Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fluvial Geomorphology Modeling below Watana Dam Study

Study Plan Section 6.6

Initial Study Report

Part A: Sections 1-6, 8-10

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Tetra Tech

Watershed GeoDynamics

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LIST OF ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

Abbreviation	Definition
1-D	one-dimensional
2-D	two-dimensional
AEA	Alaska Energy Authority
ADCP	Acoustic Doppler Current Profiler
AGL	Above Ground Level
ASPRS	American Society for Photogrammetry and Remote Sensing
BEI	Bank Energy Index
cfs	Cubic feet per second
CIRWG	Cook Inlet Region Working Group
CVA	Consolidated Vertical Accuracy
DEM	Digital elevation model
EFDC	Environmental Fluid Dynamics Code
FA	Focus Area
FERC	Federal Energy Regulatory Commission
FVA	Fundamental Vertical Accuracy
FGM	Fluvial Geomorphology Modeling below Watana Dam Study
GAA	Geomorphic Assessment Area
GIS	Geographic Information System
HEC	Hydraulic Engineering Center
HEC-RAS	Hydraulic Engineering Centers River Analysis System
IFIM	Instream Flow Incremental Methodology
IFS	Instream Flow Study
ILP	Integrated Licensing Process
IMU	Inertial Measurement Unit
ISR	Initial Study Report
LED	light-emitting diode
LiDAR	Light Detection and Ranging
LR	Lower River
LWD	large woody debris
m	meters
Mat-Su	Matanuska-Susitna
MC	main channel
MR	Middle River
NDEP	National Digital Elevation Program
NMFS	National Marine Fisheries Service
OS	Operating Scenario
PDO	Pacific Decadal Oscillation

Abbreviation	Definition
Project	Susitna-Watana Hydroelectric Project
PRM	Project River Mile
RIFS	Riparian Instream Flow Study
RM	River Mile
RMSEz	Root Mean Square Error in the Z axis (vertical)
RSP	Revised Study Plan
SC	side channel
SPD	Study Plan Determination
SRH-2D	Sedimentation and River Hydraulics – Two-Dimensional
SuWa	Susitna Watana
SVA	Supplemental Vertical Accuracy
TIN	Triangulated Irregular Network
TM	Technical Memorandum
TWG	Technical Wrokgroup
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USGS	U.S. Department of the Interior, Geological Survey
USR	Updated Study Report
WSE	Water Surface Elevation

1. INTRODUCTION

On December 14, 2012, Alaska Energy Authority (AEA) filed its Revised Study Plan (RSP) with the Federal Energy Regulatory Commission (FERC or Commission) for the Susitna-Watana Hydroelectric Project (FERC Project No. 14241), which included 58 individual study plans (AEA 2012). Included within the RSP was the Fluvial Geomorphology Modeling below Watana Dam Study, Study 6.6. RSP Study 6.6 focuses on the modeling planned for assessing the effects of the proposed Project and its operations on water quality 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 (TWG) participants for comment a Draft Fluvial Geomorphology Modeling Approach Technical Memorandum (Geomorphology Modeling TM; Tetra Tech 2013h) 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. The National Marine Fisheries Service (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 June 30, 2013.

The Final Geomorphology Modeling Approach TM and several other TMs developed by the Geomorphology Study (ISR Study 6.5) to provide information to support the Fluvial Geomorphology Modeling below Watana Dam Study are listed below:

- Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments (Tetra Tech 2013a)
- Initial Geomorphic Reach Delineation and Characterization, Middle and Lower Susitna River Segments (Tetra Tech 2013b)
- Reconnaissance Level Assessment of Potential Channel Change in the Lower Susitna River Segment (Tetra Tech 2013c)
- Stream Flow Assessment (2013d)
- Synthesis of 1980s Aquatic Habitat Information (2013e)
- Mapping of Aquatic Macrohabitat Types at Selected Sites in the Middle and Lower Susitna River Segments from 1980s and 2012 Aerials (2013f)
- Mapping of Geomorphic Features and Assessment of Channel Change in the Middle and Lower Susitna River Segments from 1980s and 2012 Aerials (2013g)
- Fluvial Geomorphology Modeling Approach (2013h)
- Field Assessment of Underwater Camera Pilot Test for Sediment Grain Size Distribution (2013i) (Note: Included as Attachment A)

Following the first study season, FERC's regulations for the Integrated Licensing Process (ILP) require AEA to "prepare and file with the Commission an initial study report describing its overall progress in implementing the study plan and schedule and the data collected, including an explanation of any variance from the study plan and schedule" (18 CFR 5.15(c)(1)). This Initial Study Report (ISR) on Fluvial Geomorphology Modeling below Watana Dam has been prepared in accordance with FERC's ILP regulations and details AEA's status in implementing the study, as set forth in the FERC-approved RSP and as modified by FERC's April 1 SPD, and includes the Final Geomorphology Modeling TM filed with FERC on June 30, 2013 (Tetra Tech 2012) (collectively referred to herein as the "Study Plan").

2. STUDY OBJECTIVES

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 (Study 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 below Watana Dam Study address these questions.

Specific objectives of the Fluvial Geomorphology Modeling below Watana Dam 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.

3. STUDY AREA

RSP Section 6.6.3 initially established the study area for this study. The Fluvial Geomorphology Modeling below Watana Dam Study utilizes an approach in which the entire study length is being assessed by a 1-D Bed Evolution Model to determine potential reach-level Project effects. More detailed 2-D Bed Evolution modeling is being performed in locations referred to as “Focus Areas”. The modeling approach is discussed in more detail in Section 4.1.2.1 and in the Modeling Approach TM (Tetra Tech 2013h). Specific study areas are associated with each of the two modeling scales.

3.1. Downstream Study Limit

The study area for the Fluvial Geomorphology Modeling below Watana Dam was initially identified in the RSP as the portion of the Susitna River from Watana Dam (Project River Mile [PRM] 187.1 [RM 184]) downstream to PRM 79 (River Mile [RM] 75). This downstream limit was set to extend the study into the upper portion of the Lower Susitna River Segment. This limit extends the study 9 miles downstream of the lower limit of Geomorphic Reach LR-1. Initial evaluation of information from the 1980s studies indicated that it was unlikely that Project effects on the geomorphology of the Susitna River would extend downstream of Geomorphic Reach LR-1. This initial assessment was 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 increase 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 could 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 and completed in Q1 2013 (Tetra Tech 2013a through 2013g)—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 (Study 6.5), and additional 2012 habitat mapping (Study 9.9) operations modeling and the Open-water Flow Routing Model (RSP Section 8.5.4.3)—were used to reassess the extent to which Project operations could potentially influence habitats in the Lower River Segment. An assessment of the downstream extent of Project effects was completed in Q1 2013 and the results presented in technical memorandums (R2 Resource Consultants [R2] 2013a and R2 2013b) in collaboration with the TWG. This assessment was supported by the results presented in the TMs prepared by the Geomorphology Study (Tetra Tech 2013a through 2013g). The assessment guided the decision to extend studies into the Lower River to PRM 29.9, and to the determination of which geomorphic reaches were subject to reach and Focus Area level modeling of the Susitna River fluvial geomorphology in 2013. Figure 3.1-1 shows the current limits of the Fluvial Geomorphology Modeling below Watana Dam Study.

The 1-D Bed Evolution Model study area currently includes the entire Middle Susitna River Segment from the Watana Dam site (PRM 187.1 [RM 184]) downstream to the Three Rivers Confluence area (PRM 102.4 [RM 98]). It includes the majority of the Lower Susitna River Segment from the Three Rivers Confluence area downstream to Susitna Station at PRM 29.9. (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 is 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.)

The final 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 PRM 29.9 (Susitna Station) in Geomorphic Reach LR-5, the 1-D modeling will be continued farther downstream in the Lower Susitna River

Segment in a next year of study. 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. Table 3.1-1 provides a summary of the steps and dates involved in the process that was used to assess and adjust the downstream study limit in Q1 2013, and, if necessary, will be used to adjust the downstream study limit for the Fluvial Geomorphology Modeling below Watana Dam Study in a next year of study.

3.2. Focus Areas

The bed evolution modeling approach includes 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 (PRM 187.1 to PRM 29.9 excluding Devils Canyon as noted above). 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 is being applied in the ten selected Focus Areas (R2 2013a and R2 2013b for more details on Focus Area selection). Focus Areas involve portions of the Susitna River and its floodplain where detailed study efforts are being jointly conducted by several study teams including the Fish and Aquatics Instream Flow (Study 8.5), Riparian Instream Flow (Study 8.6), Geomorphology (Study 6.5), Ice Processes in the Susitna River (Study 7.6), Groundwater (Study 7.5), and Characterization and Mapping of Aquatic Habitats (Study 9.9) studies. The Focus Areas are at the core of a highly integrated, multidisciplinary effort to evaluate potential Project effects for key resource areas across a range of representative sites.

The 2-D models—bed evolution and hydraulic—are being 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 are being applied to each Focus Area, within the selected 1-D modeling study area. The Focus Areas were selected to be representative of important habitat conditions and the various geomorphic reach types. The Focus Areas were chosen jointly by the Fish and Aquatics Instream Flow (Study 8.5), Riparian Instream Flow (Study 8.6), Geomorphology (Study 8.5), Ice Processes in the Susitna River (Study 7.6), and Characterization and Mapping of Aquatic Habitats Study (Study 9.9) studies to facilitate maximum integration of available information among the studies. Sites were 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 cover the range of riverine aquatic habitat types (see R2 2013a and R2 2013b and ISR Study 8.5 Section 4.2.1.2.1). The portions of the tributaries that fall within the Focus Areas are part of the 2-D model domain including the current tributary delta or alluvial fan areas.

Selection of 10 Focus Areas was performed in Q1 and Q2 of 2013 in coordination with the TWG. The process and results are documented in two TMs (R2 2013a and R2 2013b). The first TM provides the initial recommendations for 10 Focus Areas and the second TM provides adjusted locations based on input from the TWG. The resulting locations are provided in Figure 3.2-1.

4. METHODS AND VARIANCES IN 2013

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. These study components build on earlier efforts documented in technical memoranda (Tetra Tech 2012, Tetra Tech 2013a through 2013g) performed under the Geomorphology Study (Study 6.5). These technical memoranda (TMs) helped guide the development of this study. As examples, the geomorphic reach delineation (Tetra Tech 2013b) was developed in 2012 in order to provide other studies a tool to help stratify the Susitna River system including selection of Focus Areas. The sediment transport TM (Tetra Tech 2013a) provides sediment transport relationships that help define sediment supply to the bed evolution model developed in this study. The assessment of potential channel change in the Lower Susitna River (Tetra Tech 2013c) was developed to help inform the decisions on the downstream limit for the this study as well as several other studies.

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 numerical models that can accurately simulate fluvial geomorphic processes that influence the morphology of the Susitna River channel and floodplain downstream of Watana Dam.

4.1.1. Existing Information and Need for Additional Information

During the 1980s studies of the Susitna Hydroelectric Project, various efforts were carried out to characterize sediment supply and sediment transport capacity. 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).

R&M Consultants, Inc. (1982a) considered three primary influences of the Susitna River backwater on 19 tributaries discharging into it between the Devils Canyon dam site and the Susitna-Chulitna confluence: (1) fish access into the streams, (2) sediment deposition at the confluences, and (3) reduced flow velocity in the stream channel. Tributaries that were expected to encounter a possible impact on Alaska Railroad structures crossing them were also considered. Qualitative assessments of creek stability under post-Project conditions were made based on field surveys and observations. These assessments included factors such as bed load transport, creek hydrology, bed material, and confluence geometry. The qualitative assessments were followed up with semi-quantitative analyses where determined necessary. These analyses included calculation of bed-material transport by relating flow and slope to sediment discharge and bed-material size. Channel slopes were surveyed, mean annual flood peak flows were estimated using regression equations, bed-material gradations were visually estimated, and pre-Project to post-Project changes in Susitna River water-surface elevation at each tributary mouth were calculated from hydraulic modeling simulations of the mean annual flood; sediment discharge was not quantified. A rigorous mathematical development of sediment transport capacity was determined to be beyond the scope of the study, so this previous work illustrates the need for quantification of the sediment supply delivered from major tributaries to the Middle and Lower Susitna River Segments.

R&M Consultants, Inc. (1982b) describes analyses of sedimentation within the proposed Watana and Devils Canyon Reservoirs. The annual sediment load entering the reservoirs was estimated using the flow-duration sediment-rating curve method for the nearest gaging stations; an areal sediment yield was estimated for the tributary areas draining directly into the reservoirs. No information is provided regarding the development of the sediment-rating curves or the flow-duration curves. The average annual sediment loads are summarized in Table 4.1-1. The sediment contributed by the tributaries directly to the reservoirs was estimated from the unit sediment runoff per square mile between the U.S. Geological Survey (USGS) gages near Cantwell and at Gold Creek (i.e., 425 tons of total sediment load per square mile per year).

Harza-Ebasco (1984) includes estimates of average annual sediment loads at the Watana Dam site by interpolating the loads at the USGS gages near Cantwell and at Gold Creek. The loads at the USGS gages were calculated using the flow-duration sediment-rating curve method. Suspended-sediment measurements near Cantwell were collected between 1962 and 1972 and a curve was visually fitted to all data points. Average annual sediment loads were calculated using the suspended sediment-rating curve, the flow-duration curve (based on 13 years of measurements: 1962 to 1972 and 1981 to 1982), and an assumed bed load equal to 3 percent of the suspended load (Table 4.1-2). Suspended-sediment measurements at Gold Creek were collected from 1949 to 1982; separate curves were visually fit to data collected from May through October and November through April. Using the same methods as used near Cantwell, the average annual loads were calculated. An areal scaling was used to interpolate the sediment loading at the Watana Dam site, which is located between the two gages.

The differences in the sediment loads calculated in R&M Consultants, Inc. (1982b) and Harza-Ebasco (1984) indicate the need to use updated measurements of sediment transport to refine the sediment loading into Watana Reservoir, and the corresponding sediment loads conveyed downstream to the Middle Susitna River Segment.

None of the reviewed studies from the 1980s include explicit calculations of sediment transport capacity in the Susitna River downstream of the Watana Dam site at locations other than USGS gages. However, samples of bed material and simulated hydraulics were used to infer mobilization of bed material (as summarized in ISR 6.5 Section 4.3.1). Harza-Ebasco (1984) includes sediment gradations derived from sieve analyses of 17 bed-material samples from the mainstem Susitna River, 2 samples from the Chulitna River, and 29 samples from side channels of the Susitna River upstream from the Three Rivers Confluence. R&M Consultants, Inc. (1985) includes gradations derived from sieve analysis of multiple bed-material samples collected along the length of 8 cross-sections located approximately between the Three Rivers Confluence and the USGS gage at Sunshine. R&M Consultants, Inc. (1982c) describes the development and calibration of HEC-2 numerical hydraulic models for two reaches of the Susitna River: (1) the upper study reach from Deadman Creek downstream to Devil Creek, and (2) the middle study reach from the outlet of Devils Canyon downstream to the Susitna-Chulitna confluence. To accommodate the island and split-channel conditions, separate models were developed for flows above/below 20,000 cubic feet per second (cfs; the flow at which side channels were judged to be hydraulically connected). Harza-Ebasco (1983) describes refinements to the R&M Consultants, Inc. (1982c) HEC-2 models using new and updated cross-section geometry and improved calibration datasets based on staff gage measurements. Calibration was focused on adjustments to the initial estimates of Manning's n-values. The Harza-Ebasco (1983) modeling approach still relied on separate models for flows above/below 20,000 cfs. The models were developed to simulate water-surface elevations, average channel velocities, and stage-discharge rating curves at all surveyed sections between the mouth of Devils Canyon and the USGS gage at Sunshine.

Holly et al. (1985) document the BRALLUVIAL numerical simulation program for computation of long-term bed evolution in multiply-connected fluvial channels. The model code was developed to forecast the effect of possible flow modulation by two proposed Susitna hydropower dams on sediment deposition patterns in the highly braided 15-mile reach of the Susitna River from the Chulitna–Talkeetna confluence downstream to the Sunshine Bridge. The code was based on the sedimentation methodology previously developed for simple channels (i.e., the IALLUVIAL code); however, it was necessary to develop a new water flow methodology to handle multiple flow paths of the braided system. The resulting combination of new and existing techniques was based on assumption of quasi-steady, one-dimensional flow, and incorporated procedures for treatment of highly non-uniform sediments, sediment sorting, bed armoring, flow-dependent friction factor, and alternate drying and flooding of perched channels. The total load transport model and friction-factor relations previously developed were re-calibrated for the limited Susitna bed-sediment data. Although preliminary tests were performed as described in this report, actual use of the model was the responsibility of Harza-Ebasco Susitna Joint Venture. Use of the model was reportedly described in a companion report, but a copy of that report to review has not been located.

The lack of historical mobile bed modeling highlights the need to develop sediment transport models that can simulate the geomorphic responses of the Susitna River to potential changes in hydrology and sediment supply from existing conditions to post-Project conditions.

While the existing information just summarized provides useful context for developing and calibrating these models, the uncertainty and limitations of the existing information confirm the need for refined evaluations to provide the needed model input and calibration datasets. Both 1-D and 2-D Bed Evolution 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 bed evolution models.

4.1.2. Methods

AEA implemented the methods as describe in the Study Plan with no variances. 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

The first bullet includes the field data collection efforts that provided first-hand information to assist in the development of the modeling approach, and ultimately, the models themselves.

4.1.2.1. Development of Bed Evolution Model Approach and Model Selection

This section provides an updated description of (1) the bed evolution model approach, particularly in regard to the model selection process described in more detail in the Modeling Approach Technical Memorandum (Tetra Tech 2013h); and (2) the methods for applying both the reach-scale 1-D model and the local-scale 2-D bed evolution models. This section includes a description of the tasks completed during 2013, tasks that are ongoing, and tasks that will be completed during the next year of study. The tasks completed during 2013 are described in Section 5 of this ISR.

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 (Study 6.5) provides a considerable part of the required investigation. Based on the study results and input from the Fish and Aquatics Instream Flow (ISR Study 8.5), including the Open-water Flow Routing Model (ISR Study 8.5 Section 4.3), Riparian Instream Flow (ISR Study 8.6), Ice Processes in the Susitna River (ISR Study 7.6), Characterization and Mapping of Aquatic Habitats (ISR Study 9.9), and Fish Barriers in the Middle and Lower Susitna River and Susitna Tributaries (ISR Study 9.12) 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 that will be considered 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 perspectives 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 (1) outline the identified issues considered, and (2) summarize the development of the modeling approach, the model selection, and the model development.

Issues Considered: To develop the modeling approach, specific issues were identified and were differentiated into reach-scale and local-scale 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 bed-load 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 separate topic in Section 4.1.2.6.

<u>Synthesis of Reach-Scale and Local-Scale Analyses</u>: The final step in the development of the modeling approach 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.

Development of Modeling Approach: The 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, the capabilities of 1-D and 2-D Bed Evolution models, and the need to evaluate potential Project effects over the majority of the system and at small habitat scales, a combination of 1-D and 2-D modeling approaches is required. Considering the broad physical expanse of the Susitna River system, the general hydraulic and sediment transport characteristics of the various geomorphic reaches that make up the overall study area (ISR Study 6.5 Section 5.1) 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 flow distribution, habitat, breaching, and erosion/deposition issues related to changing hydrology, sediment supply, ice, and large woody debris (LWD) conditions.

The 2-D models will be applied to the 10 Focus Areas that are representative of important habitat conditions, the various geomorphic reaches, associated channel classification types, and selected primary tributaries. These Focus Areas were chosen in coordination with the licensing participants and the Fish and Aquatics Instream Flow (Study 8.5), Riparian Instream Flow (Study 8.6), Ice Processes in the Susitna River (Study 7.6), and Characterization and Mapping of Aquatic Habitats (Study 9.9) studies to facilitate maximum integration of available information between the studies. The selection of Focus Areas is documented in two technical memorandums, the first filed in Q1 2013 (R2 2013a) and the second in Q2 2013 (R2 2013b) as well as the Fish and Aquatics Instream Flow Study (ISR 8.5 Sections 4.1.2.3 and 5.1.3).

