- Results from the 1-D mobile boundary sediment-transport model(s) that extend from the location of the proposed dam to a yet-to-be determined downstream limit.
- Results from the 2-D sediment-transport models for proposed Focus Areas.
- A report describing the model runs, and interpreting the model results.

6.6.4.3. Study Component: Coordination and Interpretation of Model Results

The goal of this study component is to ensure that the information from Geomorphology Study is properly considered and incorporated into the modeling studies, that the results the modeling studies are used to update and refine the understanding of key processes identified in the Geomorphology Study, and to provide the necessary results to the other resources studies that will require knowledge, and where possible and appropriate, quantification of potential natural and Project-induced geomorphic changes. The extent of the study area is the Susitna River downstream of Watana Dam, the specific downstream boundary of which will be determined in the Bed Evolution Model Development, Coordination, and Calibration study component (Section 6.6.4.1).

6.6.4.3.1. Existing Information and Need for Additional Information

Several studies require the results of the Fluvial Geomorphology Modeling Study to conduct their efforts. These include the Fish and Aquatics Instream Flow (FA-IFS) (Section 8.5), Groundwater (Section 7.5), Riparian Instream Flow (R-IFS) (Section 8.6), and Ice Processes (Section 7.6) studies. The primary concern is whether the Project will affect aspects of the channel morphology including, but not limited to, substrate characteristics, cross-sectional geometry, connectivity with off-channel habitats and in the most general sense, the distribution of geomorphic features that comprise the aquatic and riparian habitats.

6.6.4.3.2. Methods

As discussed in Section 6.5.4.11, initial work for the Geomorphology Study identifies the specific geomorphic processes that affect aquatic and riparian habitat, channel stability and related issues that require further quantification, identifies a significant portion of the data needs, and provides the basic information and context for the Fluvial Geomorphology Modeling Study. During the Fluvial Geomorphology Modeling Study, results from the Geomorphology Study are used in conjunction with knowledge of the specific needs of the other resource teams to insure that the models are developed in an appropriate manner to address the key issues and to provide a reality check on the model results. After completion of the modeling, the study team uses the results from both studies in an integrated manner to provide interpretations with respect to the issues that must be addressed, including predictions of potential changes to key geomorphic features that comprise the aquatic and riparian habitat. This information is then provided to the other resource teams for use in their evaluation of potential project effects.

6.6.4.3.2.1. Integration of Geomorphology and Fluvial Geomorphology Modeling Study Results

The purpose of this task is to integrate the Geomorphology and Fluvial Geomorphology Modeling Studies to insure that results from both studies are used in a coordinated manner to identify and, to the extent possible, quantify the potential influence of the Project on key geomorphic and habitat features. Section 6.5.4.11 provides a detailed discussion of the specific aspects of the Geomorphology Study that will be used to guide development of the models and interpretation of the model results for the Fluvial Geomorphology Modeling Study, particularly as they relate to the habitat indicators. Additional examples of key coordination activities between the two studies include the following (It is important to understand that other activities may be identified as the study teams gain additional understanding of the key processes that drive potential Project effects):

- The LWD component of the Geomorphology Study will provide information on the status of LWD recruitment to the project reach under existing conditions and qualitative information about the potential effect of the Project on future LWD recruitment. Results from the bed evolution modeling will provide quantitative estimates of certain key processes that affect LWD recruitment under both existing and Project conditions, including potential changes in bank erosion rates.
- The Geomorphology Study will identify key locations that control connectivity between the main channel and the side channels, side sloughs and upland sloughs, and will assess how these locations have evolved over the period of coverage of the historical aerial photography. The Fluvial Geomorphology Modeling study will quantify the hydraulic and sediment transport behavior of the existing locations, and will provide quantitative projections of how these areas will change in the future under both existing (no Project) and Project conditions based on the bed evolution modeling results.
- The Geomorphology Study, coupled with the field data collection activities for the Fluvial Geomorphology Modeling Study, will identify the geomorphic characteristics (i.e., channel geometry, gradient, substrate, bank material and vegetation) that are important drivers of habitat conditions within the side channels, side sloughs, and upland sloughs under existing and Project conditions. The modeling, particularly 2-D bed evolution modeling at the Focus Areas, will provide a means of directly quantifying these processes by providing detailed hydraulic information and projections of changes in substrate and bed elevations. This will include quantification of the frequency and duration of substrate mobilization and the potential for fines infiltrations and flushing in spawning areas. Other aspects, such as potential changes in channel width, will be estimated based on a combination of the model output and relevant geomorphic relationships.

6.6.4.3.2.2. Coordination of Results with Other Resources Studies

The Fluvial Geomorphology Modeling and Geomorphology Study (Section 6.5) teams will interact extensively with the Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3), Fish and Aquatics Instream Flow (Section 8.5), Riparian Instream Flow (Section 8.6), Ice Processes (Section 7.6), and Characterization and Mapping of Aquatic Habitats (Section 9.9) study teams. The types of interaction will vary depending on the specific study, but a considerable amount of physical data describing the system, including transects, topography/bathymetry, substrate characterization, aerial photography, and pre- and post-Project flows generally will be shared. Selection of joint Focus Areas for detailed studies will be an important aspect of the collaboration. By selecting common sites, the potential for exchange of information between the study teams will be maximized to ensure the most effective and extensive use of Focus Area data.

Because of the detailed spatial nature of the information produced by the models, GIS will likely be an important tool for visually illustrating and conveying model results for use in the other studies. Development of the plan for transferring results in a manner that will facilitate efficient and effective use by other studies will require considerable effort. The details of the plan will be worked out as the overall modeling approach is developed in the Technical Workgroup meetings and through informal coordination with the respective study teams.

The 1-D and 2-D bed evolution models provide quantitative predictions of a range of key variables that are directly related to the geomorphic and habitat conditions along the study reach at a range of spatial and temporal resolutions (Table 6.6-5 and Table 6.6-7). As noted in Table 6.6-6, the values of many of these variables can be used directly to assess geomorphic and habitat conditions, while additional analysis of other variables outside the context of the model is required to obtain useful predictions (Table 6.6-7). The output variables can be broadly grouped into hydraulic conditions (water-surface elevations, depth, velocity, bed shear stress) and sediment transport/bed morphology conditions (substrate size gradations, sediment transport rates, changes in bed elevation).

<u>Mainstem (Open-water) Flow Routing Study (Section 8.5.4.3):</u> It is anticipated that the Mainstem (Open-water) Flow Routing Study will provide the pre- and post-Project hydrology information for all studies, including the Fluvial Geomorphology Modeling Study. This hydrology information will include mainstem pre- and post-Project flows at various points along the study area and inflows for gaged and ungaged tributaries. This information is expected to be provided for the 50-year, extended flow record.

For the Fluvial Geomorphology Modeling effort, the upstream boundary condition at RM 184 will be the existing condition or pre-Project daily flows from the extended flow record. For the post-Project condition, the upstream boundary condition will be the average daily releases from Watana Dam unless load-following scenarios are evaluated. In the latter case, the Project outflows will need to be on an hourly or possibly finer time increment. Estimated daily inflows from tributaries provided by the Mainstem (Open-water) Flow Routing Model will be input along the length of the 1-D sediment transport model and may be inputs to the localized 2-D models depending on the location and specific issues to be addressed.

<u>Fish and Aquatics Instream Flow Study (FA-IFS) (Section 8.5):</u> The primary initial interaction with the FA-IFS will be in the selection of the Focus Areas for detailed study. Part of the selection process will consider the use of the specific sites as well as the types of habitat present at the site by target fish species. The local-scale 2-D models can be used to evaluate instream habitat quality on a spatially-distributed basis rather than the cross-sectionally-based approach used in traditional Instream Flow Incremental Methodology (IFIM) studies.

For the FA-IFS, an assessment of whether the current channel geometry and substrate characterization used in evaluation of habitats will remain relatively unchanged over the period of the license under both the pre- and post-Project conditions will be important. The Geomorphology Study will determine the equilibrium status of each reach such that the distribution of habitat conditions over the timeframe of the license (assumed to be 50 years, corresponding to the maximum FERC licensing period) will be adequately reflected by existing channel morphology. If it is determined that the river is not in a state of dynamic equilibrium, the Geomorphology Study will provide projections of the direction and magnitude of the changes under both existing and Project conditions. Changes in the relative occurrence of aquatic habitat types and the associated surface area versus flow relationships that may occur as a result of the Project will be an important outcome of these studies. As part of this evaluation, pre- and post-

Project changes in channel dimensions (width and depth) and the proportion and distribution of geomorphic features and habitat types will be estimated for each of the delineated reach types using the channel classification system to be developed for the Susitna River. This will provide the FA-IFS with an important part of the information required to evaluate the post-Project effects on aquatic habitat. Other important information to be provided by the Fluvial Geomorphology Modeling study for the Instream Flow Study includes the following:

- Identification of zones of substrate mobilization, deposition, and scour at the reach scale for pre- and post-Project flow regimes.
- Potential changes in off-channel habitat connectivity due to aggradation and degradation.
- Pre- and post-Project changes in spatial and seasonal patterns of the fine sediment (wash load) transport and the associated Project effects on turbidity.
- Changes in substrate composition in both the main channel and off-channel habitats.
- Pre- and post-Project large woody debris (LWD) recruitment and transport.

<u>Riparian Instream Flow Study (Section 8.6):</u> Riparian vegetation plays a large role in the development of islands and off-channel habitats, primarily by protecting surfaces from erosion and promoting sediment deposition. Vegetation can also contribute to channel narrowing by encroaching onto bars and islands and 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; thus, there is a feedback mechanism between the two processes. As a result, the influence of riparian vegetation on the morphology of the Susitna River is an important consideration in these studies. The R-IFS, Geomorphology and Fluvial Geomorphology Modeling studies need to be closely coordinated because of the interaction described above. The collaboration will begin with coordinated selection of the Focus Area among the R-IFS, Ice Processes, Geomorphology and Fluvial Geomorphology Modeling study teams. By analyzing the same Focus Areas in a coordinated manner, the teams will develop an understanding of the interaction between the processes that are responsible for creation and maintenance of the islands and off-channel habitats. 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. Similarly, profiling of deposited sediments in the riparian corridor to identify the types of sediments that make up the floodplain will also contribute to the understanding of the physical processes and development of the functional model for linkage of the geomorphology, riparian vegetation, and ice processes.

The results of the fluvial geomorphology model along with applicable geomorphic principles will be applied to interpret model results. An understanding of the geomorphology of the system will also be used to provide a reality check on the extent of changes indicated by the modeling.

Examples of the linkage between the R-IFS and the Fluvial Geomorphology Modeling include the following:

- Altering Manning's n-values to represent establishment (increased n) or removal (decreased n) of vegetation.

- Application of shear stress parameter to determine the erodibility of banks and potential influence of and on vegetation.
- Interpretation of flow and sediment transport patterns to determine areas of sediment deposition within and adjacent to vegetation.
- More accurate water surface elevations and flow distributions from the local-scale 2-D models than is provided by the 1-D models for periods when the flows only partially inundate the riparian corridor.
- Estimation of the change in the rate of floodplain and island building under the with-Project condition and between various operational scenarios. This can be accomplished by scaling the historical rates of sedimentation developed from the R-IFS by the ratio of the with-Project rate of sediment delivery to the floodplain surfaces to the existing rate. The 2-D model will be applied to simulate sediment delivery to the floodplains and islands.
- Use of geomorphic threshold relationships to understand the potential for removal of vegetation by the flows and the potential for additional channel narrowing due to changes in the vegetation patterns.

<u>Ice Processes Study (Section 7.6):</u> 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. In both examples these influences affect channel morphology. Ice jams can also directly influence the channel morphology by diverting flows onto floodplains 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 normally not be mobilized by rafting large cobbles and boulders.

There will be close collaboration between the Geomorphology and Ice Process studies to identify the key physical processes that interact between the two. Working together to analyze the conditions at the Focus Areas will be a key part of this collaboration. A significant portion of the influences of ice processes on morphology are directly related to their effects on riparian vegetation. Additionally, influences of ice processes beyond the riparian vegetation issues that may be incorporated directly into the Fluvial Geomorphology Modeling may include the following:

- Simulating the effects of surges from ice jam break-up on hydraulics, sediment transport, and erosive forces using unsteady-flow 2-D modeling with estimates of breach hydrographs.
- Simulating the effect of channel blockage by ice on the hydraulic and erosion conditions resulting from diversion of flow onto islands and the floodplain.
- Use of the 2-D model output to assess shear stress magnitudes and patterns in vegetated areas, and the likelihood of removal or scouring.
- Use of the 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.

Water Quality Modeling (Section 5.6): The Fluvial Geomorphology Modeling Study will have two primary areas of interaction with the Water Quality Modeling Study. The first involves the determination of reservoir sediment trap efficiency. The EFDC model that is being used for studying the water quality of the reservoir, Middle and Lower Susitna River Segments will be used to perform a determination the final determination of reservoir sediment traps efficiency. This will provide a more accurate determination of the fine sediment settling than use us the empirical equations that are described in Section 6.5.4.8.2.1 that will be used for the initial estimate of trap efficiency. The Geomorphology Study will provide the Water Quality Modeling study with the sediment inflow to the reservoir based on the sediment supply analysis conducted in Section 6.5.4.3. The second are of interaction is the routing of fine sediment, silt and clay, downstream. Both the 1-D bed evolution model form this study and the EFDC model from the water quality will route fine sediments in the Middle Susitna River Segment and upper portion of the Lower Susitna River Segment. The water quality models interested in the fine sediment in order to estimate the Project effects on turbidity, while the Fluvial Geomorphology Modeling Study is primarily interested in fine sediment in terms of the Project effects on areas of deposition in the main channel, off-channel and floodplain areas. The results of each model in terms of fine sediment transport results will be compared to insure consistency.