The integrated approach incorporating 1-D modeling at the reach-scale and 2-D modeling at the local-scale provides 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.
- 1-D Bed Evolution Model uses cross-sectional data that are being obtained as part of the Open-water Flow Routing Model (ISR Study 8.5 Section 4.3). (Note: the majority of the sections were obtained in 2012 and 2013. Additional sections will be surveyed during the next year of study.)
- The 1-D Bed Evolution Model will provide the boundary conditions for the 2-D model, including starting water-surface elevations and upstream sediment supply.
- 2-D Bed Evolution modeling applied at the Focus Areas that are also chosen for the Ice Processes in the Susitna River (ISR Study 7.6) and Riparian Instream Flow (ISR Study 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 Areas 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.

4.1.2.1.1. 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) characteristics of the bed material and wash load; and (4) the availability of necessary data for model development and calibration. In addition, because of the wide range of sediment sizes present in the Susitna River, both the 1-D and 2-D Bed Evolution models must be capable of routing sediment by size fraction, and ideally be capable of addressing deposition of fine sediment (wash load). While 2-D modeling provides 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. Two-dimensional (2-D) modeling is being used to evaluate the detailed hydraulic and sediment transport characteristics that control the complex geomorphic features and habitat at the local scale. A variety of candidate models were evaluated for application on the Susitna River. Selection of the 1-D and 2-D Bed Evolution models for this study (Study 6.6) was initiated in 2013 and will be completed in the next year of study. Section 5.1.1.1 describes the current progress on 1-D and 2-D Bed Evolution Model selection for this Study.

One-Dimensional (1-D) Bed Evolution Model Selection

Most 1-D movable-boundary sediment transport models (bed evolution 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 computational time-step and corresponding boundary conditions (e.g., discharge and stage), the water-surface profile is calculated using the step-backwater method or hydrodynamic equations 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. Where 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-section geometry and bed-material gradations from the previous time-step.

One-dimensional (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. One-dimensional 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. However, 1-D models are 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.

One-dimensional models that were considered for this study included the U.S. Army Corps of Engineers HEC-RAS (version 4.1; USACE 2010a) (version 4.2.0, beta release; USACE 2013), 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). More details and discussions regarding the potential benefits and limitations of each of these models are included in a Tetra Tech TM (2013h). As described in Section 5.1.1.1.1, the preferred models (HEC-6T and HEC-RAS version 4.2.0 beta) appear to best meet the criteria described below and are well suited for simulating conditions on the Susitna River. Final selection between these two models will occur in the next year of study.

The criteria used for selecting a 1-D Bed Evolution Model for this Project were primarily based on required functionality given the specific conditions of the Susitna River and its tributaries (Tetra Tech 2013h):

- The model must accommodate sufficiently large number of cross-sections to model over 100 miles of river including split-flow reaches.
- The model must be capable of storing sufficiently large number of hydrograph ordinates to model flows over the 50-year license period.
- The model must be capable of simulating sufficient number and range of sediment sizes to represent the range of materials.
- The model must include either (or both) the Parker (1990) or Wilcock and Crowe (2003) bed-load sediment transport equations because these are the most applicable to the range of coarse bed conditions in the Susitna River and tributaries.
- Closed-loop sediment transport capability must be included to model sediment transported around islands and in multiple channel reaches common in the Lower Susitna River Segment, but also present in the Middle Susitna River Segment.

There are also several desirable characteristics that influenced the decision about whether models are otherwise similar in their capabilities and performance. The desirable characteristics included public domain, high-level project experience with the model, unsteady flow routing capabilities, and advanced graphical user interface for model input and review of results. HEC-RAS Version 4.2.0 beta has all four of these characteristics while HEC-6T does not have an advanced graphical user interface or unsteady flow routing capabilities. Whether HEC-6T or HEC-RAS 4.2.0 beta are ultimately used for the final modeling, the model development is most efficiently performed using the HEC-RAS version.

Two-Dimensional (2-D) Bed Evolution Model Selection

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

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

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

A full description of the candidate 2-D bed evolution models is provided Tetra Tech (2013h).The following 2-D models were considered for this study:

- SRH-2D Version 3 (USBR)
- ADH version 3.3 (USACE)
- MD_SWMS (USGS)
- MIKE 21 (Danish Hydraulic Institute)
- River2D (University of Alberta)

The criteria for selecting a 2-D bed evolution model for this project are primarily based on required functionality based on the specific conditions of the Middle Susitna River Segment. The required characteristics to include:

- Capability for sufficiently large number of elements to model the Focus Areas at the required spatial resolution.
- Flexible mesh (irregular mesh) to accurately depict geometric and hydraulic variability.
- Capability to simulate a sufficient number and range of sediment sizes to represent the range of materials in each Focus Area.
- Sediment transport calculations must be performed by size fraction, especially to simulate bed-material sorting and armoring processes in coarse bed channels.

- The model must include either (or both) the Parker (1990) or Wilcock and Crowe (2003) bed load sediment transport equations, as these are the most applicable to the range of coarse bed conditions in the Susitna River and tributaries.
- The model must be numerically stable under a wide range of flow conditions, especially as portions of the network wet and dry.

As with 1-D bed evolution models, there are several desirable characteristics that influenced the decision if models are otherwise similar in their capabilities and performance. The desirable characteristics include: public domain, high level of experience with the model, moderate to fast execution speed, and advanced graphical user interface for model input and reviewing results.

During 2013, based upon analysis and as explained in Section 5.1.1.1.2, AEA selected River2D and SRH-2D models as the preferred 2-D bed evolution models for this study (Tetra Tech 2013h). Final selection between these two models will occur in 2014.

4.1.2.1.2. Model Development

Overview of 1-D Bed Evolution Model Development

The following steps are being followed to develop the 1-D Bed Evolution Model. With few exceptions (as noted) the model development is very similar regardless of the selected model. An overview of calibration and validation is included below and is discussed in more detail in Section 4.1.2.5.1. Review and quality control procedures will be implemented throughout the model development process and are not indicated as individual steps. Section 5.1.1.2.1 provides the progress in 2013 on the following steps with significant progress having been made in steps 1 through 5. The steps are (Tetra Tech 2013h):

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

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

Overview of 2-D Model Development

The following steps are being followed to develop the 2-D Bed Evolution and Hydraulic models of the Focus Areas. An overview of model calibration and validation is included below and is discussed in more detail in Section 4.1.2.5.2. Review and quality control procedures will be implemented throughout the model development process and are not indicated as individual steps. Section 5.1.1.2.2 provides the progress in 2013 on the following steps with significant progress having been made in steps 1 through 6 and 8. The steps are (Tetra Tech 2013h):

1. Determine the overall model layout.
   - Downstream boundary stage-flow conditions developed from 1-D Bed Evolution Model.
   - Upstream (i.e., inflowing) discharge and sediment supply from 1-D Bed Evolution Model.
   - Tributary flow and sediment input from tributary models.
2. Develop geometric base data.
   - Data from TIN (Triangulated Irregular Network) surface representation from land and bathymetric survey including necessary break lines, and
   - Data from LiDAR bare-earth dataset for island and floodplain areas not surveyed.
3. Develop model network.
   - Determine node and element locations and configurations to accurately represent geometry (bathymetry and topography) and changes in roughness. This may be either a network of triangular elements or a combination of triangular and quadrilateral elements, depending on the selected model.
   - Refine the network in areas of appreciable change or areas of significant habitat interest.
   - Determine the node elevations from the geometric data.
   - Review mesh quality to assure that element size transitions and other modeling requirements are reasonably met. These include increased mesh refinement where there is appreciable geometric change or where velocity magnitude or directions changes occur. Identifying where additional model refinement is needed is somewhat based on experience and judgment. Large element sizes may miss large-scale flow separation (circulation) or may have numerical instabilities (oscillating or greatly changing velocities). If the instabilities are too large the model will terminate. Areas of instability are easily identified in the model results and these areas will be refined. The model results will also be reviewed to determine if there are currents that are not "reasonably" depicted based on our experience and these areas will be refined.
4. Develop flow resistance (roughness) and turbulence stress data.
   - Channel base roughness based on bed-material size.
   - Adjust base roughness to account for other sources of flow resistance such as obstructions (including LWD) and bed forms. Note: Project-related changes in amounts of LWD and sediment size can be related to flow resistance values. Also note that LWD will be simulated by including large debris areas as part of the geometry.

- Channel bank and floodplain (overbank) roughness based on land use, vegetative ground cover, and obstructions using field observations and aerial photography.
- Turbulence stress data, such as eddy viscosity coefficients, are used to incorporate internal flow stresses. Reasonable values depend on each model's numerical representation of these stresses. ADCP data will be used to calibrate these coefficients.

5. Develop bed-material gradation and layer information.
   - Surface sampling conducted throughout the channel network,
   - Subsurface sampling, and
   - Bank material samples.
6. Develop water and sediment inflows for existing and with-Project conditions.
   - For fully unsteady models, use complete flow hydrographs.
   - Steady flow simulations will be performed for habitat analysis based on the range of flows in the simulation record.
   - Develop sediment inflow rating curves based on tributary models and from the 1-D Bed Evolution Model.
7. Other considerations.
   - Ice jam breakup hydrographs,
   - Ice jam blockage of main channel or lateral features causing redistribution of flow,
   - LWD as obstructions or changes in roughness, and
   - Erodibility of floodplain areas.
8. Test the hydraulic model over a range of flow conditions.
   - Further evaluate mesh quality and the need for additional mesh refinement for areas with appreciable changes in velocity magnitude or direction to adequately capture flow transitions.
9. Calibrate and validate the hydraulic model.
   - Adjust flow resistance input values (within reasonable limits) to calibrate the hydraulic results. Calibration and validation will be performed using available data including:
     - Measured water-surface elevations throughout the focus areas during site survey and water-surface elevations measured at other times.
     - Measured velocities collected using acoustic Doppler current profiler along selected cross sections and longitudinal profiles. Note that flow resistance values in 2-D models are often lower than comparable 1-D models because 2-D models directly account for processes that 1-D models must treat as lumped flow resistance parameters.
     - Water-level loggers.
     - Discharge distribution between main channel and secondary channels.
     - High-water mark information if available.

Test the sediment transport model.

- Conduct a sediment transport time-step sensitivity analysis to evaluate appropriate computational time steps for different flow magnitudes. These tests identify the longest stable time-step for model applications.

10. Calibrate and validate the sediment transport model.

    - Adjust sediment inflow rates and sizes, bed layer properties, sediment transport time step (within reasonable limits) to calibrate the hydraulic results using available data including:
        - Main channel bed level changes observed in the 1-D Bed Evolution Model,
        - Comparisons of cross sections using 1980s and current data and between the 1-D and 2-D bed Evolution Models, and
        - Longitudinal profiles.

11. Run and evaluate the results of the sediment transport simulations.

4.1.2.2. Coordination with other Studies

As previously discussed, a combination of 1-D and 2-D Bed Evolution models are being 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 modeling approach uses a reach-scale 1-D Bed Evolution Model to evaluate the potential effects of the Project on the overall aggradation/degradation behavior of the study reach, and a series of representative, local-scale 2-D Bed Evolution models at key locations where the dynamic behavior of the channel and habitat cannot be adequately assessed using the 1-D modeling approach or are better assessed using a 2-D model. The 1-D Bed Evolution Model provides boundary conditions for the individual 2-D Bed Evolution Models. Because of this modeling approach, it is important to coordinate with other studies because results from the detailed 2-D Bed Evolution Model are only available at specified locations that have been selected (e.g. Focus Areas) identified by the Fish and Aquatics Instream Flow (Study 8.5), Riparian Instream Flow (Study 8.6), Ice Processes in the Susitna River (Study 7.6), and Characterization and Mapping of Aquatic Habitats (Study 9.9) study teams and in consultation with the licensing participants. Section 5.1.2 describes the coordination activities conducted in 2013. Table 4.1-3 summarizes the interactions of modeling between the fluvial geomorphology modeling and other study components. Model inputs are divided into four types of boundary conditions including hydrology, hydraulic, sediment, and geometry, and the source of the input is identified. The results of each fluvial geomorphology model are also summarized including the type of result and the recipient study component. The comprehensive modeling approach is described in detail in Tetra Tech (2013h).

Though not specifically included in Table 4.1-3, additional 2-D Bed Evolution modeling will be conducted for a range of ice blockage and breakup conditions to evaluate erosion and deposition potential. Also not included in the table are changes in LWD that may occur over time. Descriptions of LWD and ice effects on sediment transport and model simulations are described in Sections 4.1.2.7 and 4.1.2.8.

Focus Areas have been identified (R2 2013a, R2 2013b), with each covering a length of river on the order of one to several miles that includes a representation of each geomorphic reach (excluding Devils Canyon) in the Middle Susitna River. The 2-D Bed Evolution modeling will be applied at each of the Focus Areas. During the Q1 2013 TWG meetings adjustments of the proposed Focus Areas were finalized. The Focus Areas also included selected primary tributary confluences. Coordination among the studies was necessary to ensure efficient collection of field data, because a considerable amount of the data necessary for development and calibration of the 1-D and 2-D Bed Evolution models are either required for the other studies, or are more easily obtained along with data that are required for those studies. For example, the Fish and Aquatics Instream Flow Study obtained velocity magnitude and direction, flow depth, and discharge measurements, the data from which would be very useful for calibration of the 2-D models. The collection of the cross sections for the 1-D model and the bathymetry and topography for the 2-D model are also being collected under the Fish and Aquatics Instream Flow Study. In the winter of second study season, this study will collect subaqueous bed-material data for the modeling by lowering a laser/camera through the ice thickness transect holes that will be bored in conjunction with winter data collection by the Ice Processes in the Susitna River Study (Study 7.6).

The temporal resolutions for model execution were 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 is also an important factor. Because a key purpose of the 1-D Bed Evolution model is assessment of the long-term sediment balance in the study reach, this model is being 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 Bed Evolution Model, much shorter time-periods are being evaluated.

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

An important aspect of coordination between other studies was 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 4.1-4 is an update of the model precedence. In the event that the precedence established in the table changes, a revised table will be provided.

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 2-D River Water Quality Model. If there are significant discrepancies, then parameters within the models will be checked and adjusted if necessary. In some cases, the discrepancies may be explained by the formulation of the models or the resolution of the data used by each model.

4.1.2.3. Model Resolution and Mesh Size Considerations

As described in Section 5.1.3, required model resolution and mesh sizes were identified in 2013 for 2-D Hydraulic and Bed Evolution models. Selection of the appropriate mesh size for the 2-D models 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 main stem can typically be performed using a relatively coarse mesh because the topographic and hydraulic variability is less pronounced than 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 above to develop and accurate model can push the limitations imposed by items 4 and 5 above. 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.

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 coarser spatial resolution may be appropriate include the following:

- Main channel
- Floodplains
- Large side channels

The RSP indicated that a single mesh could be used for both the habitat and bed evolution modeling but that some Focus Areas may require different resolution meshes. However, it is now anticipated that separate habitat (hydraulic) and bed evolution models will be developed for each Focus Area. 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. The resolution of the hydraulic mesh size was coordinated with the Fish and Aquatics Instream Flow Study (ISR Study 8.5) to identify the areas requiring finer mesh resolution as well as the mesh sizes. Due to model size limitations and/or the long simulation times associated with detailed meshes, a coarser mesh will be used for the bed evolution modeling because issues related to bed evolution associated with sediment transport processes can be adequately addressed at a coarser scale. The use of two different mesh resolutions achieves the best combination of model results and accuracy within available computer and model limitations.

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 RSP Study 6.6 Sections 3.1 and 4.1.2.4. The selection was further detailed and refined in two technical memorandums filed in Q1 2013 (R2 2013a) and Q2 2013 (R2 2013b). A total of 10 Focus Areas were selected and presented in R2’s (2013a) March technical memorandum, *Selection of Focus Areas and Study Sites in the Middle and Lower Susitna River for Instream Flow and Joint Resource Studies—2013 and 2014*. These selected Focus Areas were modified in May 2013 (R2 2013b) and stand as the working locations for the 10 Focus Areas. Explanation and methods describing the modifications can be found in the aforementioned technical memorandum (R2 2013b) and ISR Study 8.5 Sections 4.1.2.3 and 5.1.3.

4.1.2.5. Model Calibration and Validation

Calibration and validation of the 1-D and 2-D Bed Evolution models is a stepwise process. These efforts have been initiated in 2013 and preliminary results are discussed in Section 5.1.5. Calibration is used to confirm the precision of model results, whereas validation is used to confirm the accuracy of model results. Table 4.1-5 provides a general summary of the sources and types of datasets that will be available to calibrate and validate the 1-D and 2-D models. For both the 1-D and 2-D models, the sediment transport routines rely on simulated hydraulics, so the hydraulic components of the models will be calibrated and validated before the sediment transport components are calibrated and validated. The following subsections describe the model calibration and validation methodology for both the1-D and 2-D models.

4.1.2.5.1. One-Dimensional (1-D) Bed Evolution Model

Discharges along the study reach will be obtained from the three Susitna River USGS gages and will be used as boundary condition data for the 1-D Bed Evolution Model. These gages will also provide a continuous record of stages and water-surface elevations at the gage locations that can be used as calibration data. These calibration data will be supplemented with stage data from the “Surface Water Stations” that were established in the Middle and Lower Susitna River segments in 2012 as part of the Instream Flow Study (ISR Study 8.5). A total of 13 stations, complete with pressure transducers, were initially established in 2012; although it is expected that water level data will be available for only 8 of these stations due to loss of the pressure transducers. Additional sources of water-level data for model calibration will include water-surface elevations surveyed during the cross-section and bathymetric surveys in 2012 and 2013 and also include water surface elevation data collected at the "Focus Area Stations" established in 2013 as part of the Groundwater Study (ISR Study 7.5). Some of these "Focus Area Stations" are equipped with pressure transducer transducers.

Specific calibration and validation criteria will be established for the 1-D model during the model development phase. The hydraulic component of the 1-D Bed Evolution Model will be calibrated by adjusting the flow resistance and other loss coefficients (within reasonable limits) so that the predicted water-surface elevations are within an established tolerance of the measured or surveyed water-surface elevations (i.e., the selected calibration criteria). The hydraulics will be calibrated to as wide a range of flow conditions as is reasonable given the available calibration datasets. However, more weight will be given to calibrating to moderate and high flows because of their influence on the mobilization and transport of sediment. The hydraulics will be validated following the same procedure as used for calibration except that a separate validation dataset will be used. In addition to the formal calibration and validation processes, the simulated water-surface elevations will be compared to water-surface elevations generated by the Open-water Flow Routing Model (ISR Study 8.5 Section 4.3) to ensure that the models are producing consistent results. The sediment transport portions of the 1-D Bed Evolution Model will be calibrated using (1) available sediment transport measurements and the associated sediment-rating curves at USGS gaging stations for both bed load and suspended load, mean bed elevation profiles from 1982and 2012 surveys, and (3) comparisons of 1980s and 2012 bed surface gradations. For coarse-grained rivers such as the Susitna River, the bed-material load transport is dominant with respect to channel forming processes, so only bed material will be considered in the calibration and validation 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, so wash load will be considered in the riverine water quality modeling (ISR Study 5.6 Section 4.8). The sediment transport components will 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 (Study 6.5), by making model runs for specific time-periods. Pending data availability, comparison of simulated and measured sediment transport will be considered for the validation process. If additional data is collected or identified that could improve the calibration and validation of the sediment transport component of the model, it will be considered.