6.6.4.3.2.3. Information Required

The following available existing information will be needed to conduct this component of the modeling study:

- Study plans for other studies

The following additional information will need to be obtained to conduct this component of the modeling study:

- Locations of sites for other studies
- Lists of output required for other studies, including list of key habitat indicators.
- Output formats required for other studies
- Schedule dates for providing output

6.6.4.3.3. Study Products

The products of this component of the modeling study will include summarized results from the 1-D and 2-D sediment-transport modeling in an appropriate format. This will include the values of variables that are taken directly from the models (Table 6.6-6) and variables or indicators that are computed from a combination of the direct model output and other available information using appropriate relationships outside the direct context of the model (Table 6.6-7).

Although the desired format of the model output is not known at this time, the formatted products could include the following:

- Spreadsheets summarizing predicted hydraulic conditions.

- Spreadsheets summarizing the sediment-transport results at various times during the 1-D mobile boundary sediment-transport simulations.
- ArcGIS shapefiles, and where necessary, spreadsheets, representing the predicted hydraulic conditions (velocity magnitude and direction, water depth, shear stress magnitude and direction, etc.) at various times during the 2-D modeling simulation at each of the Focus Areas.
- ArcGIS shapefiles, and where necessary, spreadsheets, representing the sediment-transport results (predicted change in bed elevation, sediment size, etc.) at various times during the 2-D modeling simulation at each of the Focus Areas.

6.6.5. Consistency with Generally Accepted Scientific Practice

A wide range of temporal scale processes, unknown initial and forcing conditions, unresolved heterogeneities, and unanticipated mechanisms make geomorphic prediction challenging and problems of scale important (Wilcock and Iverson 2003). Fluvial geomorphologic analyses typically involve focusing on a variety of spatial scales at which landforms have characteristic features (Grant et al. 1990; Rosgen 1996; Thomson et al. 2001). These scales generally reference the river channel width (W) due to the similarity of forms among systems of different absolute size that are governed by the same underlying processes (Pasternack 2011). For example, the analysis could include an assessment at the watershed scale, river segment scale (10^3-10^4 W), morphologic or reach scale (10^0-10^1 W), and Focus Area local scale (10^{-1}-10^0 W). As discussed in more detail below, the Geomorphology Modeling Study will require both reach-scale (1-D modeling) and Focus Area local-scale (2-D modeling) analyses. Synthesis of the reach-scale and local scale analyses will therefore be necessary to identify potential Project-induced changes in the relative occurrence of aquatic habitat types and associated surface area versus flow relationships. In addition to the results of the hydraulic and sediment transport modeling, this synthesis will require application of fluvial geomorphic relationships to develop a comprehensive and defensible assessment of potential Project effects. Examples of this type of integrated analysis that have been successfully performed by the Project team include instream flow, habitat, and recreation flow assessments to support relicensing of Slab Creek Dam in California; a broad range of integrated geomorphic assessments and modeling to assist the Platte River Recovery Implementation Program in Central Nebraska; and ongoing work to support the California Department of Water Resources and Bureau of Reclamation to design restoration measures for the San Joaquin River in the Central Valley of California downstream of Friant Dam.

1-D and 2-D models are commonly used tools to assess hydraulic and sediment transport conditions in rivers[1]. The potential models that are described in the model selection section have been in use by the engineering and geomorphic community for many years (in some cases, many decades) for evaluating both existing/baseline conditions and predicting the likely effects of proposed changes in flow regime, sediment supply, and other natural and anthropogenic factors. All of the proposed models have been developed using scientifically-sound relationships to describe the physical processes that are important to the analysis. The proposed modeling steps,

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[1] The March 2008 Edition of the American Society of Civil Engineers *Journal of Hydraulic Engineering* was entirely dedicated to the practice and challenges associated with sediment transport modeling.

that include initial reconnaissance to understand the study reach, field data collection to obtain quantitative information necessary to build the model inputs files, calibration steps to ensure model results are consistent with field conditions, and modifications to the model input to represent the range of potential future conditions, are commonly employed by practitioners and researchers. Results from the application of these types of models have provided significant technical basis for FERC licensing of numerous projects through the U.S. and similar licensing throughout the world.

<u>One-Dimensional Modeling at the Reach Scale</u>: Potential 1-D models that are being considered` for this study include the U.S. Army Corps of Engineers HEC-RAS (version 4.1; USACE 2010a), the Bureau of Reclamation's SRH-1D (version 2.8; Huang and Greimann 2011), DHI's MIKE 11 (version 2011; DHI 2011a), and Mobile Boundary Hydraulics' HEC-6T (version 5.13.22_08; MBH 2008). Based on the information above and experience with these models, the Geomorphology Study team tentatively proposes to use HEC-6T for the reach-scale sediment transport analysis. This proposal is based on confidence gained that HEC-6T is capable of effectively and efficiently modeling the processes that are important for this scale of geomorphic analysis. HEC-6T has been successfully applied to model the sediment-transport conditions in a wide range of river systems for a variety of studies. The study team is currently using the model to evaluate sediment augmentation for habitat restoration purposes in the Central Platte River in Nebraska (Tetra Tech 2010). It was successfully used to evaluate the effects of seismic retrofit options for San Clemente Dam on sediment-transport through the reservoir and in the downstream Carmel River (Mussetter Engineering, Inc. 2008).

<u>Two-Dimensional Modeling at the Local Scale:</u> Potential 2-D models that are being considered for this study include the U.S. Bureau of Reclamation's SRH2-D version 3 (Lai 2008; Greimann and Lai 2008), USACE's Adaptive Hydraulics (ADH) version 3.3 (USACE 2010b), USGS's MD_SWMS modeling suite (McDonald et al. 2005; Nelson et al. 2010), and DHI's MIKE 21 version 2011 (DHI 2011b) River2D modeling suite (University of Alberta 2002; University of British Columbia 2009). The selection of the 2-D model will be coordinated with the other pertinent studies and the licensing participants. In addition to the User's Manuals that are available with each of the potential models, a number of standalone references are also available that provide guidance for development and application of the 2-D models, or highlight successful application of 2-D geomorphologic modeling. For example, Pasternack (2011) includes an entire chapter that provides instruction for 2-D model development, and separate chapters for SRH-2D model execution and interpretation of SRH-2D model results. Conaway and Moran (2004) present successful application of MD_SWMS to modeling sediment-transport conditions in Alaskan rivers. MD_SWMS has also been successfully used to model sediment-transport and Island formation in a gravel bed portion of the Snake River (McDonald et al. 2005).

6.6.6. Schedule

A schedule for the Fluvial Geomorphology Modeling Study has been developed, and indicates the Model Development, Coordination, and Calibration study component will be completed by the end of the second quarter 2014; the Model Existing and with-Project Conditions study component will be completed by the end of the fourth quarter 2014; and Coordination on Model Output study component will be completed by the end of the fourth quarter 2014. The Initial Study Report (ISR) and the Updated Study Report (USR) explaining the actions taken and data collected to date will be due within one and two years, respectively, of FERC's Study Plan

Determination. A more specific breakdown of the anticipated schedule is presented in Table 6.6-8.

6.6.7. Relationship with Other Studies

A flow chart describes study interdependencies (Figure 6.6-4) and outlines the information and products required from other studies and the timing of delivery to successfully complete the Fluvial Geomorphology Modeling Study on schedule. In the study interdependencies chart, the studies providing input are listed in the five sided boxes at the top of the chart. The sections of the corresponding study's RSP which develop and provide the information are shown in parentheses. The rectangular boxes below the five sided boxes list the major information and products that the other studies will provide to the Fluvial Geomorphology Modeling Study. The primary studies that the Fluvial Geomorphology Modeling Study will require information from are listed below and in Table 6.6-9.

- Geomorphology Study (Section 6.5)
    - Geomorphic Reach delineation
    - Sediment transport rating curves and sediment balance
    - Identification of key physical processes
- Fish and Aquatics Instream Flow Study (Section 8.5)
    - Collaboration on Focus Area selection
    - Identification of specific areas of interest with focus areas
    - Velocity and transect measurements for hydraulic calibration
- Riparian Instream Flow Study (Section 8.6)
    - Floodplain sedimentation rates
    - Soil samples
- Groundwater Study (Section 7.5)
    - Level logger information
- Characterization and Mapping of Aquatic Habitats Study (Section 9.9)
    - Assistance in identifying tributaries to study
    - Identification of specific areas of interest with focus areas
- Ice Processes Study (Section 7.6)
    - Identification of ice influences
- Reservoir Operations Modeling (Engineering)
    - Project outflow for alternative scenarios
- Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3)
    - Cross-sections

    - Measured water surface elevations from level loggers
    - Hourly flows for alternative scenarios throughout the study area
- Water Quality Modeling Study (Section 5.6)
    - Reservoir trap efficiency for existing conditions and alternative scenarios
- Glacial and Runoff Changes Study (Section 7.7)
    - Potential increase in sediment supply from glacial surge

The USGS will provide the extended hydrologic record for 11 gage locations for a period of 61 years. This information will be used as the hydrologic record for analysis of existing stream flow characteristics and will also provide the flows to be used by the Reservoir Operations Study (Engineering) and the Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3) to generate flow conditions in the Middle and Lower Susitna River Segments for the with-Project conditions.

The timing of delivery of each type of information or study product to be provided to the Geomorphology study is the provided in parentheses by quarter and year. For example, "(Q4-12)" indicates the information will be provided in the fourth quarter of 2012. Table 6.6-9 provides these interdependencies in tabular form including the study providing the information and which area of the Fluvial Geomorphology Modeling Study requires the information or study product.

The chart indicates which areas of the Fluvial Geomorphology Modeling Study require the information. The Fluvial Geomorphology Modeling Study areas are identified in the blue ellipses and include:

- Field Data Collection
- 1-D, 2-D and tributary delta model development and calibration
- 1-D, 2-D and tributary delta modeling of baseline and alternative scenarios
- Integration of reach- and local-scale modeling and geomorphic analysis

The flow chart also shows products and information the Fluvial Geomorphology Modeling Study will provide to other studies and the timing of their delivery. Table 6.6-10 provides these study interdependencies in tabular form including the area of the Fluvial Geomorphology Modeling Study providing the information and which study requires the information or study product. The products and information the Fluvial Geomorphology Modeling Study will provide are identified in the rectangles below the study area ellipses. The quarter and year that the products and information will be provided to other studies is indicated in the parentheses adjacent to each item. At the bottom of the chart, the studies that require the information from the Fluvial Geomorphology Modeling Study are listed in the five sided boxes. In parentheses adjacent to each study is the section of the RSP that the product or information will support. The primary studies requiring information from the Fluvial Geomorphology Modeling Study are listed below. The information they will require is identified in Table 6.6-10 (Note: Table 6.6-6 and 6.6-7 provide a detailed list of 1-D and 2-D model output and other information the Fluvial Geomorphology Modeling and Geomorphology Studies will provide to other studies):

- Geomorphology Study (Section 6.5)

- Fish and Aquatics Instream Flow Study (Section 8.5)
- Riparian Instream Flow Study (Section 8.6)
- Characterization and Mapping of Aquatic Habitats Study (Section 9.9)
- Groundwater Study (Section 7.5)
- River Recreation Flow and Access Study (Section 12.7)
- Water Quality Modeling Study (Section 5.6)

6.6.8. Level of Effort and Cost

Initial estimates of the costs to perform the components of the Fluvial Geomorphology Modeling Study are provided in Table 6.6-11. The total effort for the Fluvial Geomorphology Modeling Study is estimated to cost between approximately $2.3 million and $2.8 million.

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6.6.10. Tables

Table 6.6-1. Schedule for the downstream study limit determination process for the Fluvial Geomorphology Modeling Study.

Step in Downstream Geomorphology Study Limit Determination	Date
RM 75 downstream geomorphology modeling limit proposal in RSP	December 2012
Recon. level assess. of Project effects in the L. Susitna River Segment and flow routing model results	January 2013
Tech. memorandum on recon. level assessment of Project effects in the Lower Susitna River Segment	January 2013
TWG meeting for confirmation of downstream geomorphology modeling limit	Feb / Mar 2013
1-D bed evolution modeling and 2013 Geomorphology Study results and tech memo	January 2014
TWG meeting(s) to reevaluate and confirm or adjust downstream modeling limits	Feb / Mar 2014
Collect additional data if need identified (Summer 2014)	Summer 2014

Table 6.6-2. Evaluation of potential 1-D bed evolution models.

Evaluation Criteria	Models			
	HEC-RAS	SRH-1D	MIKE 11	HEC-6T
General				
Proprietary/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	●	●	●	●

Notes: ● = Yes; ○ = No; NL = No Limit
[1] Not currently available, but in development.

Table 6.6-3. Evaluation of potential 2-D bed evolution models.

Evaluation Criteria	Model				
	SRH-2D	ADH	SToRM	MIKE 21	River2D
General					
Proprietary/cost (if applicable)	○	○	○	● / $20,000	○
Unsteady flow capability	●	●	●	●	●
Ice for fixed bed	○	○	○	●	●
Ice for moveable bed	○	○	○	●	●
Number of transport equations supported	4	2	○[1]	10	2
Supports user defined transport equation	○	●	○[1]	●	○
Relative execution speed: Fast (F), Slow (S)	F	S	F	F	S
Model stability: High (H), Moderate (M), Low (L)	H	M	M	H	H
Experience with model: High (H), Moderate (M), Low (L)	H	M	L	L	M
Moveable boundary simulation	●	●	○[1]	●	●
Grid Structure/Model Formulation					
Finite element (FE)/ Finite Volume (FV)	FV	FE	FV/FE	FV/FE	FE
Grid structure: Flexible Mesh (FM)	FM	FM	FM	FM	FM
Model Size Limitations					
# of grid elements	16,000	Unlimited	Unlimited	Unlimited	>100,000
Sediment Sizes Supported					
Wash load (silts, clays)	○	●	○[1]	●	○
Considers settling	○	●	○[1]	●	○
Sand	●	●	○[1]	●	●
Gravel and cobble	●	●	○[1]	●	●

Notes: ● = Yes; ○ = No; U = Unknown, currently investigating capabilities; NL = No Limit
[1] Not currently available, but in development.