4.1.2.5.2. Two-Dimensional (2-D) Bed Evolution Model

As noted in Section 4.1.2.1 (The hydrodynamic component of the 2-D models will be calibrated by adjusting the flow resistance input values (within reasonable limits) so that the predicted water-surface elevations match, as reasonably as possible, the measured water-surface elevations. The discharges in the main and secondary channels measured using the ADCP will be compared to the predicted flow distributions. In addition, the measured velocities collected using ADCP along selected cross sections and longitudinal profiles will be compared to the predicted velocities at the same discharge.

Calibration of the velocities and depth are critical to the Fish and Aquatics Instream flow Study. 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 typically require velocity measurements collected during 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 Bed Evolution Model will be first calibrated based on the available measured sediment transport data and the associated sediment-rating curves for both bed load 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 (Study 6.5), 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.

4.1.2.6. Tributary Delta Modeling

Section 5.1.6 describes the tributary delta model development performed at 11 tributaries during 2013. Additional tributaries will be modeled in the next year of study. Determination of tributary sediment loads has been the focus of 2013 activities and other tasks, such as the modeling of delta deposits and potential for barriers to fish access, will also be investigated in the next year of study.

Under post-Project conditions, tributaries are expected to be the primary source of bed-material sediment to the Middle Susitna River Segment. The sediment supply from the tributaries is important not only as input to the bed evolution modeling of the Susitna River, but also to assessing potential Project effects on the ability of fish to access the tributaries and the extent of clear water habitat associated with some tributary confluences. The post-Project flow regime has the potential to change the elevation and location where sediment loads from tributaries are initially deposited because the mainstem may be at a different stage relative to pre-Project hydrology when the tributaries are at peak flow. Potential changes in deposition patterns correspond to potential changes in sediment delivery from the tributaries into the mainstem. Additionally, the ability of the mainstem to mobilize and transport sediment deposited in tributary deltas may also be altered by the post-Project hydrology. Modeling sediment transport and deposition processes at select tributary mouths in the Middle and Lower Susitna River Segments is therefore necessary. Assessing fish access into tributaries that drain directly into Watana Reservoir is based on tributary delta modeling as described in the Geomorphology Study (ISR 6.5 Section 4.8.2.2) and the methods are being closely coordinated between studies.

As a precursor to modeling geomorphic changes at select tributary deltas, the sediment supply to the deltas must be characterized; a numerical modeling approach is being used for this purpose. Numerical modeling of sediment supply will be carried out using software such as HEC-RAS (USACE 2010a), SAMWin (Ayres Associates 2003), or spreadsheet applications coupling HEC-RAS hydraulic results with an applicable transport function. Model inputs will include tributary channel geometry, energy loss parameters, bed-material gradation, tributary hydrology, and an appropriate sediment transport function. Simulated hydraulics will be calibrated where calibration datasets exist; lacking datasets to calibrate the simulated sediment transport, the modeled sediment transport capacities can only be reviewed and adjusted based on professional judgment. In addition to quantifying the sediment supply to the tributary deltas, the modeling results will be used to develop sediment supplies for other non-modeled tributaries to quantify inputs to the bed evolution models. For example, the calculated unit-sediment yields at the modeled tributaries will be regressed against factors such as contributing drainage area and watershed slope to develop regression relationships. If robust relationships can be identified, these relationships will be applied to the non-modeled tributaries. Alternate approaches to quantifying sediment yield may also be considered, such as previous studies of regional sediment yields (Guymon 1974).

Once the sediment supplies at the selected tributaries have been characterized, tributary delta modeling will be carried out. The tributaries to be modeled were preliminarily selected in conjunction with the instream flow and fish and aquatic resources studies and the licensing participants based on existing fish use and the potential for Project effects. Final selections are being confirmed based on observations during reconnaissance of existing delta morphology and estimates of potential Project effects on the ability of fish to access the tributaries.

At the selected tributaries, a numerical model will be developed to characterize changes in delta morphology using (1) estimated bed-material supply from the tributary, (2) the topography and the bathymetry of the existing confluence, (3) measurements of the characteristics of the existing tributary deposits, and (4) the ability of the mainstem in the area of the confluence to mobilize and transport those deposits. The approach includes field observations to characterize the sediment transport regime as a basis for identifying appropriate methods of estimating bed-material 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 provided (ISR Study 8.5 Section 8.5.5.3). The topography in the area of the expected delta will be based on surveys or LiDAR-derived mapping. Slopes and gradations of existing tributary deposits will be collected during field surveys. The ability of the mainstem in the area of the confluence to mobilize sediment deposited on the deltas will be quantified using numerical 1-D hydraulic models. The models will be used to identified the riverward extent of the delta foreset slope under various post-Project hydrologic conditions. The estimates, measurements, and modeling results will provide a basis for characterizing how Project operations at different points in time affect the formation of tributary deposits. Volumes of sediment will be distributed within the confining topography considering topset and foreset slopes affected by Project operations to estimate delta morphologies. Tributary confluences in Focus Areas will be simulated as part of the 2-D Bed Evolution modeling effort to provide detailed information on delta evolution.

4.1.2.7. Large Woody Debris Modeling

Large woody debris modeling will be performed during the next year of study. Mapping of large woody debris has been conducted as part of Geomorphology Study using the methods presented in Section 4.9 and corresponding results presented in Section 5.9 of the ISR Study 6.5. 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 below Watana Dam Study, recognizing that bank erosion is a key process in large woody debris recruitment. Both the 1-D and 2-D hydraulic 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 the Geomorphology ISR (Study 6.5) Section 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 (PRM 187.1 [RM 184]) will be estimated in the Geomorphology Study (ISR Study 6.5 Section 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 (ISR Study 6.5 Section 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 (Study 8.6) and the Riparian Vegetation Study Downstream of the Proposed Watana Dam (Study 11.6).

The impacts of the Project on the rates of bank erosion and large woody debris recruitment will 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 will 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 the Geomorphology Study (ISR Study 6.5 Section 4.9).

A detailed survey of large woody debris within 7 Focus Areas was performed as part of the fieldwork in 2013 as described in the Geomorphology ISR Section 4.9 and the remaining Focus Areas will be included in a next year of study. 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 to develop estimated changes in the aquatic habitat indicators (ISR Study 8.5 Section 4.6).

Large woody debris will also factor directly into the 1-D and 2-D Bed Evolution and Hydraulic Model parameters. At the reach-scale, large woody debris increases overall flow resistance, reduces velocity, and reduces sediment transport (Smith et al. 1993, Shields and Grippel 1995; Assani and Petit 1995; Buffington and Montgomery 1999). The cumulative drag force of debris in a particular reach will be distributed over the reach by equating area-distributed drag force to the equivalent shear stress to compute an incremental increase in flow resistance associated with the LWD (Hygelund and Manga 2003). For existing conditions, the amount of debris, type of obstruction, size, and other attributes will be used to evaluate the contribution of debris to total flow resistance. The input flow resistance coefficients will then be modified in the Project-conditions models to reflect changes in LWD due to the Project by proportioning the amounts of debris and the resulting total flow resistance based on the altered LWD supply. Depending on the relative LWD supply, effects on reach-average hydraulics may be negligible in some areas, but could be significant in others. In general, LWD supply from upstream of the dam will be eliminated by the Project, but LWD supplied from tributaries downstream from the dam will be unchanged. If bank erosion rates decrease based on the BEI analysis, then this supply will also be reduced.

4.1.2.8. Wintertime Modeling and Load-Following Operations

Wintertime conditions analysis of erosion and deposition processes will be performed, if needed, during the next year of study. It is currently not proposed to execute the bed evolution 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 (ISR Study 6.5 Section 4.3.2.3) 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 with the 1-D Bed Evolution Model and possibly the 2-D Bed Evolution Models for the early portion of the winter period. This effort could 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 bed evolution modeling into the winter period will be made in consultation with the licensing participants and in coordination with the Fish and Aquatics Instream Flow (Study 8.5), Instream Riparian Flow (Study 8.6), Ice Processes in the Susitna River (Study 7.6), and Characterization and Mapping of Aquatic Habitats (Study 9.9) studies.

Other aspects of winter and spring conditions that affect geomorphic processes will also be considered for 1- and 2-D bed evolution modeling. As part of the Ice Processes in the Susitna River Study (Study 7.6), predictive ice, hydrodynamic and thermal modeling using River1D is planned for the Middle River between the proposed dam and the Three River Confluence near Talkeetna (ISR Study 7.6 Section 4.6). Additional ice-related, reach-scale modeling will be performed as part of the Fluvial Geomorphology Modeling below Watana Dam Study. It is tentatively assumed that the existing bed material is stable (i.e., below incipient motion conditions) under ice conditions, due to reduced velocities and shear stresses associated with low river flows and the ice cover. The validity of this assumption under both existing and with-Project conditions will be tested by performing an incipient motion analysis using shear stress results from the River1D modeling. If the results indicate that substantial sediment transport should occur at the reach scale, the 1-D Bed Evolution Model will be adjusted to incorporate appropriate rates of sediment transport for ice covered conditions. 1-D dynamic hydraulic modeling will also be performed of ice jam breakup surges to develop inflow hydrographs for 2-D dynamic hydraulic models. The 1-D hydraulic modeling will be performed using HEC-RAS and will be similar to dam break simulations of the rapidly released water stored above the ice jam.

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

The Geomorphology studies (Studies 6.5 and 6.6) and Ice Processes in the Susitna River Study (Study 7.6) are working together to identify the key physical processes that interact between the two. A significant portion of the influences of ice processes on morphology are directly related to their effects on riparian vegetation. The Geomorphology and Ice Process studies are also coordinating with the Riparian Instream Flow Study (Study 8.6) to identify and interpret evidence of ice conditions such as ice scarring locations and elevations on trees. Additional influences of ice processes that may be incorporated into the 2-D modeling include:

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

The analyses of ice-affected morphologic change will rely on observations and information from the Ice Processes in the Susitna River Study, the Riparian Instream Flow Study, and geomorphology field work (Section 4.1.2.9). The results of River1D and River2D simulations, performed by the Ice Processes in the Susitna River Study (Study 7.6), will also be used. The information to be developed for both existing and with-Project scenarios will include: (1) size, location, and frequency of ice jams, (2) location, extent, and duration of bank attached ice, (3) location, extent, and duration of ice blockage in main versus secondary channels, (4) model output from River1D and River2D ice model simulations, (5) estimates of fine-sediment concentrations during ice cover conditions, and (6) field observations of the impacts of ice movement or flow diversion on floodplain areas. The types of analyses and specific conditions to be evaluated will be coordinated with the other study teams and agencies as information from the 2013 field season is evaluated.

4.1.2.9. Field Data Collection Efforts

The field data collection effort to support both the Geomorphology Study and the Fluvial Geomorphology Modeling below Watana Dam Study is presented in this section. The majority of this effort was conducted during the 2013 field season but no data were collected in areas where access was not obtained. If the subsequent need for additional data is identified during the model development process, Focus Areas are modified, or the downstream limit of the 1-D Bed Evolution Model is extended below PRM 29.9, additional data will be collected during the next year of study. Section 5.1.9 includes the results of 2013 data collection efforts. The methods described below will be also used in the next year of study.

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

At the start of the summer 2013 field season, a reconnaissance of the entire Fluvial Geomorphology Modeling below Watana Dam study area (PRM 187.1 to PRM 79[RM 184 to RM 75]) as well as the remainder of the Lower Susitna River Segment (PRM 79 to PRM 3.3[RM 75 to RM 0]) was conducted. This site reconnaissance was carried out to observe, characterize and inform the following:

- Hydraulic and geomorphic controls (natural and man-made) that 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.
- 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 were developed to assist crews during field activities. The mapping included 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, private land holdings and safety related information.

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

4.1.2.9.1. 1-D Bed Evolution Model

The primary field data collected in 2013 in support of the 1-D Bed Evolution Model include the following:

1. Supplemental cross-sections. The supplemental cross-sections were surveyed as part of Study 8.5 (ISR Study 8.5 Section 4.3).
2. Bed-material samples along the main channel and tributaries
    a. Surface pebble count (Wolman count)
    b. Subsurface bulk samples
3. Bank material samples

4. Spot elevations to verify LiDAR in the area of the supplemental cross-sections (ISR Study 8.5 Section 4.3). LiDAR are being used to provide the floodplain portion of the cross-sections. LiDAR verification is discussed in Section 4.1.2.9.5.
5. Estimation of n-values at supplemental cross-sections
6. Observations of depositional or erosional features at the supplemental cross-sections
7. Water-surface elevations

Supplemental Cross Sections

Supplemental cross-sections are 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 Open-water Flow Routing Model (ISR Study 8.5 Section 4.3) will be used in development of the 1-D Bed Evolution Model; however, their spacing is such that additional cross-sections were collected in 2013 to complete the 1-D Bed Evolution Model. There were 88 cross-sections surveyed in 2012 between PRM 80 and 188 (RM 75 and RM 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. Supplemental cross-sections were surveyed in 2013 and additional cross sections will be surveyed during the next year of the study to complete the cross-sectional database for the 1-D Bed Evolution Model. Presently, approximately 40 cross sections have been identified for survey during the next year of the study with a dozen in the Lower River and the remainder in the Middle River. The locations of cross sections to be surveyed during the next year of the study will be finalized based on initial runs of the Open-water Flow Routing Model (ISR Study 8.5 Section 4.3) and the 1-D Bed Evolution Model. The bathymetric and topographic data collected at the Focus Areas are another source of geometric data for the 1-D Bed Evolution Model.

Tributary cross-sections surveys were conducted to provide input to the HEC-RAS models, which in turn being used in conjunction with the tributary sediment sampling and flow hydrographs to estimate the tributary sediment loads.

Bed-material Sampling

Bed-material samples distributed throughout the study area were collected to support the 1-D Bed Evolution Model development. In general, sample sites were located approximately every 2 miles throughout the Middle River (below PRM 146.6) and approximately every 3 miles throughout the Lower River (between the Yentna Confluence and Three Rivers Confluence). In general, three surface and 1 subsurface samples were collected at each bed-material sample site. Characteristics of the substrate making up these features were measured using techniques appropriate to the size range of the material at that location.

In coarse-grained areas, defined by a definite clast-supported, cobble-gravel armor layer, surface samples were taken using the pebble count method (Wolman 1954) for a minimum of 300 measurements per sample site. The measurements were collected by using a gravelometer along three 100-foot transects oriented parallel to flow at heads of bars and islands. Where individual particles exceeded the size of the gravelometer (256 mm), a metric tape was used to measure the b-axis of the particle. Where individual particles located on transects were less than 2 mm in diameter (i.e. sand), the particle was noted on the field form but was not included in determining the gradation of the surface sediments. Instead, the less than 2 mm particles were removed until a particle greater than 2 mm in size was identified below the finer sediments. This particle was then measured and included in the gradation. In general, when the sampled surface was above water, each transect was placed along the particle imbrication axis located on the Left, Center, and Right sides (orientation defined looking downstream) of the sampled area (see Figure 4.1-1). In addition, transects were established such that they encompassed any obvious variability across the sample surface. Sampling was performed at 1-foot increments along each 100-foot transect for a total of 300 measurements. An example field data sheet is illustrated in Figure 4.1-2. If a particle spanned more than the 1-foot interval along a transect, it would be counted for each interval intersected. If the sampled area was less than 100 feet in length, two 50-foot parallel transects were established less than 10-feet apart. If a transect tape could not be placed due to a below-water sample area, a random step method was performed.

In areas where the surface material was sufficiently fine, defined by greater than 20 percent sand and fine- to medium-gravel, bulk samples were collected for laboratory grain size analysis. A bulk sample would be gathered by excavating at least 10 pounds of sediment from the sampled area. The sediment was placed in a sample bag with an aluminum tag identifying the date, river, PRM, sample type, sample name, and field team identification. The tag information was verified before being placed in the sample bag. A GPS point was taken at each subsurface sample location.

Considering the generally coarse-grained nature of the substrate in the Susitna, Chulitna, Talkeetna and Yentna rivers, bed-material sampling was conducted using a combination of surface and subsurface sampling. After completion of surface sampling in each area, the surface armor layer at the 50-foot interval on the center transect was removed and a sufficient quantity of material based on the sizes of the sediments in the surface gradations (generally between 400 and 500 lb) was excavated from the site. The minimum weight of the bulk sample was based on ASTM D75-71 guidelines. Figure 4.1-3 and Figure 4.1-4 identify the basis for determining sample depth and sample weight and is summarized in Table 4.1-6.For practical purposes, an upper limit for minimum sample weights was set at about 400 pounds. The bulk sample was weighed with a field scale to determine the total bulk weight. Particles larger than 45 mm were separated into size classes using a gravelometer. Particles smaller than 45mm and larger than 16 mm were field sieved into size classes. The individual size classes were weighed and recorded. The remaining sample consisting of the less than 16 mm size class was weighed and recorded. The less than 16 mm material was then re-mixed with a shovel and a bulk sample, of approximately 10 pounds or more, was collected for further laboratory sieve analysis. The difference in wet (field condition) and dry weights of the collected sample were used to estimate the dry weight of the entire less than 16mm fraction to enable the gradation of the entire bulk sample to be determined. For quality control purposes, the total weight of the subsurface sample was compared against the sum of the weights for each particle class size. A 2-percent tolerance between the initial and final sample weights was used. This check was performed in the field. An example of a complete subsurface field data form is identified in Figure 4.1-5.

At each bed-material sample site a GPS point was taken as well as photographs of the subsurface sample pit, overview photos of the subsurface sample location which included the bar/island surface at the sampling site, overview photos upstream and downstream of the sampling location and photos of relevant general site conditions.

Based on the collected field data, the overall gradation was later determined by combining 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.

Bed-material data in the main channel is difficult to measure under open-water conditions on the Susitna River. During the open-water period, flows are typically high and associated higher river stages make shallow water or dry pebble count methods in the deeper parts of the channel not feasible. Turbidity associated with the open-water period glacial melt and runoff significantly reduces visibility, and prevents the use of alternative sampling methods such as the use of underwater cameras. However, during the wintertime ice-covered period, the turbidity is about 100 times less (Tetra Tech 2013i – Attachment A) and visibility is good.

The Fluvial Geomorphology Modeling below Watana Dam Study worked with the Fish and Aquatics Instream Flow Study (ISR Study 8.5) and Ice Processes in the Susitna River (ISR Study 7.6) in the winter of 2013 to determine whether subaqueous bed-material gradations could be determined in the main channel under iced-over conditions using a camera equipped with two lasers to provide scale. The pilot wintertime bed-material sampling was performed using several underwater cameras and parallel lasers submersed through augered holes in the ice above the main channel at ESS40 near PRM 107 and at FA-104 (Whiskers Slough) near PRM 105 (Tetra Tech 2013i – Attachment A). The underwater cameras were used to acquire images of bed material that could be analyzed based on the type of camera used, method of scene illumination, and resolution of separate grain sizes. The parallel lasers were used to project a constantly spaced scale reference onto each image, with a distance of 4 inches between the lasers. In addition, the following study goals were evaluated:

- whether or not frazil ice, turbidity, or other moving material interfere with the acquisition of images,
- how much time is required to collect sample images at a site,
- whether or not main channel velocities are too high for securing and operating camera and laser equipment mounted to a pole lowered to the bed, and
- identification of other challenges or constraints to performing underwater camera sampling of main channel bed material during the winter.

Different equipment combinations were used for bed-material image sampling, including four cameras, one set of two green lasers, and three underwater light sources. The cameras used included a GoPro Hero3 Black Edition (GoPro), a SplashCam Deep Blue Pro (SplashCam), a Deep Sea Power & Light Wide-I SeaCam (Wide-I), and an AquaVu camera. The lasers were Deep Sea Power & Light SeaLaser 100’s. The lights used were two Princeton Tec scuba flashlights, a Brinkman Q-Beam Starfire II, and LED lights integrated on the AquaVu camera. Additionally, both 8-inch and 10-inch diameter power ice augers were used to drill holes through the ice and Marshalltown aluminum push button handle sections were used to deploy the equipment through the holes in the ice. A ruggedized laptop was used to record images from the SplashCam, Wide-I, and AquaVu cameras since these cameras did not have internal storage media. The GoPro camera did have internal storage media for recording images acquired.