Table 6.6-4. Summary of model parameter precedencies for water resources models to be applied in the Susitna-Watana licensing effort.

Model	Study Section	Software Program	Precedence (Parameters that the model results will be adopted for as the governing values)
Operations Model	Engineering	HEC ResSim	Project releases (discharge from the dam including spills) and reservoir pool elevations. The model will be refined throughout the study period to reflect any changes in project configuration and as operations scenarios are developed. (Available Q4 2012)
Initial Flow Routing Model (Hydrologic Routing)	Engineering	HEC ResSim	Discharge, stage and other hydraulic parameters such as velocity and depth from RM 184 to RM 84 until the Mainstem Open-Water Flow Routing Model is developed (Q1 2013)
Mainstem Open-Water Flow Routing Model (Hydraulic Routing)	8.5	HEC-RAS	Discharge, stage and other 1-D hydraulic parameters such as velocity and depth from RM 184 downstream to RM 74 once the model is developed (Q1 2013 version 1) during open water periods. Model will be updated with additional cross-section from 2013 fieldwork (Q4 2013 ver. 2) and finalized (Q4 2104 ver. 3). Provides boundary conditions to 2-D Bed Evolution Model.
Susitna River Ice Processes Model (Hydraulic Routing)	7.6	River 1D	Discharge, stage, and other 1-D hydraulic parameters such as velocity and depth from RM 184 to RM 100 during periods of ice formation, ice cover and ice break-up once model is developed (Q4 2013 ver. 1, Q4 2014 ver. 2). The model will also provide water temperature, ice extents and ice thickness for the same period.
Susitna River Ice Processes Model – Focus Areas	7.6	River 1D River 2D	Hydraulic conditions, water temperature, ice extents and ice thickness within the focus areas during periods of ice formation, ice cover and ice break-up.
Susitna River Water Quality Model	5.6	EFDC	Water temperature during the open water period and other water quality parameters year round from RM 184 to RM 26
1-D Bed Evolution Model (Hydraulics and Sediment Transport)	6.6	TBD[1] (Q2 2013)	One-dimensional sediment transport characteristics, bed aggradation/degradation and substrate gradation in the main channel from RM 184 to RM 74. May be used to determine these parameters for localized off-channel habitat within focus areas. Mainstem Open-Water Hydraulic Routing Model will take precedence for 1-D hydraulics.
2-D Bed Evolution Model (Hydraulics and Sediment Transport)	6.6	TBD[2] (Q2 2013)	Detailed two-dimensional hydraulic and sediment transport characteristics, bed aggradation/degradation and substrate gradation within the focus areas. Will provide two-dimensional velocity and depth for FA-IFS within focus area where applied during the open water period. Boundary condition of downstream water surface elevation and upstream inflow supplied by Mainstem Open-Water Flow Routing Model

Notes:

1 Candidate Models: HEC-RAS, HEC-6T, SRH-1D, MIKE-11
2 Candidate Models: SRH-2D, MIKE-21, SToRM, ADH, River-2D

Table 6.6-5. Potential Focus Areas in the Middle and Lower Susitna River Segments.

Feature	Downstream RM	Upstream RM	Geomorphic Reach	Reach Type
Below Dam	182.0 (184.7)[1]	183.0 (185.7)[1]	MR-1	SC2
MR2-wide	170.7 (173.6)[1]	172.5 (175.4)[1]	MR-2	SC2
MR2-narrow	168.5 (171.6)[1]	170.0 (173.0)[1]	MR-2	SC2
Portage Cr	148.3 (151.8)[1]	148.8 (152.3)[1]	MR-5	SC2
Slough 21	141.0 (144.4)[1]	142.1 (145.7)[1]	MR-6	SC3
Indian R	138.4 (141.8)[1]	140.0 (143.4)[1]	MR-6	SC3
Slough 11	135.3 (138.7)[1]	136.6 (140.0)[1]	MR-6	SC3
Slough 8A	124.2 (128.1)[1]	126.1 (129.7)[1]	MR-6	SC3
Slough 6A	111.8 (115.3)[1]	113.0 (116.5)[1]	MR-7	SC2
Whiskers Slough	101.0 (104.8)[1]	102.2 (106.0)[1]	MR-8	MC1

Notes:

1 Values in parenthesis are Project River Miles (PRM)

Table 6.6-6. Primary output variables for which values are taken directly from the 1-D and 2-D mobile-boundary models and relevance to other studies.

Variable	Description of Model Output	Spatial Resolution	Relevance to Other Studies
1-D mobile-boundary model			
Water-surface profiles	Steady-state water-surface profiles for all discharges	Cross-section	Geomorphology
Cross-sectionally averaged hydraulic conditions	Flow depth, velocity, bed shear stress, channel top width	Cross-section	FA-IFS, R-IFS, Geomorphology
Bed material load transport rates	Transport rates by grain size fraction	Cross-section	Geomorphology
Bed material (i.e., substrate) gradations	Change in surface layer bed gradations by cross-section over time (0, 25, 50 years)	Cross-section	FA-IFS, Geomorphology
Bed elevation	Changes in bed elevation with time	Cross-section, longitudinal profile	FA-IFS, R-IFS, Geomorphology, GW
2-D mobile-boundary model			
Water-surface elevations	Steady and unsteady water-surface elevations	Grid element	FA-IFS, R-IFS, Geomorphology, GW
Depth-averaged hydraulic conditions	Flow depth , velocity (magnitude and direction), bed shear stress	Grid element	FA-IFS, R-IFS, Geomorphology, GW
Flow distribution among multiple channels (including side channels)	Discharge in each branch (including side channels) over range of flows; changes associated with bed evolution model results	Channel width	FA-IFS, R-IFS, Geomorphology, GW
Bed material load transport rates	Transport rates by grain size fraction, including supply to and transport through side channels	Grid element	FA-IFS, R-IFS, Geomorphology, GW
Bed material (i.e., substrate) gradations	Change in substrate gradations by grid element over time, including side channels and side sloughs	Grid element	FA-IFS, R-IFS, Geomorphology, GW
Bed elevation	Changes in bed elevation with time, including side channels and side sloughs. Evolution of mouths and spawning areas of particular interest	Grid element	FA-IFS, R-IFS, Geomorphology, GW
Breaching flows	Magnitude, frequency and duration of flows overtopping control at the head of side channels	Grid element →side channel width	FA-IFS, Geomorphology

Table 6.6-7. Key variables needed for the impact assessments for which results are obtained through additional analysis of predictions taken directly from the 1-D and 2-D mobile-boundary models.

Variable	Description	Spatial Resolution	Relevance to Other Studies
1-D mobile-boundary model			
Wash load transport rates	Correlations between wash load transport rates and discharge	Gage locations	WQ, R-IFS
Overbank sedimentation rates	Rate of sediment delivery into overbanks and vertical accretion rates	Reach-averaged	R-IFS, Geomorphology
Breaching flows	Magnitude, frequency and duration of flows overtopping control at the head of side channels	Site	R-IFS, Geomorphology
Side channel connectivity	Frequency, duration and inundation extent of backwater flows into side channels	Site	R-IFS
Bed Material Motion Thresholds (aka Incipient Motion Analysis)	Frequency and duration of flows sufficient to cause general mobilization of bed material	Cross-section and/or reach-averaged	FA-IFS, Geomorphology
Bed material transport capacity rating curves	Bed material transport capacity (total and by-size fraction) as a function of discharge	Cross-section and/or reach-averaged	Geomorphology
Effective Discharge	Magnitude and frequency of flows that transport the most sediment over defined period of time	Reach-averaged	Geomorphology
Bank erosion rates	Estimated rate of erosion into main and side channel banks	Cross-section and/or reach-averaged	R-IFS, Geomorphology
LWD recruitment	Quantities of LWD delivered to mainstem and side channels due to bank erosion	Reach	R-IFS, Geomorphology
Deposition rates at tributary mouths	Evolution of tributary mouth fans/bars over time	Geomorphology unit	FA-IFS, Geomorphology
Hydraulic conditions at tributary mouths	Potential effect of changes in tributary mouths and effects on fish passage into tributaries	Geomorphology unit	FA-IFS, Geomorphology
2-D mobile-boundary model			
Weighted-useable-area versus discharge curves	Hydraulic conditions (velocity, depth, substrate size) provided to FA-IFS for WUA estimates	Grid element→ Habitat unit	FA-IFS, Geomorphology
Overbank sedimentation rates	Rate of sediment delivery into overbanks and vertical accretion rates	Grid element	R-IFS, Geomorphology
Bed Material Motion Thresholds (aka Incipient Motion Analysis)	Frequency and duration of flows sufficient to cause general mobilization of bed material	Grid element→ Habitat unit	FA-IFS, Geomorphology
Bank erosion rates	Changes in bank shear stress and bank energy index (BEI)	Model reach	R-IFS, Geomorphology

Variable	Description	Spatial Resolution	Relevance to Other Studies
Changes in side channel, side slough and upland slough geometry	Evolution of channel width and depth	Grid element →side channel width	FA-IFS, R-IFS, Geomorphology
Fine sediment interactions in spawning areas	Potential for infiltration and flushing of fines from spawning substrate, including side channels and side sloughs	Grid element→ Habitat unit	FA-IFS, R-IFS, Geomorphology
LWD recruitment	Changes in bank erosion rates that could affect LWD recruitment	Grid element	FA-IFS, R-IFS, Geomorphology

Table 6.6-8. Schedule for implementation of the Fluvial Geomorphology Modeling Study.

Activity	2012				2013				2014				2015
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
Selection of 1-D and 2-D Models		—	—	—	—	●							
Selection of Focus Areas			—	—	—●								
Coordination w/ Other Studies on Modeling Needs Including Focus Areas				—	—	—	—	—	—	—	—●		
2013 Field Data Collection / Supplemental Field Data Collection 2014						—	—	●	/	—	—●		
Coordinate with Other Studies on Processes Modeled				—	—	—	—●						
1-D Model Development and Calibration						—	—	—					
Perform 1-D Modeling of Existing Conditions and Initial Project Run								—	—●				
Reevaluate Downstream Study Limits Based on 1-D Results									—	●			
2-D Model Development and Calibration							—	—	—	—			
Perform 2-D Modeling of Existing Conditions										—	—●		
Perform 1-D Modeling of Alternative Scenarios									—	—	—	—●	
Perform 2- Modeling of Alternative Scenarios											—	—●	
Post Process and Provide Model Results to Other Studies										—	—	—●	
Interpretation of Channel Change and Integration with Other Studies										—	—	—●	
Initial Study Report /Updated Study Report								—	Δ		—	—	—▲

Legend:
- —— Planned Activity
- ● Technical Memorandum or Interim Product
- Δ Initial Study Report
- ▲ Updated Study Report

Table 6.6-9. Information and products required by the Fluvial Geomorphology Modeling Study from other studies.

Source of Product or Information	Information or Product to be Provided	Timing
Information or Products Required for: Field Data Collection		
Fish and Aquatics Instream Flow Study (Section 8.5) Riparian Instream Flow Study (Section 8.6) Groundwater Study (Section 7.5) Ice Processes Study (Section 7.6) Characterization and Mapping of Aquatic Habitats Study (Section 9.9)	Collaboration on Focus Area selection	Q1-13
	Collaboration on modeling needs	Q2-13
	Sharing of field data	Q3-13
	Locations of specific interest within the Focus Areas	
Information or Products Required for: 1-D, 2-D and Tributary Delta Model Development and Calibration		
Geomorphology Study (Section 6.5)	Sediment supply	Q4-12 & Q4-13
	Historical channel change	Q1-13
	Identify physical processes	Q4-13
	Initial estimates of reservoir sediment trap efficiency	Q3-13
	Flood frequency and flow duration	Q3-13
Water Quality Modeling Study (Section 5.6)	Reservoir sediment trap efficiency for alt. scenarios	Q2-14
Glacial and Runoff Change Study (Section 7.7)	Potential increase in sediment supply from glacial surge	Q1-14
Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3)	Tributary inflows and accretions	Q3-13
Reservoir Operations (Engineering)	Base case annual hydrographs for representative years	Q3-13
Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3)	Base case continuous record daily flows (50 years)	Q3-13
Information or Product Required for: 1-D, 2-D and Tributary Delta Model Baseline and Alternative Scenarios Analysis		
Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3)	Tributary inflows and accretions	Q3-13
Reservoir Operations (Engineering)	Base case annual hydrographs for representative years	Q3-13
	Alt. scenarios annual hydrographs for representative yrs	Q4-14
Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3)	Base case continuous record daily flows (50 years)	Q3-13
	Alt. scenarios continuous record daily flows (50 years)	Q4-14

Source of Product or Information	Information or Product to be Provided	Timing
Information or Product Required for: Integration of Reach- & Local-Scale Modeling and Geomorphic Analysis		
Geomorphology (Section 6.5)	Bed material mobilization and effective discharge	Q4-13 & Q4-14
	Assessment Project effects on geomorphic processes and threshold relationships	
Ice Processes (Section 7.6)	Geomorphic influences from ice	Q4-13
Riparian Instream Flow Study (Section 8.6)	Historical floodplain sedimentation rates	Q1-14
	Vegetation age classes	Q1-14

Table 6.6-10. Information and products the Fluvial Geomorphology Modeling Study will provide to other studies.