Bank Material Sampling and Bank Observations

Bank observations were performed throughout the Middle Susitna River Segment below PRM 146.6. Observations were performed primarily at cross-section locations and intended to document any substantial changes in bank and floodplain material within the various geomorphic reaches along the river. Data recorded included a floodplain/island description, an estimate of roughness (Manning's n value) along the floodplain/island, stratigraphic section of the bank, height and angle of the bank, and any other general observations including high-water marks and effects of ice processes. Figure 4.1-6 shows an example of a bank observation data sheet. Periodic bank samples were taken in addition to bank observations. However the concentrated effort for bank sampling during the 2013 field data collection effort was performed in the Focus Areas. See Section 4.1.2.9.2 Focus Areas below for detailed methods on bank sampling.

Some additional bank observations were recorded along the Middle Susitna River. These included identification of eroding banks, bedrock outcrops, and riprap protected banks. This effort was performed throughout the Middle River downstream of PRM 146.6.Visibly eroding banks, areas of riprap bank protection, and rock outcrops were identified and marked on a set of field maps covering the Middle River in primary channels accessible by boat. Within the Focus Areas, the locations of eroding banks were identified and mapped as part of the Geomorphology Study (ISR Study 6.5).

Spot Elevations for LiDAR Verification

Surveys of spot elevations were performed throughout the study area as part of the survey efforts (see sections 4.1.2.9.1.1 and 4.1.2.9.2.1) conducted under Study 8.5 Section 4.3. Section 4.1.2.9.5 provides additional detail on the LiDAR verification and acquisition.

Manning n Estimation

Manning n values were estimated during bank observations (Section 4.1.2.9.1.3). A range of values were identified based on vegetation density and ground surface variability. These values were recorded on bank observation data sheets. Channel Manning n values will be developed as part of the model calibration and validation process (Section 4.1.2.5).

Erosional and Depositional Features

Erosional and depositional features (eroding banks or pointbar accretion) were recorded on the bank observation data sheet (Section 4.1.2.9.1.3). In addition to individual cross sections, the main channel banklines were mapped in field maps as erosional, protected by riprap, or controlled by rock outcrops during transit along the river.

Water Surface Elevations

Water surface elevations were primarily collected at part of cross section surveys conducted as part of Study 8.5 (see section 4.1.2.9.1.1 above). The Study 8.5 efforts also included additional surveys of water surface elevations at different times so that many cross sections had 2 or 3 water surface elevations for model calibration and validation purposes. As part of this study, some cross section observations (Section 4.1.2.9.1.3) included water surface elevation surveys and a concentrated effort of these surveys was conducted during high flow conditions. When cross sections were surveyed as part of this study the cross section endpoints were used as the control point and a level loop was performed between the control point and the water's edge. The date and time of each survey was recorded to assign an approximate discharge to each measurement.

4.1.2.9.2. Focus Areas

The primary field data collected at the Focus Areas by the Geomorphology and Fluvial Geomorphology Modeling below Watana Dam studies included the following:

1. A combination of bathymetry (single beam), cross-section data, and spot elevations necessary to develop a TIN for the portion of the site for which LiDAR is not available. (These included the main channel, side channels, side sloughs, upland sloughs, tributaries, and open water areas that were inundated at the time the LiDAR was acquired.) Note: These data were collected as part of Study 8.5 (ISR 8.5 Section 4.6.1.2.2).
2. All obstructions in the off-channel habitats such as beaver dams were documented.
3. Large woody debris survey and characterization of its influence on the geomorphology of the channels, side channels and sloughs (Also see Study 6.5 ISR Section 4.9).
4. Bed-material samples in the main channel, sloughs, and side channels
    a. Surface pebble count (Wolman count)
    b. Subsurface bulk samples
    c. Winter sampling in conjunction with the Ice Processes in the Susitna River Study (Study 7.6) (see 1-D Bed Evolution Model field data section (Section 4.1.2.9.1) and description of geomorphic mapping below)
5. Bank material samples.
6. Spot elevations collected in the Focus Areas as well as part of the 1-D cross section surveys are being used to verify LiDAR. The elevation data were collected as part of the Fish and Aquatics Instream Flow Study (Study 8.5 ISR Sections 4.3 and 4.4). The LiDAR verification is presented in Section 4.1.2.9.5.
7. Estimation of n-values in the channels, side channels, sloughs, and tributaries.
8. Observations on depositional or erosional features.
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. Note: These data were collected as part of Study 8.5 (ISR Section 4.6).
11. Installation of level loggers and associated readings to support calibration of water surface elevations produced by the 2-D model. Note: These data were collected as part of Studies 7.5 (ISR 7.5 Section 4.5), 8.5 (ISR 8.5 Section 4.3, 4.4 and 4.5) and 8.6 (ISR 8.6 Section 4.6).
12. Current meter measurements of velocity were considered for areas where the ADCP cannot be used. (Note: The areas where ADCP data were collected were deemed sufficient for model calibration purposes and no current meter measurements were collected in 2013).
13. 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

(Additional information from Studies 7.6 (ISR 7.6 Sections 4.1 and 4.2) and 8.6 (ISR 8.6 Section 4.4.4.1).

14. Any evidence of past extreme events.
15. Overall narrative description and assessment of the geomorphology of the Focus Area including identification of key physical processes and controls.
16. Spot surveys water surface elevations

Geomorphic mapping of the Focus Areas was conducted during the field data collection at an appropriate level of resolution to delineate the key geomorphic features that influence the dynamics and the distribution of aquatic and riparian habitats at the site. This mapping included features at the scale of the individual habitat units on the order of the channel width in side channels and sloughs, banklines, large LWD clusters, and other features including lateral and vertical controls. Detailed topography and bathymetry were collected at the Focus Areas as part of the Ice Processes in the Susitna River (ISR Study 7.6 Sections 4.1 and 4.2) Fish and Aquatics Instream Flow Study (ISR Study 8.5 Section 4.4.6.1.2.2)

Bathymetric and Land Survey

Bathymetric, land, and LiDAR surveys were performed to develop a TIN (Triangulated Irregular Network) of the Focus Areas. The bathymetric and land surveys were conducted as part of the survey efforts in Study 8.5. The LiDAR acquisition was performed as part of this study and is described in Section 4.1.2.5.9. The bathymetric survey included below-water areas in the main channel using cross sections surveyed at approximate 200-ft spacing. The cross section spacing was reduced to approximately one-half channel width in side channels and other lateral features. The land survey included near-shore below water shots, water's edge, top-of-bank, and breakpoints between the water's edge and top-of-bank. Land survey was also performed in shallow side channels inaccessible by the bathymetric survey boat.

Mapping of Obstructions

Beaver dams in the off-channel habitats were documented using field photographs, GPS waypoints, and field observations which included identifying if the beaver dam appeared active, inactive, or unknown. Where possible, a height of the beaver dam was measured with a stadia rod.

Large Woody Debris Mapping

Large woody debris surveys were performed at seven Focus Areas in 2013. Additional surveys and characterization of LWD was performed outside of the Focus Areas in both the Middle and Lower River. Methods, sample areas, and study area maps for the LWD survey are provided in Appendix D of ISR Study 6.5.

Bed-material Sampling

Bed-material sampling within Focus Areas was conducted to characterize the bed materials in the main channel, side channels, sloughs, and tributaries. Sediment sampling (involving a combination of surface and subsurface sampling) was conducted in at least 4 locations along the main and primary side channels. At least two bed-material samples were collected along the main channel using the sediment sampling procedures identified in Section 4.1.2.9.1, which consisted of three pebble counts along 100-foot transects and one subsurface sample at the 50-foot interval of the center transect).

To characterize the bed materials in the side (secondary) channels, additional surface samples and subsurface samples were collected above and below water. The above water sampling was conducted at the heads of bars and dry channels, and the below water sampling was conducted in riffles and runs. Like the bed-material sampling identified in Section 4.1.2.9.1, surface sampling in secondary channels required identifying if the substrate was either coarse grained (definite clast supported cobble-gravel armor layer) or fine grained (greater than 20 percent sand and fine- to medium- gravels). If coarse grained, a pebble count was conducted along one 100-foot transect placed along the imbrication axis. If the sample area above water was less than 100 feet long, multiple smaller transects that fit the sample area were established and 100 measurements were collected. If the sample area was below water, the random step method was used. Because some of the surface sampling was performed at the base of banks, care was taken to ensure that in-place particles were being measured and not particles dislodged from above. Where larger particles that could not be picked up were present, the median (b) axis was measured using a metric tape. Pebble counts were recorded on field data sheets (previously presented Figure 4.1-2).

The subsurface sampling locations (with the exception of the 2 sample sites collected along the main channel in conjunction with the 1-D Bed Evolution Model data collection effort) were broken into two categories: (1) locations with an armor layer, or (2) locations within a sufficiently fine-grained surface layer. In subsurface sample locations with an armor layer, one pebble count (method identified in the preceding paragraph) was performed. The subsurface sample pit was excavated at the center of the transect line. Field sieve procedures followed those identified in Section 4.1.2.9.1. In locations with sufficiently fine-grained material, a bulk sample was collected and placed in a sample bag with an etched aluminum tag identifying PRM (approximated since location was off the main thalweg), date, Focus Area, and sample name. Additionally, a GPS point was taken.

Bank Material Sampling

Bank samples were collected throughout the 7 Focus Areas studied in 2013 and effort was made to represent the various geomorphic surfaces. The samples were typically collected at nearly vertical, exposed banks on floodplains and islands. A scaled photo and GPS waypoint were taken and the bank stratification was described in a field book. A 5-10 lb bank sample was collected and placed in a sample bag with an etched aluminum tag identifying PRM, date, Focus Area and sample name.

Spot Elevations for LiDAR Verification

Surveys of spot elevations were performed throughout the study area as part of the survey efforts (see sections 4.1.2.9.1.1 and 4.1.2.9.2.1) conducted under Study 8.5 Section 4.3. Section 4.1.2.9.5 provides additional detail on the LiDAR verification and acquisition.

Manning n Estimation

Manning n values were estimated at cross sections for overbank areas based on vegetation density and ground surface irregularity (see Section 4.1.2.9.1.5). The overbank conditions at

Focus Areas were mapped and will have Manning n values that are consistent with the 1-D models. Manning n values in the main channel bed and along lateral features will be developed primarily during model calibration based on surveyed water surface elevations (4.1.2.9.2.16) and ADCP velocity and discharge measurements (4.1.2.9.2.10).

Bank Material Sampling

Bank materials were sampled along the main channel and side channels within the Focus Areas. In most cases a single bank sample was collected but when there appeared to be appreciable vertical chance the bank was sampled in two or three vertical locations.

Field Verification and Mapping of Geomorphic Features

Field verification of geologic features that provide lateral and vertical controls of the Susitna River was performed as described in ISR 6.5 Section 4.1.2.3 Geomorphic Characterization of the Susitna River. See ISR 6.5 Section 4.1.2.3.1 Surficial Geology for corresponding methods.

ADCP Velocity Measurements

ADCP velocity measurements were collected as part of ISR Study 8.5 (See Study 8.5 Section 4.6). These data were collected at cross sections and along the channels within the focus areas. The individual velocity measurements provide depth-averaged velocity magnitude and direction data that will be compared to the velocity magnitude/direction results of the 2-D models for calibration and validation. The cross sectional ADCP data will also be used to calculate discharge in the main channel and side channels to compare with the flow distributions computed by the models.

Level Loggers

Level logger data were collected as part of Studies 7.5 (ISR Section 4.5), 8.5 (ISR Section 4.3, 4.4 and 4.5) and 8.6 (ISR Section 4.6). The stage data collected by these will be available for calibration of the 1-D and 2-D models.

Current Meter Velocity Measurements

No current meter velocity measurements were made in 2013 because the areas where ADCP data were collected were deemed sufficient for model calibration and validation purposes.

Mapping of Evidence of Ice Processes

Identification and mapping of effects of ice processes on geomorphology was performed during geomorphic surface mapping of Focus Areas. Evidence of ice scars, ice eroded banks, overbank sand deposition, and ice rafted cobbles and boulders were noted in field books, photographed, and mapped on Focus Area mapbooks. The ice-specific observations help provide an understanding of ice processes and geomorphology on the Susitna River (ISR Study 6.5 Sections 5.1.3.2 and 6.1.3.2). Mapping of evidence of ice processes was also performed by the Riparian Instream Flow Study (ISR Study 8.6 Section 4.4.4.1)

Evidence of Extreme Events

Evidence of past extreme events was noted in fieldbooks and on Focus Area geomorphic surface mapping. The information used, in part, to classify the geomorphic surfaces.

Geomorphic Narrative and Characterization

Geomorphic mapping was conducted in the field which included documentation and mapping of: geomorphic surfaces, eroding banks, effects of ice processes, types of channels, locations of lateral weirs (berms) and general site specific information. The Geomorphology Study presents a detailed description of this effort (ISR Study 6.5 Section 4.1.2.3). In addition, bank heights of the various geomorphic surfaces were measured using a stadia rod and inclinometer. The bank heights were measured relative to water-surface elevation and were converted to an elevation using the daily discharge at Gold Creek on the day of measurement and stage-discharge rating curves (ISR Study 6.5 Appendix A.3) developed from the preliminary Open-water Flow Routing Model. Because bank heights were measured on multiple days at different discharges and throughout the Focus Areas, the stage-discharge rating curve that was closest to the center of the Focus Area was used. It is recognized that this will tend to overestimate the surface heights in the downstream portions of the Focus Area and underestimate the surface heights in the upstream portions of the Focus Area; more precise surface heights will be developed based on the output from the 1-D and 2-D hydraulic models and using either the 2013 LiDAR or the indexed 2011 MatSu LiDAR data.

Surveys of Water Surface Elevations

Water surface elevations were surveyed during the data collection efforts by this study and during data collection efforts by other studies. Edge-of-water was surveyed during the bathymetric surveys (Section 4.1.2.9.2.1) and at the main and side channel cross sections during ADCP data collection (Section 4.1.2.9.2.10). Additional water surface elevations were surveyed as part the data collected in Focus Areas by this study. When elevations were surveyed as part of this study a control point was set and a level loop was performed between the control point and the water's edge. The control point was surveyed later to establish the elevation in the project datum. The date and time of each survey was recorded to assign an approximate discharge to each measurement.

4.1.2.9.3. Tributary Deltas

A site reconnaissance and data collection was conducted at key tributaries that were identified to have the potential to deliver significant quantities of sediment to the reach and/or importance to other study teams. The data collected included cross-section surveys, surface and sub-surface bed-material sampling, and observations and photographs of erosional and depositional features.

The tributary study sites were selected by the Team Leader and were typically located outside of the backwater influence of the Susitna River and upstream of fan heads adequately quantify sediment input from the tributary. The cross-sections locations were selected to include the hydraulic controls and channel sections that were representative of the sediment transport conditions. In general, the cross-sections extended across the channel onto the floodplains/terraces and the cross-section spacing was on the order of 1 to 2 channel widths. Typically 4 to 10 cross-sections were surveyed at each site with an average cross-section spacing of 1 to 3 times the active channel widths, depending on the site complexity. The surveys were conducted using standard engineering survey techniques using a survey level, survey rod and tape measure with closed level loops.

Surface and sub-surface bed-material samples were collected to characterize the gradation of the sediments along the surveyed reach, and included at least one representative sample of the surface material on the fan at the interface with the Susitna River. Additional pebble counts were conducted at some sites to quantify the roughness characteristics of the channel.

4.1.2.9.4. Field Data from Other Studies

In addition to the above field data collected as part of the Geomorphology Study (Study 6.5), the following data collected by the Fish and Aquatics Instream Flow (Study 8.5), Riparian Instream Flow (Study 8.6), Ice Processes in the Susitna River (Study 7.6), and Groundwater (Study 7.5) studies are available to support the Fluvial Geomorphology Modeling below Watana Dam Study.

The following data have been obtained from the various studies:

- Open-water Flow Routing Model cross-sections collected in 2012 (ISR Study 8.5 Section 4.3).
- Fish and Aquatics Instream Flow Study supplemental transects collected in 2013 (ISR Study 8.5 Section 4.3).
- Information developed in the Geomorphology Study on channel changes that have occurred since the 1980s (ISR Study 6.5 Section 4.4).
- Information developed in the Geomorphology Study on the physical processes most important to accurately modeling the study reach (ISR Study 6.5 Section 4.1).
- Bathymetric and topographic survey information collected in the Focus Areas to represent the geometry of the Focus Areas (ISR Study 8.5 Section 4.6).

The following data are being obtained:

- Hydraulic calibration information used in the development of the Open-water Flow Routing Model including water surface elevations and associated discharges (ISR Study 8.5 Section 4.3).
- Information describing the influence of ice processes on channel and floodplain morphology (ISR Study 7.6 Sections 4.1 and 4.2 and ISR Study 8.6 Section 4.4.4.1).
- Information describing the influence of riparian vegetation on channel and floodplain morphology (ISR Study 8.6).
- Soil classification and gradations from Riparian Instream Flow Study test pits in the floodplain and on islands (ISR Study 7.6 Section 4.5).
- Thickness and aging of floodplain and island deposits from the Riparian Instream Flow Study (ISR Study 7.6 Section 4.5).
- Mapping of vegetation and associated age classes from the Riparian Vegetation Study Downstream of Watana Dam (ISR Study 11.6 Section 4.1) and the Riparian Instream Flow Study (ISR Study 8.6 Section 4.5). The velocity and depth measurements collected by the Fish and Aquatics Instream Flow Study to characterize habitat for calibrating the hydraulic model(s) (ISR Study 8.5 Section 4.6).
- 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 (ISR Study 8.5 Section 4.6).

4.1.2.9.5. LiDAR Verification and Acquisition

Two LiDAR data sets are available for various portions of the Susitna River. The Matanuska-Susitna Borough (Mat-Su) LiDAR was acquired in 2011 and AEA acquired higher density LiDAR in 2013 (SuWa LiDAR). The original Mat-Su LiDAR was not indexed or verified using surveyed ground points. AEA decided to acquire the high-density LiDAR to provide more accurate information, but unfavorable conditions limited the amount of LiDAR that was acquired in 2013. Therefore, in order to supplement the 2013 LiDAR data, the Mat-Su LiDAR was indexed and the verification process for the 2011 Mat-Su LiDAR was repeated. The following sections describe the methods for acquiring and processing the Su-Wa and for verifying and indexing the Mat-Su LiDAR.

LiDAR Acquisition and Processing

Keystone Aerial Surveys acquired LiDAR data with an Optech ALTM Gemini Airborne Laser Terrain Mapper System. The system includes an Inertial Measurement Unit (IMU), a 33-167kHz laser rep rate, multi-pulse capability and four returns from each outgoing pulse. The data were collected to meet a minimum of 8 points per square meter density at 800 meters Above Ground Level (AGL) to support the project requirements.

The overall acquisition area was broken up into 13 priority areas. The total 2013 LiDAR area was 557 square miles. Of that, 371.5 square miles were within the river corridor and 185.5 square miles were within the reservoir area. Priority areas were determined by the study teams and ranked in order of importance to schedule. The project flight plan required that with favorable weather and river flow conditions the priority areas would be flown in order, but that areas with lower priority would be flown when unfavorable conditions limited access elsewhere.

The LiDAR acquisition also required low flow conditions to maximize LiDAR point returns on the bare ground along the river. The flow levels were determined by 3 USGS gage stations along the Susitna River. The Middle Susitna River was to be acquired at less than 17,000cfs (+/- 10%) from the Gold Creek gage. The Talkeetna River was to be acquired at less than 20,000cfs at the Gold Creek gage and the Chulitna was to be acquired at less than 15,000cfs at the Chulitna Gage. The Lower Susitna River was to be acquired at less than of 55,000cfs (+/- 10%) at the Sunshine Gage. There was also a tidal requirement from PRM 0 to 17. These areas were only to be acquired during time windows around low tide.

The airborne LiDAR dataset was requested to meet the specifications shown in Table 4.1-7. Upon receipt of the collected data, LiDAR and GIS specialists review the acquisition report and confirm the results by performing an initial quality assurance and quality control assessment. This assessment verifies LiDAR point cloud data coverage within the project area, point density, vertical accuracy, accurate matching between flight lines, compliance with the ASPRS LAS v.1.2 technical specifications document, and other specifications requested for the 2013 Susitna-Watana project.

Once the initial quality assurance and quality control assessments were performed and the LiDAR data were validated, the unclassified LiDAR point cloud files (LAS) were prepared for an initial clean-up. All pulses were merged into the "Unclassified" or "Default" class (ASPRS Class 1) to be used by the ground classification routine. A rough minimum elevation threshold filter was applied to the entire dataset in order to eliminate the most extreme low/high point outliers. A second clean-up process was applied to search for isolated and low points using several algorithm iterations using Terrascan macros. The “Low Points” macro searches for possible error points that were clearly below the ground surface. The “Isolated Points” macro then searches for points that were without any neighbors within a specified radius. The “Low Points” as well as the “Isolated Points” were classified into the “Noise” class (ASPRS Class 7), which excludes them from subsequent steps.

A first classification process (unsupervised) was performed using all points in the previously cleaned “Unclassified”/”Default” class (ASPRS Class 1). Each laser return was assigned an “echo”: Only, First-of-Many, Last-of-Many, or Intermediate. To begin classification, the ”First-of-Many” and ”Intermediate” returns were removed from consideration as Bare-Earth points by assigning them to the Medium Vegetation class. The remaining points, the “Only” and “Last-of-Many” returns were placed in the “Unclassified”/”Default” class (ASPRS Class 1). The Bare-Earth class was developed from this set of returns by an iterative method. First, a rectangular filter was passed over the points in the “Unclassified”/”Default” class (ASPRS Class 1) , and a set of local low points was selected to seed the Bare-Earth class. Then the rest of the points in “Unclassified”/”Default” class (ASPRS Class 1) were compared to the triangulated surface defined by the set of Bare-Earth points, and those that were found be close enough to fall within an acceptable angle and height of the surface were added to the Bare-Earth class (ASPRS Class 2). The process was repeated with the expanded Bare-Earth class until the number of points being added to the Bare-Earth class declines. Standard practice in the LiDAR industry acknowledges that no ground classification is perfect. Valid ground points on edges or sharp features are commonly misclassified by LiDAR point cloud processing software packages, leaving blank areas (gaps) in the ground surface. Using proprietary techniques, potential anomalies (e.g., artificial pits, “spikes” on the ground, etc.) were identified during the first classification process (unsupervised) to be corrected in further steps. The application of those techniques provides a semi-automated quality control of the first point cloud classifications and improves the efficiency of the next classification process.

After the unsupervised classification, a second classification process was applied (supervised), where the Bare-Earth model class (ASPRS class 2) were inspected in a tile-by-tile basis and edited as necessary. The Bare-Earth model was visualized as a triangulated irregular network surface (TIN) with contours and potential gap polygons overlaid. Irregularities or voids in the ground surface were subjected to special scrutiny, typically by generating and studying sectional views of the questionable area. Incorrectly classified points were reclassified as necessary, and the classification routine was re-run locally to correct nearby points. This careful review of each tile is central to making a consistently high-quality DEM.

The LiDAR point classification process was complete by performing a second vertical accuracy assessment using only points classified as Bare-Earth (ASPRS Class 2), and exporting the LiDAR-derived data to create the final deliverables.

2011 Mat-Su LiDAR Verification

Ground survey data collected in 2013 as part of the Fish and Aquatics Instream Flow Study cross section and Focus Area survey efforts (ISR Study 8.5 Sections 4.3, 4.4 and 4.6.1.2.2) were used as a control to evaluate the 2011 Matanuska-Susitna Borough LiDAR data. The verification was based on the comparison of ground survey points collected in the Lower and Middle Susitna River areas with a Triangulated Irregular Network (TIN) constructed from LiDAR points around each survey point. Figure 4.1-7 shows the locations of the ground control points. The 522 ground survey points were classified according to major land cover types found in both the Lower and Middle Susitna River, in order to perform the three vertical accuracy tests for a LiDAR dataset recommended by the National Digital Elevation Program (NDEP) and adopted by ASPRS, which are:

a. Fundamental Vertical Accuracy (FVA)
b. Supplemental Vertical Accuracy (SVA)
c. Consolidated Vertical Accuracy (CVA)

There are three major land cover types in the Lower and Middle Susitna River areas,

a. Open terrain
b. Brush land/Low vegetation
c. Forest land

As shown in Figure 4.1-7, 522 ground survey points were used for the verification of the 2011 Mat-Su LiDAR. Figures 4.1-8 and 4.1-9 show examples of the ground survey points the Whiskers Slough Focus Areas (FA 104). The Fundamental Vertical Accuracy was performed by comparing the 174 ground survey points collected on open terrain land cover to the Triangulated Irregular Network (TIN) constructed from the classified LiDAR point cloud (ASPRS point class 2) in a radius of 30 feet for each point. Fundamental Vertical Accuracy measures vertical accuracy in areas of open terrain. The fundamental accuracy is the value by which vertical accuracy can be equitably assessed and compared among different datasets.

Supplemental Vertical Accuracy measures the vertical accuracy in ground cover categories other than open terrain. The Supplemental Vertical Accuracy test was performed by comparing the 348 ground survey points collected on forest and brush land cover to the Triangulated Irregular Network (TIN) constructed from the classified LiDAR point cloud (ASPRS point class 2) in a radius of 30 feet for each point.

The Consolidated Vertical Accuracy was performed by comparing all 522 ground survey points collected on all the land cover types to the Triangulated Irregular Network (TIN) constructed from the classified LiDAR point cloud (ASPRS class 2) in a radius of 30 feet for each point. For comparison, Table 4.1-8 shows the vertical accuracy limits and the equivalent contour intervals. All vertical accuracy tests were performed in an automated fashion using the industry standard LiDAR processing software Terrascan.

2011 Mat-Su LiDAR Indexing

The 2011 Matanuska-Susitna (Mat-Su) Borough LiDAR dataset was indexed in order to improve on the vertical accuracy of this data set. Indexing is an elevation adjustment to true ground using surveyed data. The indexing process started by reshaping and renaming the 2011 Mat-Su LiDAR dataset according to the 2013 Susitna-Watana (Su-Wa) LiDAR files index.

The retiled and renamed version of the 2011 Matanuska-Susitna Borough LiDAR dataset was compared against 525 ground survey points collected in 2013 on open terrain land cover type, distributed over the study area between PRM 31 and PRM 147. This comparison was performed similarly to the process explained in the 2011 Mat-Su LiDAR Verification (Section 4.1.2.9.5.2) by subtracting the laser point cloud elevation at known locations from the ground survey point elevations in order to obtain the average elevation difference (Mean). The average elevation difference was subtracted from the LiDAR point cloud elevation values in order to adjust them to true ground. This process is also called 'Datum shift'.

Once the vertical Datum shift was applied, the indexed LiDAR dataset was compared against the 174 ground survey points on open terrain land cover type utilized for the 2011 Mat-Su LiDAR verification. With the statistical results of the comparison, a final inspection of the extreme elevation difference values is performed in order to remove outliers within the ground survey point dataset. According to ASPRS "*An outlier is an error of major proportion, normally identified and removed during editing or quality control processing. A potential blunder may be identified as any error greater than three times the standard deviation (3 Sigma) of the error. Errors greater than three times the standard deviation should be analyzed to determine the source of the blunder and to ensure that the blunder is not indicative of some unacceptable source of systematic error"*(ASPRS 2004). Potential outliers were analyzed before removing from the ground survey verification dataset.

4.1.2.10. Information Required

In addition to the field data collection effort described in the previous section, the following existing information is being used to conduct this study:

- Historical and current aerial photographs (ISR Study 6.5 Sections 4.4, 4.5 and 4.7).
- Historical channel cross-sections (ISR Study 6.5 Section 4.3).
- LiDAR to develop sub-aerial topography and extend surveyed transects across the floodplain (2011 Mat-Su and 2013 Su-Wa LiDAR described in Section 4.1.2.9.5).
- Extended flow records from USGS mainstem and tributary gages (ISR Study 6.5 Section 4.6 and ISR Study 8.5 Section 4.3).
- 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 (ISR Study 8.5 Section 4.3).
- Historical bed-material sample data (ISR Study 6.5 Section 4.1).
- List of key indicators from the other studies (Fish and Aquatics Instream Flow Study (Study 8.5), Riparian Instream Flow Study (Study 8.6), Ice Processes in the Susitna River Study (Study 7.6), and Groundwater Study (Study 7.5)) 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.

4.1.3. Variances from Study Plan

No variances from the methods occurred during the implementation of this study component in 2013. While land access was not available for portions of the river and tributaries adjacent to

Cook Inlet Regional Working Group (CIRWG) lands in 2013, this was not considered a variance because this study was designed to collect data over multiple years.

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

AEA implemented the methods as described in the Study Plan, with no variances. The methods are included in the RSP Section 6.6.4.2 and additional detail is provided in the modeling approach technical memorandum (Tetra Tech 2013h). Because this study component will be conducted in the next year of the Study, the only analysis that has been performed relates to the selection of hydrologic conditions that will be simulated in the 1-D reach-scale modeling and 2-D local-scale modeling. The hydrologic analysis, which is included as Appendix E, recommends which 50-year period will be included for reach-scale modeling and the representative years for local-scale modeling.

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 was determined in study component Bed Evolution Model Development, Coordination, and Calibration.

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.

4.2.2. Methods

4.2.2.1. Existing Conditions – Base Case Modeling

The Study Plan includes five operation scenarios. The first is the existing conditions or without-Project scenario. 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 Operation Model (ISR Study 8.5 Section 4.3) and Open-water Flow Routing Model (ISR Study 8.5 Section 4.3) and the model run for flows representative of each scenario. A 50-year, continuous period of record that represents the length of the FERC licensing period will be used for the 1-D bed Evolution Modeling, and shorter modeling periods will be used for the 2-D Bed Evolution 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. Section 5.2.1 provides the preliminary results of the selection of the 50-year hydrologic record for 1-D Bed Evolution Modeling.

The shorter periods for the 2-D Bed Evolution Model will include specific years or portions of annual hydrographs for selected years of wet, average, and dry hydrologic conditions and warm and cool Pacific Decadal Oscillation (PDO) phases. Therefore, up to six annual hydrologic conditions will be considered. (The inclusion of the warm and cool 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. Section 5.2.1 provides the preliminary results of the selection of representative annual hydrologic conditions for 2-D modeling.

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.

4.2.2.2. Future Conditions – with-Project Scenarios

The four with-Project scenarios will represent a maximum load-following, an intermediate load-following, a base-load, and a run-of-river scenario. The four with-Project scenarios 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 Bed Evolution Model to determine the reach-scale Project effect and the 2-D Bed Evolution 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.

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 up to six representative years (wet, average, and dry for warm and cool 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 depending on the selected transport equation. Section 6.2.3 includes further discussion of the evaluation of uncertainty in the 1-D and 2-D Bed Evolution models.

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 Bed Evolution Model results are used to facilitate analysis of processes at the reach-scale, while the 2-D Bed Evolution 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 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. If the 1-D Bed Evolution Model indicates that there is sufficient bed change to warrant adjustments to the 2-D model downstream stage boundary conditions, then the geometry of the 2-D models will also have to be modified. As shown in Figure 4.2-1, this potentially would occur at the year-25 and year-50 points in time. This would also affect the 2-D Hydraulic Models that will provide hydraulic input to the fish habitat analyses and could also affect ice processes, flow routing, and groundwater models. In addition, results from the 1-D Bed Evolution Model 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 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 (Study 6.5), Fish and Aquatics Instream Flow (Study 8.5), Riparian Instream Flow (Study 8.6), Ice Process in the Susitna River (Study 7.6) studies, where appropriate, to quantify anticipated Project impacts at the Study Reach Scale.

4.2.2.5. Information Required

The following available existing information is 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.
- Sediment inflow rating curves for the major tributaries.
- 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 (Fish and Aquatics Instream Flow Study (Study 8.5), Riparian Instream Flow Study (Study 8.6), Ice Process in the Susitna River Study (Study 7.6), Groundwater Study (Study 7.5)) 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 below Watana Dam Study.
- Data on PDO index during the extended flow record.

4.2.3. Variances from Study Plan

No variances from the methods occurred during the implementation of this study component in 2013.

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 from 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 (PRM 187.1) to Susitna Station (PRM 29.9).

4.3.1. Existing Information and Need for Additional Information

Several studies require the results of the Fluvial Geomorphology Modeling below Watana Dam Study to conduct their efforts. These include the Fish and Aquatics Instream Flow (Study 8.5), Groundwater (Study 7.5), Riparian Instream Flow (Study 8.6), and Ice Processes in the Susitna River (Study 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 formation, maintenance and distribution of geomorphic features that comprise the aquatic and riparian habitats.

4.3.2. Methods

As discussed in Study 6.5 ISR Section 4.11, initial work for the Geomorphology Study identified the specific geomorphic processes that affect aquatic and riparian habitat, channel stability and related issues that require further quantification, identified a significant portion of the data needs, and provided the basic information and context for the Fluvial Geomorphology Modeling below Watana Dam Study. During the Fluvial Geomorphology Modeling below Watana Dam 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 will use 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.

4.3.2.1. Integration of Geomorphology and Fluvial Geomorphology Modeling below Watana Dam Study Results

The purpose of this task is to integrate the Geomorphology and Fluvial Geomorphology Modeling below Watana Dam Studies to insure that results from both studies are used in a coordinated manner to identify and, to the extent possible, quantify drivers for the existing conditions and the potential influence of the Project on key geomorphically related habitat features. Study 6.5 ISR Section 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 below Watana Dam Study, particularly as they relate to the geomorphically-based habitat indicators. Additional examples of key coordination activities between the two studies include the following (note that other activities may be identified as the study teams gain additional understanding of the key processes that drive existing conditions and potential Project effects):

- The LWD component of the Geomorphology Study is providing information on the status of LWD recruitment to the project reach and the effects of LWD on geomorphic processes, Manning's n values and in-stream habitat (Study 8.5) under existing conditions and qualitative information about the potential effect of the Project on future LWD recruitment and hence geomorphic processes, Manning's n values and in-stream habitat. Results from the bed evolution modeling, as well as the Ice Processes in the Susitna River Study (Study 7.6) and Riparian Instream Flow Study (Study 8.6), will provide quantitative estimates of certain key processes (fluvial and ice) that affect LWD recruitment under both existing and Project conditions, including potential changes in bank erosion rates.
- The Geomorphology Study is identifying 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 as well as in terms of the channel evolution model developed in the Geomorphology Study (Study 6.5) ISR (Section 4.1.2.3). In a next year of study, the Fluvial Geomorphology Modeling below Watana Dam 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 as well as the results of the River1D Ice Processes Model and the River2D Focus Area Models (Study 7.6).
- The Geomorphology Study, coupled with the field data collection activities for the Fluvial Geomorphology Modeling below Watana Dam Study, is identifying 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 being implemented at the Focus Areas, will provide a means of directly quantifying these processes by providing detailed hydraulic information and projections of changes in substrate, bed elevations, and hydraulic connectivity with the mainstem. 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.

4.3.2.2. Coordination of Results with Other Resources Studies

The Fluvial Geomorphology Modeling below Watana Dam Study and Geomorphology Study (Study 6.5) teams are interacting extensively with the Water Quality Modeling (Study 5.6), Open-water Flow Routing Model (Study 8.5 Section 4.3), Fish and Aquatics Instream Flow Study (Study 8.5), Riparian Instream Flow Study (Study 8.6), Groundwater Study (7.5), Ice Processes in the Susitna River Study (Study 7.6), and Characterization and Mapping of Aquatic Habitats (Study 9.9) study teams. The types of interaction vary depending on the specific study, but a considerable amount of physical data describing the physical characteristics and dynamics of the system, including transects, topography/bathymetry, substrate characterization, aerial photography, and pre- and post-Project flows generally are being shared. Selection of joint Focus Areas for detailed studies was an important aspect of the collaboration (R2 2013a, R2 2013b). By selecting common sites, the potential for exchange of information between the study teams is being maximized to ensure the most effective, integrated, and extensive use of Focus Area data.

Because of the detailed spatial nature of the information produced by the models, GIS is 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 facilitates efficient and effective use by other studies requires considerable effort. The details of the plan are being worked out as the overall modeling approach is being developed through informal coordination with the respective study teams, internal team meetings, the November 2013 Instream Flow Study Technical Team meeting, the Technical Workgroup meetings and the Proof of Concept effort in progress. This latter effort is a demonstration of the initial integration of the various modeling efforts being conducted under the Fish and Aquatics Instream Flow Study (Study 8.5), the Ice Processes in the Susitna River Study (Study 7.6), Groundwater Study (Study 7.5), Water Quality Modeling Study (Study 5.6), Geomorphology Study (Study 6.5) and Fluvial Geomorphology Modeling below Watana Dam Study.

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 (previously presented Table 4.3-1 and Table 4.3-2). As noted in Table 4.3-1, 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 4.3-2). 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>Open-water Flow Routing Model (RSP Section 8.5.4.3):</u> It is anticipated that the Open-water Flow Routing Model will provide the pre- and post-Project hydrology information for all studies, including the Fluvial Geomorphology Modeling below Watana Dam 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 will be provided for the 50-year, extended flow record.

For the Fluvial Geomorphology Modeling below Watana Dam effort, the upstream boundary condition at PRM 187.1 (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 Open-water Flow Routing Model will be input along the length of the 1-D Bed Evolution Model and may be inputs to the localized 2-D Bed Evolution models depending on the location and specific issues to be addressed.

Fish and Aquatics Instream Flow Study(Study 8.5): The primary initial interaction with the Fish and Aquatics Instream Flow Study was in the selection of the Focus Areas for detailed study. Part of the selection process considered 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 will be used to evaluate instream habitat quality on a spatially-distributed basis rather than the cross-sectional-based approach used in traditional Instream Flow Incremental Methodology (IFIM) studies.

For the Fish and Aquatics Instream Flow Study, 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 is important. The Geomorphology Study is determining 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 studies (Study 6.5 and Study 6.6) 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 are 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 developed for the Susitna River (Tetra Tech 2013c). This will provide the Fish and Aquatic Instream Flow Study 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 below Watana Dam study for the Fish and Aquatics 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.

Riparian Instream Flow Study (Study 8.6): 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 Riparian Instream Flow Study, Geomorphology and Fluvial Geomorphology Modeling studies are being closely coordinated because of the interactions described above. The collaboration began with coordinated selection of the Focus Area among the Riparian Instream Flow Study, Ice Processes in the Susitna River Study, Geomorphology Study and Fluvial Geomorphology Modeling below Watana Dam Study teams. By analyzing the same Focus Areas in a coordinated manner, the teams are developing an understanding of the interaction between the processes that are responsible for creation and maintenance of the islands and off-channel habitats (See ISR 6.5 Section 4.1.2.3). Estimates of the ages of island and floodplain surfaces from the Riparian Instream Flow Study based on dendrochronology as well as short-lived isotope dating of floodplain and island sediments, combined with the inundation frequencies from the 1-D and 2-D modeling, are greatly facilitating 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 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 Modeling below Watana Dam Study 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 Riparian Instream Flow Study and the Fluvial Geomorphology Modeling below Watana Dam Study 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 Riparian Instream Flow Study 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.