Study the Product or Information is Provided to	Information or Product to be Provided	Timing
Information or Products Provided by: Field Data Collection		
Geomorphology Study (Section 6.5) Fish and Aquatics Instream Flow Study (Section 8.5) Riparian Instream Flow Study (Section 8.6) Water Quality Modeling Study (Section 5.6)	Cross-section and bathymetry	Q4-13
	ADCP velocity and depths	
	Bed and bank material sample results	
	Geomorphic site assessments	
	Locations of specific interest within the Focus Areas	
Information or Products Provided by: 1-D, 2-D and Tributary Delta Model Development and Calibration		
1-D, 2-D and Tributary Delta Model Baseline and Alternative Scenarios (Section 6.6.4.2)	Calibrated 1-D bed evolution model	Q4-13
	Calibrated 2-D bed evolution model	Q2-14
	Tributary delta model for selected tributaries	Q1-14
Information or Products Provided by: 1-D, 2-D and Tributary Delta Model Baseline and Alternative Scenarios Analysis		
Water Quality Modeling Study (Section 5.6)	Changes in fine sediment load for turbidity modeling	Q4-14
Geomorphology Study (Section 6.5) Fish and Aquatics Instream Flow Study (Section 8.5) Riparian Instream Flow Study (Section 8.6) Groundwater Study (Section 7.5)	Bed aggradation and degradation - reach scale	Q4-14
	Change in substrate size – reach scale	
	Changes in erosion and deposition patterns	
	Changes in bed material load transport	
	Hydraulic parameters: velocity depth and water surface elevations (WSE)	
Information or Products Provided by: Integration of Reach- & Local-Scale Modeling and Geomorphic Analysis (see Tables 6.6-6 and 6.6-7 for detailed list of information)		
Riparian Instream Flow Study (Section 8.6)	Potential changes in channel morphology	Q4-14
Groundwater Study (Section 7.5)		
Recreation and Aesthetics Study (Section 12)		
Fish and Aquatics Instream Flow Study (Section 8.5)	Potential changes in habitat: maintenance and evolution	Q4-14
	Potential changes in habitat: relative distribution	
	Potential changes in habitat: areas for specific types	
	Potential changes in habitat: connectivity of off-channel	
Riparian Instream Flow Study (Section 8.6)	Changes in floodplain sedimentation rates	Q4-14

Table 6.6-11. Fluvial Geomorphology Modeling Study costs.

Component	Task/Subtask		Estimated Cost Range
Bed Evolution Model Development, Coordination and Calibration	Development of Bed Evolution Modeling Approach and Model	Develop Approach	$50,000
		Develop Model	$400,000 to $500,000
		Field Data Collection	$900,000 to $1,100,000
	Coordination with other Studies on Processes Modeled		$50,000
	Calibration/Validation of Model		$200,000 to $300,000
Model Existing and with-Project Conditions	Model Existing Conditions (one scenario)		$200,000 to $300,000
	Model with-Project Conditions (three scenarios)		$250,000 to $350,000
Coordination on Model Output / Study Integration			$150,000 to $200,000

6.6.11. Figures

Figure 6.6-1. Example of coarse mesh applied to the Whiskers Slough potential Focus Area, Middle Susitna River Segment, Geomorphic Reach MR-8

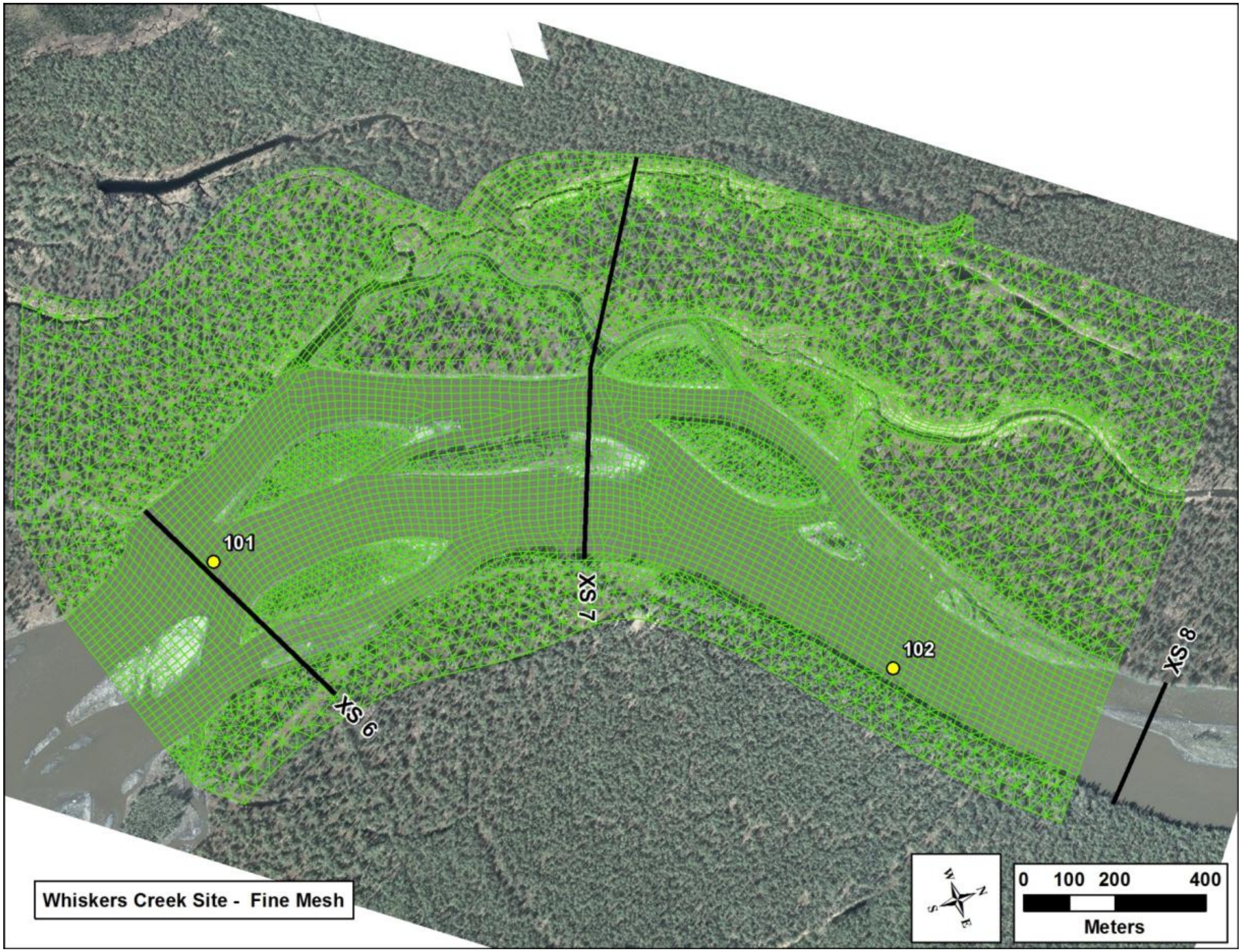

Figure 6.6-2. Example of fine mesh applied to the Whiskers Slough proposed Focus Area, Middle Susitna River Segment, Geomorphic Reach MR-8