Ice Processes in the Susitna River Study (Study 7.6): 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 and or retarding vegetation succession. 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. Ice may also be responsible for initiating channel avulsion.

There is ongoing close collaboration between the Geomorphology (Study 6.5) and Ice Processes in the Susitna River (Study 7.6) studies to identify the key physical processes that interact between the two. Working together to analyze the conditions at the Focus Areas is 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 and sediment deposition. Additionally, influences of ice processes beyond the riparian vegetation issues that may be incorporated directly into the Fluvial Geomorphology Modeling Study 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 (Study 5.6): The Fluvial Geomorphology Modeling below Watana Dam Study has two primary areas of interaction with the Water Quality Modeling Study (Study 5.6).

The first involves the determination of reservoir sediment trap efficiency. The Environmental Fluid Dynamics Cod (EFDC) model that is being used for studying the water quality of the reservoir, Middle and Lower Susitna River Segments is being used to perform the final determination of reservoir sediment trap efficiency. This model is referred to as the 3-D

Reservoir Water Quality Model. This model will provide a more accurate determination of the fine sediment settling than use of the empirical equations that are described in RSP Section 6.5.4.8.2.1 that will be used for the initial estimate of trap efficiency. The Geomorphology Study (Study 6.5) will provide the Water Quality Modeling Study (Study 7.6) with the sediment inflow to the reservoir based on the sediment supply analysis conducted in Tetra Tech 2013a. If necessary, the effects of glacial surges on sediment supply will be incorporated into the reservoir sediment supply by coordination with the Glacier and Runoff Changes Study (Study 7.7).

The second area of interaction is the routing of fine sediment, silt and clay, downstream. Both the 1-D Bed Evolution Model from this study and the 2-D version of the EFDC model from the Water Quality Modeling Study will route portions of the fine sediment load in the Middle Susitna River Segment and the Lower Susitna River Segment. This model is referred to as the 2-D River Water Quality Model. The Water Quality Modeling Study models are focused on the silt and clay portion (finer than 0.0625 mm) of the fine sediment load in order to estimate the Project effects on turbidity. The Fluvial Geomorphology Modeling below Watana Dam Study is primarily interested in fine sediment load in the sand range (0.0625mm to 2mm) to evaluate Project effects on the volumes of sediment available for deposition in the main channel, off-channel and floodplain areas. The two models will overlap in the routing of the very fine sand range (0.0625mm to 0.125mm).The results of each model for the very fine sand range in terms volumes and concentrations will be compared to insure consistency.

4.3.2.3. Information Required

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

- Study plans, technical memorandums, and reports for other studies

The following additional information is being 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

4.3.3. Variances from Study Plan

AEA implemented the methods as described in the Study Plan with no variances.

5. RESULTS

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

The preliminary results of the three tasks of this study component are discussed below. The modeling approach has been more thoroughly defined with input from the other study components and agencies. Initial model development has occurred and test simulations have been performed, but final development and calibration has not as yet been conducted.

5.1.1. Development of Bed Evolution Model Approach and Model Selection

This section documents the results of the selection of the 1-D and 2-D Bed Evolution modeling software for the project and the model development conducted to date. More detail is provided in Tetra Tech (2013h).

5.1.1.1. Model Selection

5.1.1.1.1. One-Dimensional (1-D) Bed Evolution Model Selection

The HEC-6T software was initially selected for the 1-D Bed Evolution modeling (Tetra Tech 2013h); subsequently the selection was revised to HEC-RAS Version 4.2.0 beta based on it being made available to the Geomorphology Study team (Table 5.1-1). Whether HEC-6T or HEC-RAS Version 4.2.0 are ultimately used for final modeling, the model development is most efficiently performed using the HEC-RAS interface.

5.1.1.1.2. Two-Dimensional (2-D) Bed Evolution Model Selection

Two 2-dimensional sediment transport models (River2D and SRH-2D) were selected for further evaluation based on recommendations reported in the Fluvial Geomorphology Modeling below Watana Dam Approach technical memo (Tetra Tech 2013h). Originally, there were five 2-D bed evolution models considered for the study, however, three of these models were dropped because they did not meet the selection criteria. A full description of the River2D and SRH-2D models is provided Tetra Tech (2013h) and a summary of the model evaluation criteria is listed in Table 5.1-2. An evaluation of the SRH-2D and River2D models is underway with habitat and sediment transport meshes being constructed for both models for FA-104 (Whiskers Slough) and FA-128 (Slough 8A), resulting in a total of 8 models.

5.1.1.2. Model Development

5.1.1.2.1. Overview of 1-D Bed Evolution Model Development

Model development effort conducted in 2013 thus far has followed the steps 1 through 3 outlined in Section 4.1.2.1.2 and in the Fluvial Geomorphology Modeling Approach (Tetra Tech 2013h).

1. Determine the overall model layout.
   - The model domain extends from Susitna River PRM 29.9 to Susitna River PRM 187.1. The downstream boundary was selected to correspond with a location of

known stage-flow conditions, namely the USGS gage at Susitna Station (USGS Gage 15294350). The upstream boundary is located at the site of the proposed Watana Dam, and therefore corresponds with a location of known discharge and sediment supply for both the pre- and post-Project conditions. Discharge at this location for both the pre-Project and post-Project conditions will be provided by the Open Water Flow Routing and Reservoir Operations Modeling (ISR Study 8.5 Section 4.3).

- Sediment supply for the pre-Project condition will be developed by scaling the sediment-rating curves for the Susitna River at Gold Creek USGS gaging station. Sediment supply for the post-Project condition will be provided by the Water Quality Modeling Study (ISR 5.6).
- The tributaries that will be incorporated as reaches with moveable bed in the 1-D Bed Evolution Model include the Talkeetna River and the Chulitna River. Other Susitna River tributaries will be included in the model as flow and sediment inputs, but will not be included in the model for hydraulic or sediment routing. At this time, twenty (20) tributaries have been identified for inclusion in the model as a flow and sediment input, as listed in Table 5.1-3. Sediment-rating curves will be developed for each of these tributaries as part of this study; however, the tributary hydrologic flow series will be developed as part of the Fish and Aquatics Instream Flow Study (ISR Study 8.5 Section 4.3).
- Preliminary split flow reaches for the Susitna River and Talkeetna River were identified for inclusion in the reach scale 1-D Bed Evolution Model, as shown in Figures 5.1-1 through 5.1-8. A total of fourteen (14) preliminary split flow reaches were identified on the Susitna River and one (1) split flow reach was identified on the Talkeetna River. No split flow reaches were identified within approximately the downstream-most 10 miles of the Chulitna River included in the model. On the Susitna River, split flow reaches were identified if (1) they are located within a focus area, or (2) if they are located where a modeled tributary (see Table 5.1-3) enters the Susitna River, thus ensuring that the sediment and discharge from the tributary enters the appropriate channel (main channel or side channel). As the model development progress, these split flow delineations may be revised and additional split flow reaches may be added.

2. Develop cross-section data.
    - Preliminary Susitna River, Talkeetna River and Chulitna River cross section locations were identified to represent the channel network. A total of 242 cross sections were identified for the Susitna River; a total of 14 cross sections were identified for the Talkeetna River, and a total of 17 cross sections were identified for the Chulitna River (see Figures 5.1-1 through 5.1-8). The upstream modeled extent on the Chulitna River is approximately 10 miles upstream of the confluence with the Susitna River, at a location of channel narrowing. The upstream modeled extent on the Talkeetna River is the existing USGS gaging station. During model development, it will be necessary to interpolate additional cross sections between the surveyed cross sections to maintain model stability. These preliminary locations include hydrographic cross section surveys that were completed in 2012 and 2013. These preliminary locations also include hydrographic cross section surveys that may be collected in a next year of the Study.

- Only a portion of each cross section has been/will be field surveyed, generally the below-water areas and the exposed gravel bars. For input to the model, the field surveyed data will be merged with the LiDAR data to create a composite cross section. Figure 5.1-9 is an example of a merged cross section at PRM 117.9. Several cross section locations, namely in the Chulitna River and in Devils Canyon, will not have hydrographic surveys available. For the Chulitna River sections, bathymetric geometry will be developed from the LiDAR data and surveyed bathymetry from the lower Chulitna River. The LiDAR data will be used to estimate water-surface slope (elevation drop over channel distance). Using slope, roughness, discharge, and flow top-width, the flow area will be estimated to calculate an average depth at each cross section. The channel form from the surveyed cross sections will used to guide the development of the below water channel shape. This approach is feasible because the LiDAR will be collected at low flow when depths are shallow on this wide and braided section of the Chulitna River. Within Devils Canyon, no bathymetric geometry will be estimated; this approximation is suitable since the reach is bedrock lined and will convey sediment without appreciable changes in channel geometry.
- Preliminary flow paths were delineated to represent the main channel and floodplain areas. These flow paths provide the basis for stationing between cross sections; the different floodplain and channel paths allow for different distances. The channel flow path was delineated with consideration of its use for representing the volume of bed-material (i.e., length of channel multiplied by the width between moveable bed limits); this consideration was particularly important in the Lower Susitna River Segment where multiple braided channels exist within the banks of the main channel. The floodplain flow paths are supposed to follow the centroid of flow in the overbank; during model development these flow paths may be revised if preliminary results show appreciable different flow centroids.

3. Develop flow resistance (roughness) data for cross sections.
    - Preliminary initial estimates of the Manning's roughness coefficient for the channel and the floodplain were defined and are summarized in Table 5.1-4. The Manning's roughness coefficient is one of the parameters that will be used to calibrate the hydraulics of the 1-D Bed Evolution Model. As such, the preliminary initial estimates listed in Table 5.1-4 are simply a starting point from which to initiate model calibration.

5.1.1.2.2. Overview of 2-D Bed Evolution Model Development

As described in Section 5.1.1.1.2, River2D and SRH-2D are being evaluated the input data, model parameters and model output for both of the preliminarily selected modeling software are generally similar; some differences in the models are described in the following discussion. The types of data used to develop the models are summarized in Table 5.1-5.

A preliminary SRH-2D habitat model (hydraulic fixed bed model) of FA-104 (Whiskers Slough) has been developed and run and is used as an example in the following discussion to show the 2-D Bed Evolution Model development steps. The Whiskers Slough Focus Areas was selected through coordination with the Fish and Aquatics Instream Flow Study (Study 8.5) because it was the first to have complete bathymetry and LiDAR and was used to demonstrate linkage between hydraulic results and habitat analyses for the Modeling Technical Team Meeting on

November 13–15, 2013. The model development follows Steps 1 to 5 outlined in Section 4.1.2.1.2 and in the Fluvial Geomorphology Modeling Approach (Tetra Tech 2013h).

1. Determine the overall model layout.
   - Downstream boundary stage-flow conditions were developed from Open-water Flow Routing Model developed by R2 Resource Consultants, Inc.
   - For the purpose of the example runs for the Technical Team Meeting, the upstream (i.e., inflowing) discharges for the habitat analysis (2,000, 6,000, 14,000 and 24,000 cfs) were specified by the Fish and Aquatics Instream Flow Study team and a discharge of 100,000 cfs was selected by this study to perform an initial evaluation of the channel capacity.
   - Applicable inflows from Whiskers Creek tributary were also included.
2. Develop geometric base data.
   - Data from TIN (Triangulated Irregular Network) and 2013 LiDAR survey were used to assign elevations to the mesh nodes. Figure 5.1-10 shows a TIN that was developed from the land and bathymetric survey data collected by Brailey Hydrologic Consultants and Geovera. The TIN was used to assign elevations primarily to the in-channel portions of the 2-D model. Figure 5.1-11 shows the 1-foot contour mapping for FA-104 (Whiskers Slough) developed from the TIN.
   - Data from the 2013 LiDAR bare earth data set was used to assign elevations to the un-surveyed island and floodplain areas. Figure 5.1-12 shows a 2-foot interval contour mapping developed from the LiDAR data that was used to assign elevations primarily to the un-surveyed island and floodplain areas of the 2-D model.
3. Develop model network.
   - The mesh extents are evaluated on a site-by-site basis. For example, the downstream boundary of the 2-D model is located at the downstream boundary of the Focus Area (Figure 5.1-13), whereas, the upstream boundary of the 2-D model is located approximately 1.4 miles upstream of the Focus Area boundary to provide better prediction of the flow distribution in the vicinity of the upstream end of the Focus Area and to evaluate the channel capacity between the upstream end of the Focus Area and the upstream end of the model.
   - The node and element locations and configurations are located to accurately represent the channel and overbank topography and changes in roughness. The SRH-2D meshes are composed of triangular and quadrilateral elements whereas the River2D meshes are composed entirely of triangular elements. The meshes are refined in areas of appreciable change or areas of significant habitat interest.
   - Node elevations were determined from the TIN and LiDAR from Step 2, above.
   - A review of the mesh quality was conducted to ensure that element size transitions and other modeling requirements are reasonably met. These include increased mesh refinement where there is appreciable geometric change or where velocity magnitude or directions changes occur.
4. Develop flow resistance (roughness) and turbulence stress data.
   - The bed-material sizes are being evaluated and will be used in conjunction with the substrate mapping to develop channel roughness values.
   - The channel bank and floodplain (overbank) roughness values were developed based on land use, vegetative ground cover, and obstructions using field observations and

aerial photography. Initial Manning's *n*-values (Table 5.1-4) have been developed and correlate to the geomorphic surface mapping (Figure 5.1-14). The Manning's n-values will be adjusted on a site-by-site basis, including potential influence from LWD, during model calibration.
- The two models under consideration apply different methods to predict the turbulence energy losses. The SRH-2D model uses turbulence models (parametric or k-ε) and the River2D model uses eddy viscosity coefficients. The parameters in turbulence models and/or the eddy viscosity coefficients will be calibrated using the ADCP data, which was not yet processed during this preliminary example run.

5. Develop bed and bank material gradation and layer information.
   - The bed surface, sub-surface and bank material sampling data will be evaluated in conjunction with the channel substrate mapping to develop spatially representative sediment gradations and bed layers for input to the bed evolution models. For the initial model runs, a uniform n-value of 0.03 was applied to the main and side channels (Table 5.1-4).

5.1.2. Coordination with other Studies

The coordination between various studies has contributed greatly to development of the Fluvial Geomorphology Modeling Study below Watana Dam. The nearly continuous coordination has taken place with the Geomorphology Study (Study 6.5), Fish and Aquatics Instream Flow Study (Study 8.5), Riparian Instream Flow Study (Study 8.6), Ice Processes in the Susitna River Study (Study 7.6), Groundwater Study (Study 7.5), Water Quality Modeling Study (Study 5.6), and Characterization and Mapping of Aquatic Habitats (Study 9.9). Coordination has also occurred with the Glacier and Runoff Changes Study (Study 7.7), Study of Fish Distribution and Abundance in the Upper Susitna River (Study 9.5), Study of Fish Distribution and Abundance in the Middle and Lower Susitna River (Study 9.6), Study of Fish Passage Feasibility at Watana Dam (Study 9.11), Study of Fish Passage Barriers in the Middle and Lower Susitna River and Susitna Tributaries (Study 9.12), Eulachon Run Timing, Distribution and Spawning in the Susitna River (Study 9.16), Cook Inlet Beluga Whale Study (Study 9.17), Riparian Vegetation Study Downstream of the Proposed Watana Dam (Study 11.6), River Recreation Flow and Access Study (Study 12.7), Probable Maximum Flood Study (Study 16.5) and Special Seismic Hazard Study (Study 16.6).

As examples of the outcome of this coordination the following items are listed:

- Modeling Approach TM (Tetra Tech 2013h)
- Selection of Focus Areas and their extents (R2 2013a and 2013b)
- Extension of the downstream study limits for the 1-D Bed Evolution Model
- Identification of appropriate 2-D Bed Evolution and Hydraulic models mesh size
- Continued development of the Proof of Concept modeling effort
- Selection of representative hydrologic years (wet, average and dry) and the 50 year record
- Identification of model precedence for various parameters
- Selection of Middle and Lower River tributaries for analysis in the Fluvial Geomorphology Modeling below Watana Dam Study

A large portion of the data being used by the Fluvial Geomorphology Modeling below Watana Dam Study was collected partially or in cooperation with other studies. This includes:

- Survey of 1-D Bed Evolution Model mainstem and tributary cross sections
- Survey 2-D Bed Evolution Model (Focus Area) bathymetry and topography
- 1-D and 2-D model calibration information including:
  - Spot survey of water surface elevations
  - Continuous recordings of water surface elevations
  - Flow distribution and split flow locations
  - Velocity and depth ADCP measurements in Focus Areas
- Ages of floodplain surfaces
- Stratigraphy of floodplain deposits
- Gaging of tributary flows
- Evidence and influences of ice processes including:
  - Mapping of ice scars
  - Locations and characteristics of current and historical breakup jams
  - Hydraulic conditions during ice cover
- Mapping of floodplain vegetation
- Mapping of substrate (bed material) in Focus Areas

As the studies progress in a next year of study, the level of coordination and integration will continue to increase among the various studies. Section 5.3 provides a description of the Coordination and Integration of Modeling Results.

5.1.3. Model Resolution and Mesh Size Considerations

The flexible mesh formulation available in the SRH-2D and River2D models is ideal for obtaining detailed results in areas of significant change or interest. As mentioned previously, an initial SRH-2D habitat model has been developed and run. Figure 5.1-13 (previously presented) shows the extents and mesh resolution of the SRH-2D habitat model which contains approximately 164,000 elements.

Based on input from the aquatic and riparian habitat analysis teams, and specified in the Fluvial Geomorphology Modeling Approach (Tetra Tech 2013h), the elements in the habitat mesh range in size from approximately 5 to 100 feet. Areas were identified by the aquatic habitat team members (Figure 5.1-15) to be modeled at the specified mesh resolution of 6.5 feet (2 m), which is sufficient to describe the variability in hydraulic conditions that is necessary for the habitat analysis. Figure 5.1-13 is an example of the mesh requirements of the 2-D Hydraulic Models used for aquatic habitat analysis; the darker areas located within the FA represent the fine mesh (Figure 5.1-15). Figure 5.1-16 shows a close up view of the fine mesh in the FA-104 (Whiskers Slough) SRH-2D model near the mouth of Whisker Creeks. Element sizes of up to 30 feet (~10 m) are used for the non-habitat areas of the main channel, and up to 100 feet (~30 m) in floodplain areas. The element sizes transition smoothly between these ranges to maintain good mesh quality.

For the 2-D Bed Evolution Models, the element sizes are as large as practicable, but with sufficient detail to represent variability in bathymetry, topography, roughness, and bed composition. Figure 5.1-17 shows an example of the coarser mesh developed for the SRH-2D sediment transport model. The size of the elements in the main channel are on the order of 50 to 75 feet in width and the mesh contains approximately 10,000 elements, which is significantly less than the 16,000 element limit of SRH-2D.

5.1.4. Focus Area Selection

Table 5.1-6 lists the Focus Areas, the upstream and downstream limits, the associated geomorphic reach, and the geomorphic reach type. The 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 SC1 channel type is very confined and typically single channel and therefore 1-D Bed Evolution Modeling efforts are adequate to identify project effects. The locations of the Middle Susitna River Segment Focus Areas are shown on Figure 5.1-18. More detailed maps that show individual proposed Focus Areas on recent (2011) color aerial photographs are provided in the Fish and Aquatics Instream Flow Study (Study 8.5 ISR Section 4.2.1.2.1).

The upstream boundary of the FA-104 (Whiskers Slough) 2-D Bed Evolution model is located approximately 1.4 miles upstream of the Focus Area boundary. The upstream boundary for the 2-D model was moved to evaluate the main channel discharge required to initiate flow into an upland side slough located on the right overbank. The downstream boundary of the FA-104 (Whiskers Slough) 2-D model is located at the Focus Area boundary.

At FA-128 (Slough 8A) the downstream boundary of the Focus Area is located near the downstream end of an island. The 2-D Bed Evolution model boundary was moved approximately 250 feet downstream of the Focus Area boundary (and island) to provide more uniform hydraulic conditions across the channel and better prediction of the hydraulic conditions at the Focus Area boundary. The upstream 2-D model boundary of the FA-128 (Slough 8A) coincides with the Focus Area boundary. The mesh extents of the other Focus Area 2-D Bed Evolution Models are being evaluated on a site-by-site basis and it may be necessary to extend the model boundaries outside of the Focus Areas to improve the model performance.

This expansion of efforts outside the Focus Area boundaries has already been applied to a portion of the Geomorphology Study. In order to adequately develop a geomorphic narrative for the Focus Areas (i.e. identify geomorphic trends and processes), the area of study was extended either upstream, downstream or both, from the Focus Area boundaries. These expanded areas of geomorphic study are hereby referred to as Geomorphic Assessment Areas (GAAs) and correspond with each of the 2013 studied Focus Areas. Table 5.1-7 identifies each GAA and defining PRM boundaries. Names of GAAs correspond to the numerical and common naming convention for Focus Areas. The geomorphic characterization of the 7 Focus Areas and the corresponding GAAs is provided in Geomorphology Study (ISR 6.5 Sections 4.1.2.3 and 5.1.3).

5.1.5. Model Calibration and Validation

This section briefly describes the model calibration and validation results to date for both the reach-scale 1-D Bed Evolution Model and the 2-D Bed Evolution and Hydraulic models.

5.1.5.1. One-Dimensional (1-D) Model

The reach-scale 1-D Bed Evolution model is currently in the process of being developed. Preliminary model calibration and validation will be performed in 2014 from PRM 187.1 to PRM 29.9 per the procedures outlined in the 1-D Bed Evolution Model development (Section 4.1.2.5.1 and Tetra Tech 2013h).The results will be reported on in 2014 as part of the Proof of Concept for the overall aquatic resources modeling effort. There are therefore no model calibration and validation results to present at this time.

5.1.5.2. Two-Dimensional (2-D) Bed Evolution Model

Through 2013, the model development process for both FA-104 (Whiskers Slough) and FA-128 (Slough 8A) has concentrated on the development of the hydraulic and sediment transport meshes. The initial step in the calibration process has been started at FA-104 (Whiskers Slough) as models runs for three n-values have been conducted. The 2-D Bed Evolution models are being calibrated and validated following the procedures outlined in 2-D model development (Section 4.1.2.5.2 and Tetra Tech 2013h). Velocities and flows from ADCP measurements are being used to calibrate the split flows between the various channel elements and velocities and velocities and locations within the mesh. Figure 5.1-15 (previously presented shows locations of the ADCP measurements being used in FA-104 (Whiskers Slough) for this purpose.

The SRH-2D habitat model was run using the parameters described previously for the specified habitat flows of 2,000, 6,000, 14,000, and 24,000 cfs. In addition, the model was run at 100,000 cfs (the 100-year peak flow event is 98,000 cfs) to provide an estimate of the channel capacity and overtopping discharges of the geomorphic surfaces.

Figures 5.1-19 and 5.1-20 show the predicted depth and velocity distributions, respectively, at 24,000 cfs. In general, the depths in the main channel range from 6 to 12 feet and the velocities range from 4 to 7 fps. The model output at 100,000 cfs indicates that the flow depths range up to 20 feet near the upstream end of the model (Figure 5.1-21)and velocities generally range from 8 to 13 fps along the main channel (Figure 5.1-22). Although these results are preliminary, they indicate that open-water conditions may not significantly inundate island and overbank areas at this Focus Area even at 100-year flow conditions.

5.1.6. Tributary Delta Modeling

Preliminary selections of 20 tributary deltas to be modeled were based on existing fish use and the potential for Project effects, as determined in coordination with the instream flow and fish and aquatic resources studies and the licensing participants (Table 5.1-3). The preliminary selections included 5 tributaries to the Lower River (Figure 5.1-23), and 15 tributaries to the Middle River, of which 11 enter the Susitna River within a focus area (Figure 5.1-24). Reconnaissance was planned for 13 tributary deltas during the 2013 field season (Table 5.1-6); however, reconnaissance was carried out at 10 tributaries to the Middle River, and only two tributaries to the Lower Susitna River Segment (Table 5.1-8). Due to private landowner access issues at Birch Creek in the Lower River, no reconnaissance or survey could be conducted. Due to access limitations upstream of PRM 146.1 during the 2013 field season, data collection at five of the selected Middle River tributaries could not be conducted, but is planned for in a next year of the study. Thus, final selections were confirmed at 11 of the 12 tributaries where reconnaissance was carried out during 2013. Observations made during the reconnaissance at the unnamed tributary (PRM 115.4) confirmed that no appreciable amount of sediment was delivered from the watershed, and that no delta was present. It was decided that there would be no value in modeling this tributary to characterize sediment loading for input to the 1-D and 2-D Bed Evolution models (Section 4.1.4). This decision was coordinated with the Study of Fish Passage Barriers in the Middle and Upper Susitna River and Susitna Tributaries (Study 9.12), and since this tributary is not included within the scope of that study, there is no need to assess potential Project effects on the ability of fish to access the tributary. Thus, the unnamed tributary (PRM 115.4) will be excluded from tributary delta modeling.

HEC-RAS models have been developed for 11 tributaries near their confluences with the Susitna River (Table 5.1-8); nine models are for tributaries to the Middle Susitna River Segment and the remaining two models are for tributaries to the Lower Susitna River Segment. In general, the cross section geometry and bed profiles were surveyed during the 2013 reconnaissance. Energy losses in the models were quantified using (1) roughness heights based on average bed surface gradations sampled during the reconnaissance, and (2) expansion and contraction coefficients based on professional judgment. Downstream boundary conditions for the models were set to normal depth. Preliminary hydraulic calibration was completed by adjusting initial roughness heights so that the simulated water-surface profiles visually aligned with surveyed water-surface elevations. The hydraulic calibration is limited because flows during the surveys were not measured; rather, the flows were visually estimated. Preliminary hydraulic calibration could not be completed for tributaries that were dry. Sieve analysis results for the finer gravel and sand component of the bed material have only recently been returned from the lab, so the sediment transport analyses are just now getting underway. Bed-material sediment transport curves have not yet been developed, but the calculations of sediment loading are also awaiting the synthesized flow series (ISR Study 8.5 Section 4.3).

The hydraulic models developed for the two tributaries to the Lower Susitna River Segment (Deshka River and Trapper Creek) have greater modeled lengths than the models for the nine tributaries to the Middle Susitna River Segment (Table 5.1-6). These greater lengths were necessary to encompass (1) potential post-Project backwater effects and (2) holding habitat for targeted fish species accessing the tributaries. Since these tributary channels cross the extensive floodplains along the Lower Susitna River, the slope of the channels is approximately two orders of magnitude flatter than the tributary channels that enter the Middle Susitna River, so the potential backwater influence could affect greater tributary channel length. The Deshka River hydraulic model was developed from nine cross section surveys that were conducted on October 4, 2013 by Geovera LLC as part of the Fish and Aquatics Instream Flow Study (Study 8.5). Geometry for a tenth cross section, located just upstream of the confluence with the Susitna River, was estimated from depth readings taken from a boat traveling across the river by Tetra Tech on September 26, 2013. The hydraulic model includes the lower 5.8 miles of the Deshka River. The Trapper Creek hydraulic was developed from a total of 14 cross section surveys, 4 of which were conducted between June 16th and June 20th, 2013 by Geovera LLC as part of the Fish and Aquatics Instream Flow Study (Study 8.5) and 10 of which were conducted by Tetra Tech between September 20th and September 23rd, 2013. The hydraulic model includes the lower 0.5 miles of Trapper Creek. Hydraulic calibration of both the Deshka River and Trapper Creek models is currently underway, using flow rates from installed flow gages and water surface elevations surveyed during the cross section surveys.

Since the estimates of sediment loading are an input to modeling tributary deltas, and the sediment loads are not yet quantified, no delta modeling results are available.

5.1.7. Large Woody Debris Modeling

There are as yet no results relevant to LWD modeling. The existing conditions models will have calibrated Manning n values that include LWD effects. For simulations of operational scenarios, the channel roughness parameters will be evaluated and adjusted based on anticipated changes in LWD loading. There is significant information regarding LWD in the Geomorphology Study (ISR 6.5 Section 5.9 and Appendix D).

5.1.8. Wintertime Modeling and Load-Following Operations

There are no results to report on any of the winter conditions modeling or load-following operations. These operational scenario simulations will be conducted after calibrated existing conditions models are developed. Winter condition models will also be developed after open water models are developed as part of this study component and information is available from the Ice Processes in the Susitna River Study. The Fluvial Geomorphology Modeling below Watana Dam Study will not be executing winter load-following models, but will use results from the Ice Processing in the Susitna River (ISR Study 7.6) modeling to evaluate the potential for mobilization of bed material during winter load-following operations.

5.1.9. Field Data Collection Efforts

Field data presented in this section were collected in 2013 to support both the Geomorphology Study and the Fluvial Geomorphology Modeling below Watana Dam Study. The types of data include:

1. Inputs to the 1-D Bed Evolution Model
    a. Hydraulic observations, and
    b. Sediment sampling
2. Characterization of Focus Areas
3. Characterization of tributary deltas
4. Data collected from other studies, and
5. LiDAR verification and acquisition

5.1.9.1. Inputs to 1-D Bed Evolution Model

Field data were collected in 2013 to support the development and calibration of the hydraulic component of the 1-D Bed Evolution Model, as well as the development of the sediment transport component of the model.

Hydraulic Observations: Hydraulic observations were conducted in the Lower and Middle Susitna River Segments and at the Focus Areas. These observations included a combination of the following: characterization of the bank and overbank roughness, water-surface elevation measurements, and characterization of the bank geometry. Twenty cross-section roughness observations and water-surface measurements were collected along the Susitna River and 8 cross-section roughness observations and water-surface measurements were collected at the Focus Areas (Table 5.1-9). A total of 85 water-surface elevation measurements were collected at 65 locations as part of the Geomorphology and Fluvial Geomorphology Modeling below Watana Dam studies (ISR Section 6.5 and 6.6, respectively) (Appendix D). Repeat measurements were collected at 17 locations and at varying discharges. Forty of the 85 water-surface elevations measurements, were collected between PRM 101.5 and PRM 143.9 during the mid-August high water period when the discharge at Gold Creek gage varied from 30,000 cfs to 43,600 cfs; these measurements will provide valuable data to calibrate the 1-D and 2-D Bed Evolution models. Bank profile observations were conducted at 30 locations along the Susitna River and at 6 locations in the Focus Areas.

Sediment Sampling: A summary of the number of sediment samples collected along the Susitna River and tributaries is summarized in Table 5.1-10. Figure 5.1-25 shows an example of the number and spatial distribution of the sediment sampling conducted at FA-104 (Whiskers Slough). The locations and representative grain sizes of the surface (pebble counts) and subsurface samples measurements (bulk samples and sieve samples) are reported in tables in Appendix A and mapping of the sediment sampling locations in the other 6 Focus Areas are shown in Appendix B.

Eighty-three surface (pebble counts) and associated subsurface samples (sieve samples) were collected along the Susitna River and tributaries (Table 5.1-10). It is important to note that typically 3 pebble counts were collected at each subsurface sampling location. The 3 pebble counts were combined into a single representative sample, and therefore, the total number of pebble counts is underrepresented in Table 5.1-10. A total of 314 pebble counts were collected in 2013. Of the 83 co-located surface/subsurface measurements, 16 were collected in the Lower River, 22 were collected along the Middle River in areas outside of the Focus Areas, 32 samples were collected in the Focus Areas and 13 were collected at tributaries.

An additional 56 surface samples (pebble counts) were collected along the Susitna River with 5 of these in the Middle River outside of the Focus Areas, 51 in the Focus Areas, and 12 at the tributaries (Table 5.1-10).

One bulk sample was collected along the Susitna River, two were collected at FA-104 (Whiskers Slough) and 11 were collected at tributaries.

Tests of subaqueous image acquisition of bed material at FA-104 (Whiskers Slough) near PRM 105 and at discharge measurement transect ESS40 near PRM 107 was performed on March 20 and 21, respectively. The images were acquired by auguring holes through the ice and lowering a pole attached with a camera, light and dual laser beams. A total of 5 combinations of camera type, camera mode, and light type were tested for acquiring bed-material images at Whiskers Slough site and 10 combinations were used at the ESS40 site. Each location offered varied water depth and velocities, frazil ice and ice thickness conditions. The images were reviewed and assigned quality grades ranging from poor to fair to good, with grades of good being useful for determining channel bed gradation.

At the Whiskers Slough site, only one combination achieved the image quality grade of good. That combination was with the GoPro camera, operated in video mode, and using the Princeton Tec scuba flashlights (Figure 5.1-26). Frazil ice, turbidity, and other moving objects were not an issue at this site, located off of the main channel. Additionally, water velocities were low and not an issue for securing or operating the equipment.

At the ESS40 site, all combinations with the GoPro camera achieved a grade of good for image quality. Similarly for the AquaVu camera, nearly all combinations achieved the grade of good with the exception of the combination including the AquaVu camera with the Princeton Tec scuba flashlights. Both combinations tested for the Wide-I and SplashCam were unsuccessful and images could not be acquired with this equipment at ESS40.Good scene illumination was available and both the AquaVu and GoPro cameras without lights achieved good image quality grades. Figure 5.1-27 illustrates an example of the GoPro streambed-material sample image acquired at ESS40 with the use of underwater lights, and Figure 5.1-28 is an example of the GoPro acquired sample image without the use of lights. The sample hole at ESS40 had a water depth of 10.4 feet and included an ice thickness of approximately 3.8 feet, minimal snow cover, and some frazil ice. High flow velocities were also present, but did not impact the use of submerged equipment, which could be kept vertical during insertion and removal from the ice hole.

A total of 63 bank material samples were collected in the Middle Susitna River. All but6 samples were collected at Focus Areas. At some bank locations, multiple samples were collected to characterize the different materials comprising the bank. For example, at Whiskers Creek, there were 4 locations that up to 3 samples were collected (Figure 5.1-25). The results from the laboratory sieving of all the collected samples has been completed and a list of the samples and gradation characteristics are listed in Appendix C.

5.1.9.2. Focus Areas

The data collected in the Focus Areas was conducted as part of the overall data collection effort and was collected by various studies including the Geomorphology and Fluvial Geomorphology Modeling below Watana Dam Studies (ISR Study 6.5) and the Fish and Aquatics Instream Flow Study (Study 8.5). The data collected within the Focus Areas has been described elsewhere in this report and by other studies. The following data were collected (Note: The numbering follows the items listed in Section 4.1.2.9.2.):

1. Bathymetry (single beam), cross-section data, and spot elevation data were collected and reported by the Fish and Aquatics Instream Flow Study (ISR Study 8.5).
2. Documentation of the obstructions in the off-channel habitats was conducted as part of the Geomorphology Study and is reported in ISR Study 6.5 (Section 5.1.3).
3. Large woody debris survey and characterization was conducted and is reported in ISR Study 6.5 (Section 5.9).
4. Bed-material samples in the main channel, sloughs, and side channels was conducted and reported in Section 5.1.9.1.
5. Bank material sampling was conducted and reported in Section 5.1.9.1.
6. Spot elevations to verify LiDAR in the Focus Area were conducted and reported in Section 5.1.9.5.

7. Estimation of n-values in the channels, side channels, sloughs, and tributaries was conducted and reported in Section 5.1.9.1.
8. Observations on depositional or erosional features were conducted in the Geomorphology Study and are reported in ISR Study 6.5 Section 5.1.3.
9. Field verification, and correction and/or mapping of the geomorphic features, geologic controls, and terraces were conducted and are reported in the Geomorphology Study and are reported in ISR Study 6.5 Section 5.1.3.
10. ADCP measurements were collected by the Fish and Aquatics Instream Flow Study (ISR Study 8.5).
11. Installation of level loggers and associated readings to support calibration of water surface elevations was conducted by the Fish and Aquatics Instream Flow Study (Study 8.5) and Groundwater Study (Study 7.5).
12. Current meter measurements of velocity were not collected because all velocity measurements were conducted using ADCP by the Fish and Aquatics Instream Flow Study (Study 8.5).
13. 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 were conducted as part of the Geomorphology Study and are reported in ISR Study 6.5 (Section 5.1.3) in the Ice Processes in the Susitna River Study (Study 7.6) and in the Riparian Instream Flow Study (Study 8.6).
14. Evidence of past extreme events was documented as part of the Geomorphology Study and reported in ISR Study 6.5 Section 5.1.3.
15. An overall narrative description and assessment of the geomorphology of the Focus Area including identification of key physical processes and controls was developed as part of the Geomorphology Study and reported in ISR Study 6.5 Section 5.1.3.
16. Water surface elevations were measured and reported by the Fish and Aquatics Instream Flow Study (Study 8.5) and by the Fluvial Geomorphology Modeling below Watana Dam Study (Section 5.1.9.1).

5.1.9.3. Tributary Deltas

Nine tributaries were surveyed in the Middle Susitna River between PRM 105.1 and PRM 144.6, and two tributaries were surveyed in the Lower Susitna River Segment. It was originally anticipated that 20 tributaries would be surveyed (Table 5.1-3), however, for various reasons, including limited access, 9 tributaries were not surveyed in 2013. Preliminary hydraulic models have been developed for each of the 11 surveyed tributaries. Table 5.1-8 summarizes the number of cross-sections, length of the study reach (model length), average channel width, and average channel gradient of the tributary delta sites, and Table 5.1-11 summarizes the associated sediment gradation parameters of the surface and subsurface samples at the tributary delta study sites.

5.1.9.4. Field Data from Other Studies

Field data collected from other studies include:

1. Cross section surveys (Study 8.5)
2. Bathymetric surveys within Focus Areas (Study 8.5)

3. Water-surface elevation (WSE) measurements (Studies 8.5 and 7.5)
4. Bed-material (substrate) mapping (Study 8.5)
5. Acoustic Doppler Current Profiler (ADCP) measurements (Study 8.5)
6. Stage hydrographs (Studies 8.5 and 7.5), and
7. Sediment transport measurements performed by the USGS (Study 6.5)

Cross section surveys: A total of 91 cross sections were surveyed in 2013 to support the development of the 1-D Bed Evolution Model: 79 sections along the Susitna River, 2 sections along the Chulitna River, and 10 sections along the Talkeetna River. Fifty (50) cross-sections were surveyed in the Lower Susitna River Segment between PRM 29.9 and PRM 102.4, and 29 cross-sections were surveyed in Middle Susitna River Segment between PRM 102.7 and PRM 146.1 (Table 5.1-12). Table 5.1-12 also shows the cross sections that were surveyed in 2012. PRMs are under development for the Chulitna River and the Talkeetna River, so PRMs for the surveyed sections on these rivers are not yet available. The surveys were conducted as part of the Fish and Aquatics Instream Flow Study (Study 8.5).

Bathymetric surveys within Focus Areas: The bathymetry survey data for each Focus Area that was collected as part of ISR Study 8.5 has been provided in a TIN format. The in-channel bathymetry will be merged with the overbank LiDAR data to create a combined TIN surface. The surface will be used to develop the 1-D and 2-D Bed Evolution and Hydraulic models and will be provided to other studies including the Ice Processes in the Susitna River (Study 7.6) and the Groundwater Study (Study 7.5).

Water-surface elevation (WSE) measurements: WSE measurements were collected during the Focus Area surveys as part of the Fish and Aquatics Instream Flow Study (Study 8.5). The measurements were collected along the main channel, side channels, and upland sloughs; the data were provided in an AutoCAD file containing the Focus Area survey data. Table 5.1-13 lists the number of water-surface elevation measurements collected at each Focus Area. The date and associated discharge for measurements will be obtained.