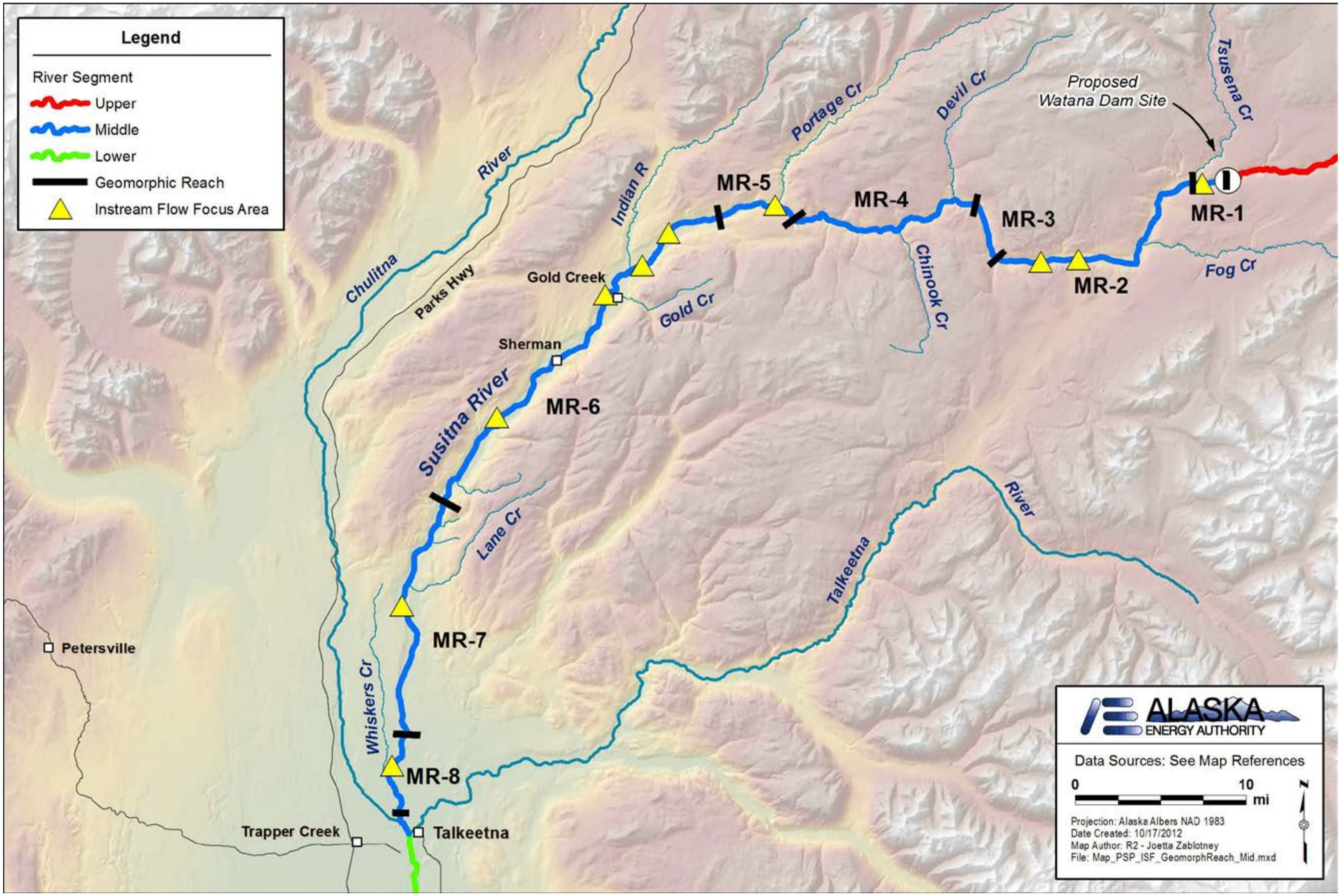

Figure 6.6-3. Locations of proposed Middle Susitna River Segment Focus Areas.

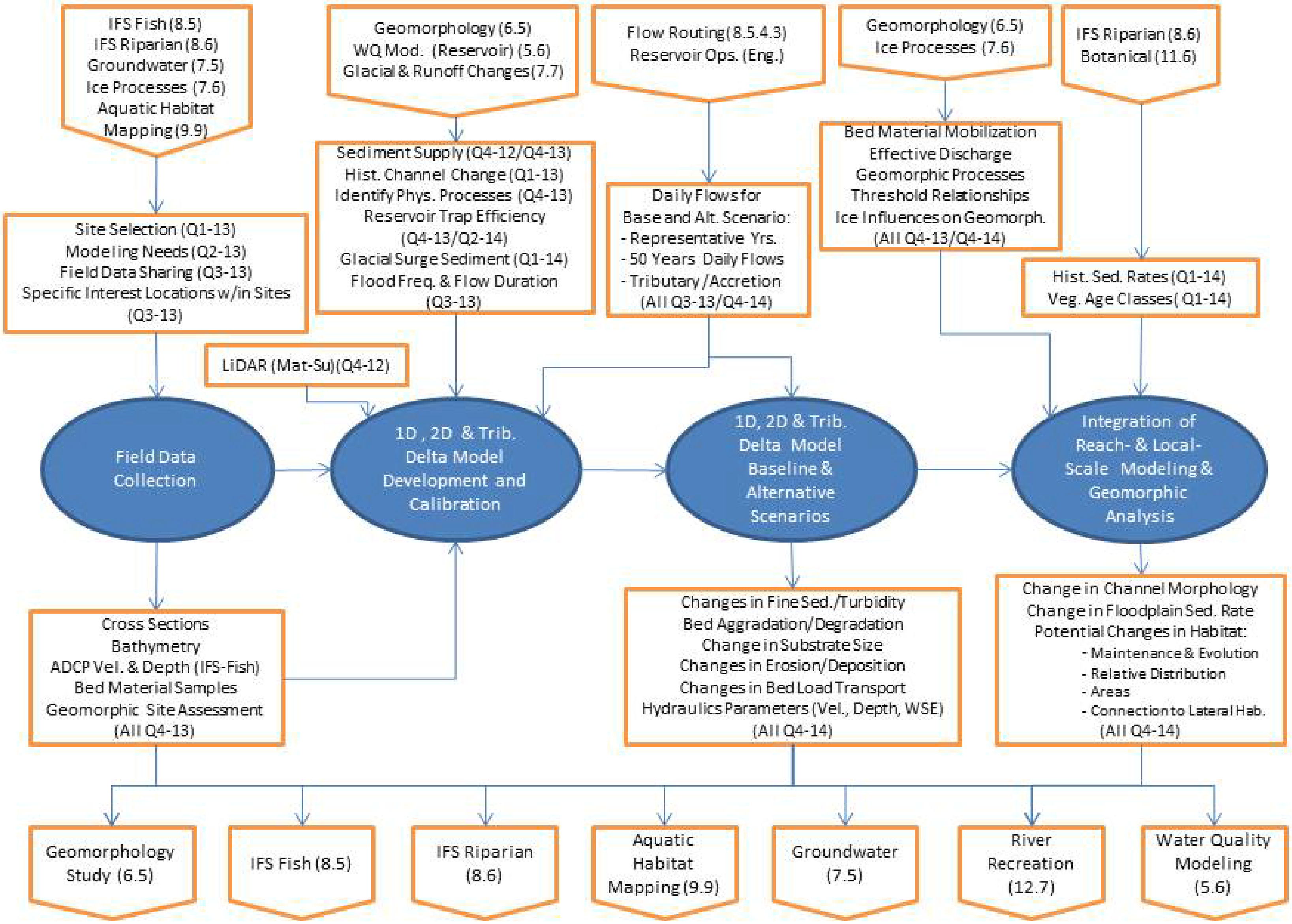

Figure 6.6-4. Study interdependencies for the Fluvial Geomorphology Modeling Study