WSE measurements collected during the ADCP surveys as part of the Fish and Aquatics Instream Flow Study (Study 8.5) has been provided in a spreadsheet format. Table 5.1-14 summarizes the number of measurements collected, the date of the survey and the coincident discharge at the Gold Creek gage.

Bed-material (substrate) mapping: Bed-material mapping was conducted as part of the Fish and Aquatics Instream Flow Study (Study 8.5) to spatially characterize the bed material. The bed-material mapping will be evaluated together with the bed-material sampling data to identify roughness zones, which in turn, will be used to specify channel roughness for the 1-D and 2-D Bed Evolution models. It will also be used to assist in specifying the bed-material gradation throughout the 2-D model domain.

Acoustic Doppler Current Profiler (ADCP) measurements: ADCP data were collected at the 7 Focus Areas in 2013 (Study 8.5). The ADCP data provide discharge measurements in the main channel and side channels that are being used to determine the flow distributions for model calibration. The velocity data are being used for the 2-D model calibration and to evaluate the roughness characteristics of the bed material. The 2-D model calibration is being conducted by comparing the depth averaged direction and magnitude of the measured velocity data with the predicted model output. It is anticipated that the bed-material roughness (k) will be back calculated using the measured vertical velocity profile data and the logarithmic vertical profile equation. Preliminary testing of this method showed promising results.

Stage hydrographs: Stage hydrographs are available from the USGS National Water Information System website (http://waterdata.usgs.gov/nwis) at the USGS gage stations.

Surface water stage measurements were collected as part of the Ground Water Modeling Study (Study 7.5). In 2012, one surface water stage recorder was installed in the Lower River, eight stage recorders were installed along the Middle River, and one stage recorder was installed in the Upper River (Table 5.1-15). A summary of the data available is listed in Table 5.1-15. Complete stage measurements for 2013 are available for the Lower and Upper River recorders, partial records are available at three recorders in the Middle River, and no data are available at the remaining five recorders in the Middle River.

Sediment transport measurements: Historically and in 2012 and 2013 the USGS collected measurements of sediment transport at various locations along the Susitna River (ISR 6.5 Section 5.2). These data will support the calibration of the bed load and suspended bed-material load transport simulated using the 1-D Bed Evolution Model.

5.1.9.5. LiDAR Verification and Acquisition

5.1.9.5.1. Su-Wa LiDAR

LiDAR data acquisition occurred between September 9, 2013 and November 8, 2013. A total of 11 flight days of acquisition were completed. Unfavorable weather prevented completion of the total acquisition area. The 2013 collected airborne LiDAR point cloud dataset covers 107.7 square miles and is located over the confluence area of Susitna, Chulitna, and Talkeetna rivers as well as a small section just south of the Three Rivers Confluence Area. The area covers priority areas 01 South, 02 South, 03, 04, and 07 as shown in Figure 5.1-29.

As shown in Tables 5.1-16 and 5.1-17, the FVA of the LiDAR meets the target accuracy of RMSEz < 9.25 cm (approximately 0.30 ft.). Including brush, low vegetation, and forested lands, SVA (RMSEz) ranges from approximately 0.5 to 0.62 ft. The vertical accuracy at the 95 percent confidence level is 1.96 times the RMSEz, which is approximately 0.5 ft. for open terrain and up to 1.2 ft. for other terrain types. These values indicate that the FVA is 1-ft contour interval equivalent and that the SVA is approximately 2-ft contour equivalent (previously presented Table 4.1-8).

The verification process followed the ASPRS guidelines for vertical accuracy reporting for LiDAR data (ASPRS 2004) which recommends,

- *"A LiDAR dataset's required 'fundamental' vertical accuracy, which is the vertical accuracy in open terrain tested to 95% confidence (normally distributed error), shall be specified, tested and reported."*
- *"If information is required on the vertical accuracy achieved within other ground cover categories outside open terrain, either to meet the same specification as the fundamental*

vertical accuracy or a more relaxed specification, then "supplemental" vertical accuracies, that is vertical accuracy tested using the 95th percentile method (not necessarily normally distributed) shall be specified, tested and reported for each land cover class of interest"

5.1.9.5.2. Mat-Su LiDAR Verification

The 2011 Mat-Su LiDAR as originally delivered was not brought to true ground by shifting to surveyed data (indexing), nor was a verification process conducted. The survey points collected in 2013, however, can still be used to assess the vertical accuracy of the Mat-Su LiDAR. The survey points were used to verify the 2011 Mat-Su LiDAR and the verification results are shown in Table 5.1-18. The Mat-Su LiDAR was collected in 2011 and the survey was conducted in 2013. The verification results are, therefore, not a complete comparison because some open areas, especially bank lines and bar heads, are prone to change due to deposition or scour. As shown, the FVA RMSEz is approximately 5 times as high for the Mat-Su LiDAR than the Su-Wa LiDAR with an approximate 4-ft contour equivalency. The SVA is approximately 1.5 times the Su-Wa LiDAR with an approximate 3-ft contour equivalency.

5.1.9.5.3. 2011 Mat-Su LiDAR Indexing

The indexing process of the 2011 Mat-Su LiDAR was completely performed in Terrascan/Microstation environment and it was corroborated using the LiDAR processing software LP360. Table 5.1-19 shows a comparison of 525 open terrain points to the Mat-Su LiDAR. The Mean difference was used to shift the LiDAR to true ground. After indexing, the vertical accuracy was reevaluated. The results, presented in Table 5.1-20, show that the RMSEz for FVA reduced to 0.92 and for SVA was largely unchanged. All the tests result in an approximate 3-ft a contour equivalence.

5.1.10. Electronic Data

The following data produced in 2013 for Study Component 1 are available on the GINA website at http://gis.suhydro.org/reports/isr:

- Subsurface Bed-material Sample Locations on the Middle and Lower Susitna Rivers shapefile
  - File name: ISR_6_6_FGM_BedSamp_Subsurface
- Subsurface (SubS) Bed-material field and lab data excel spreadsheet [surface (Sur) samples at same location are included in combined spreadsheet]
  - File name format: ISR_6.6_FGM_SuWa TtGeo Sur SubS + ***date collected*** + PRM + ***location*** + DistChart QC3 + ***initials of QC performer*** + ***date of QC***
  - File name example: ISR_6.6_FGM_SuWa TtGeo Sur SubS 20130714 PRM 103.9 DistChart QC3 LWZ 20140115
- Surface Bed-material Sample Locations on the Middle and Lower Susitna Rivers shapefile
  - File name: ISR_6_6_FGM_BedSamp_Surface
- Surface Bed-material field and lab data excel spreadsheet

- — File name format: ISR_6.6_FGM_SuWa TtGeo Sur + ***date collected*** + PRM + ***location*** + DistChart QC3 + ***initials of QC performer* + *date of QC***
- — File name example: ISR_6.6_FGM_SuWa TtGeo Sur 20130817 PRM 144.9A-FA144 DistChart QC3 MRM 20140115

- Bank Material Sample Locations within the Middle Susitna River Segment shapefile
  - — File name: ISR_6_6_FGM_Bank_Samples
- Bank Material lab data
  - — File name format: ISR_6.6_FGM_SuWa TtGeo Bank + ***sample number*** + ***date collected*** + PRM ***location*** + LabResults QC3 + ***initials of QC perfomer* + *date of QC3***
  - — File name example: ISR_6.6_FGM_SuWa TtGeo Bank1 20130907 PRM 145.7 LabResults QC3 LabResults QC3 ALS 20140114
- Cross-section Observations, Surveys and Level Loops Locations Shapefile
  - — File name: ISR_6_6_FGM_XSec_Obs_Survey
- Cross-section Level Loops excel spreadsheet
  - — File name: ISR_6.6_FGM_WSE_LevelLoops
- Cross-section Observations Summary excel spreadsheet
  - — File name: ISR_6.6_FGM_XSec_Obs_Summary
- Tributary Survey excel spreadsheets
  - — File name: ISR_6.6_FGM_WhiskersCreek_Survey
  - — File name: ISR_6.6_FGM_UnnamedTrib113.7_Survey
  - — File name: ISR_6.6_FGM_SlashCr_Survey
  - — File name: ISR_6.6_FGM_GashCr_Survey
  - — File name: ISR_6.6_FGM_LaneCr_Survey
  - — File Name: ISR_6.6_FGM_SkullCr_Survey
  - — File Name: ISR_6.6_FGM_GoldCr_Survey
  - — File Name: ISR_6.6_FGM_IndianR_Survey
  - — File Name: ISR_6.6_FGM_UnnamedTrib144.6_Survey
  - — File Name: ISR_6.6_FGM_TrappersCr_Survey
- Geomorphic Surface Mapping Shapefile
  - — File name: ISR_6_6_FGM_Surface_Mapping

5.2. File Name: Study Component: Model Existing and with-Project Conditions

This section includes the current results of data collection and analysis for this study component. The primary results from the 2013 effort involved identification of the long-term hydrologic record, selection of representative hydrologic years and investigation of the influence of PDO. The results are specific to the Fluvial Geomorphology Modeling below Watana Dam Study and have been reviewed by other studies, primarily the Fish and Aquatics Instream Flow Study (Study 8.5) and the Ice Processes in the Susitna River Study (Study 7.6). The initial results were presented at the December 3, 2013 TWG meeting and will be coordinated with the stakeholders before final selection of the various hydrologic conditions to be used in the modeling efforts.

5.2.1. Existing Conditions – Base Case Modeling

As per the Study Plan, the existing conditions modeling has not commenced and will be performed after the 1-D and 2-D Bed Evolution and Hydraulic models have been developed and calibrated. The initial selection of the hydrology to represent the existing conditions has been completed for Fluvial Geomorphology Modeling below Watana Dam. The selection has been coordinated with Fish and Aquatics Instream Flow Study (Study 8.5) and Ice Processes in the Susitna River Study (Study 7.6), and will be finalized based on input from the stakeholders. The hydrologic input for the 1-D Bed Evolution Model includes a 50-year period from the 61 years of available hydrologic record and the 2-D Bed Evolution Models include representative years. As presented in Appendix E, the 50-years were selected to include the best quality data. This was achieved by first eliminating five years (water years 1997 – 2001) when the USGS Susitna River gage at Gold Creek (gage no. 15292000) and all but one other gage were synthesized (USGS 2012) from the USGS Talkeetna River gage near Talkeetna (gage no. 15292700) reducing the number of years to 56. The USGS indicated that six water years (1954, 1956, 1958, and 1961-1963) of flow records at the Susitna River at Gold Creek gage included likely estimated flows. The annual flow hydrographs for these years include long periods of time (several weeks to approximately one month) when discharge was recorded as constant during open water periods (May through September). The six years were eliminated from the remaining 56 years to arrive at the required 50 year flow record. As a final step in this evaluation the flow duration curves for the 50-year record were compared with the complete (though partially estimated and partially synthesized) 61-year record and these curves are nearly indistinguishable. Therefore the recommended 50-year record for the 1-D Bed Evolution includes water years 1950-1953, 1955, 1957, 1959-1960, 1964-1996, and 2002-2010.

The Study Plan also indicates that up to six representative years will be used for the 2-D Bed Evolution Models of the 10 Focus Areas in the Middle Susitna River. The representative years will include wet, average and dry conditions and consider periods of warm and cool Pacific Decadal Oscillation (PDO). To investigate the influence of PDO, the 50 selected years were divided into warm and cool PDO conditions and ranked from lowest to highest by water year average annual discharge, open water average discharge approximated by May through September flows, and by maximum average daily flow. The higher-, median-, and lower-range flow years were reviewed as candidate representative wet, average and dry years including warm and cool PDO. The two most extreme flow years were excluded as candidates as they are not representative of wet or dry conditions. Similarly, dry and average years that contain extremely high peak flows were excluded and wet years that did not include high peak flows were excluded. Two wet, average and dry years were selected for each PDO condition and the annual hydrographs were compared. Appendix E Figures 5.10 (dry), 5.12 (average), and 5.14 (wet) show the annual hydrographs for the candidate years and Figures 5.11, 5.13, and 5.15 are the corresponding annual flow duration curves. There were no visually appreciable differences related to PDO between the hydrographs or flow duration curves within each hydrologic condition.

As described in detail in Appendix E, Wilcoxon Rank Sum test was used to evaluate differences in between warm and cool PDO. The test indicated that there are no statistically significant differences in mean annual flow, average open water and monthly flows (May to September), and maximum daily flows (Appendix E Tables 5.2 and 5.3). There are statistically significant differences in minimum daily and average winter and monthly flows (October to April). Based on these results, AEA recommends that the 2-D bed evolution modeling for open-water conditions will be conducted for three representative years without additional consideration of PDO. Three representative years were recommended from the original 12 candidate years of four each for wet, average and dry conditions. The three years are 1981, 1985, and 1950 to represent wet, average, and dry years. After additional analysis by the Fish and Aquatics Instream Flow and Ice Processes in the Susitna River studies, it was agreed that 1970 should be substituted as the representative dry year. These recommended years will be presented to the TWG for feedback and these three years may be revised depending on input that is received.

5.2.2. Future Conditions – with-Project Scenarios

There are no results for 1-D or 2-D Bed Evolution and Hydraulic modeling efforts for the four with-Project scenarios.

5.2.3. Uncertainty

There are no results for the evaluation of uncertainty in the 1-D and 2-D Bed Evolution and Hydraulic modeling.

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

There are no results for the synthesis of reach-scale and local-scale analyses.

5.2.5. Electronic Data

No electronic data are presented for Study Component 2 on the GINA website.

5.3. Study Component: Coordination and Interpretation of Model Results

As identified below, the effort conducted in 2013 was primarily in the area of internal coordination and integration between the Fluvial Geomorphology Modeling below Watana Dam Study and the Geomorphology Study (Study 6.5) and external coordination with the Fish and Aquatics Instream Flow Study (Study 8.5), Riparian Instream Flow Study (Study 8.6), Ice Processes in the Susitna River Study (Study 7.6), Groundwater Study (Study 7.5), Water Quality Modeling Study (Study 5.6), and Characterization and Mapping of Aquatic Habitats (Study 9.9). A wide variety of products has been developed by the Geomorphology Study (Study 6.5) that has aided the guidance of the development of the Fluvial Geomorphology Modeling below Watana Dam Study (Section 5.3.1). Coordination and integration with the other studies mentioned has centered on integration of the modeling efforts and in particular transfer of information between the various studies in terms of results from one study becoming input to another study. The modeling studies are jointly working on the Proof of Concept to develop the linkages between the various models and refine the development of the suite of results that will form a large part of the metrics that Project effects will be evaluated.

This effort has been progressing well. The Geomorphology Study has provided the information needed by the Fluvial Geomorphology Study to help guide the development of the 1-D and 2-D

Bed Evolution model. The coordination with the other modeling studies is also proceeding well through the efforts identified below (Section 5.3.2).

5.3.1. Integration of Geomorphology and Fluvial Geomorphology Modeling Study

Components of the Geomorphology Study directly contribute key information and data to the Fluvial Geomorphology Modeling below Watana Dam Study, and vice versa. Study components of the Geomorphology Study (Study 6.5) have and will continue to provide required information to the Fluvial Geomorphology Modeling below Watana Dam Study.

Results from the Geomorphology Study (Tetra Tech 2013b) were used to establish reach boundaries within the Middle and Lower River Segments, cross section locations and reach boundaries for the 1-D Bed Evolution Model and roughness boundaries for the channel and overbank surfaces for both 1-D and 2-D Bed Evolution models. Geomorphic process models that describe the formation and maintenance of lateral geomorphic features and habitats and floodplain features (Study 6.5 ISR Section 5.1.3.3) provide starting points for assessing the reasonableness of the 1-D and 2-D Bed Evolution model results and whether adjustments to the numerical or conceptual models are required. Integration of field observations and hydrologic analyses to understand the potential role of ice processes in the evolution of floodplain surfaces (ISR Study 6.5 Section 5.1.3.5.5). Sediment input to the 1-D and 2-D Bed Evolution models are directly derived from components of the Geomorphology Study (Tetra Tech 2013a). Geomorphic change over time and space resulting from the comparative aerial photo analysis (1980s and 2012 completed with 1950s underway) established the rates and locations of geomorphic change in the Middle and Lower River segments that will be used to assess model results and provide reality checks to the model output (ISR 6.5 Section 5.4 and Tetra Tech 2013g). The areas of various macrohabitat types for a specific flow represented on aerial photography provides a measure of habitat connectivity that will be used to verify model results (ISR 6.5 Sections 5.5 and 5.7, Tetra Tech 2013f). Preliminary assessments of the project effects on the Middle and Lower River Segments provide direct input for assessing the range of flows that are required to be modeled to represent geomorphic processes and channel geometries and the relative sensitivities of the identified reaches to changes in driving variables (Tetra Tech 2013c and Tetra Tech 2013d). Sediment loading to the reservoir and preliminary estimates of reservoir trap efficiency feed directly into both the 1-D and 2-D Bed Evolution modeling (ISR Section 5.8.1). Quantification of the sources, volumes and spatial distributions of large woody debris provide direct input to the models with respect to estimation of Manning's n values and a check on model estimates of bank erodibility (ISR 6.5 Section 5.9).

5.3.2. Coordination of Results with Other Resource Studies

To-date, the fluvial geomorphology models have not been fully developed and thus extensive results are not yet available. However, preliminary results for the hydraulic component of the 2-D bed evolution model have been developed for FA-104 (Whiskers Slough) and provided to the Fish and Aquatics Instream Flow Study to develop the linkages to transfer data between the models. The results of this effort were presented at the November 2013 IFS Technical Team meeting. There has been considerable coordination and discussions with other study teams at Technical Working Group meetings, the November 2013 IFS Technical Team meeting, joint field trips in 2012 and 2013, and through informal communications on the outputs required by the other study teams including; Open-water Flow Routing Model (ISR Study 8.5 Section 5.3.1), Fish and Aquatics Instream Flow (Study 8.5), Riparian Instream Flow (Study 8.6), Ice Processes in the Susitna River (Study 7.6), Water Quality Modeling (Study 5.6), Groundwater (Study 7.5) and Characterization and Mapping of Aquatic Habitats (Study 9.9) studies.

5.3.3. Electronic Data

No electronic data are presented for Study Component 3 on the GINA website.

6. DISCUSSION

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

6.1.1. Development of Bed Evolution Model Approach and Model Selection

The development of the initial 1-D and 2-D Bed Evolution models is progressing based on available surveys and data. The data appear to be sufficient but final determination of data adequacy will be made in the next year of study as the models are calibrated and run for a range of conditions.

6.1.1.1. One-Dimensional (1-D) Bed Evolution Model

Based on the information provided in Section 4.1.2.1.1 and in Tetra Tech (2013h), the Geomorphology Study team had tentatively proposed to use HEC-6T for the reach-scale 1-D sediment transport analysis. This proposal was 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 key advantages of HEC-6T are (1) its wide application experience; (2) looped network capability; and (3) large number of sediment transport equations (including both Parker (1990) and Wilcock and Crowe (2003)), sediment sizes, and hydrograph ordinates (Tetra Tech 2013h). However, subsequent to the issuance of Tetra Tech (2013h), the Geomorphology Study team was presented with new information that necessitated reconsiderations of the recommendation to select HEC-6T. The USACE Hydrologic Engineering Center (HEC) is enhancing the sediment routing algorithms in the HEC-RAS modeling software; Tetra Tech staff have been working closely with HEC staff to test the enhanced sediment routing functionality. In fall 2013, HEC staff offered to the Geomorphology Study team a previously tested beta release of the software (HEC-RAS 4.2.0). This version of the software includes the following enhancements that are relevant to the 1-D Bed Evolution modeling:

- Sediment routing for fully-unsteady hydraulics
- Sediment routing through split flows
- The Exner 7 bed sorting algorithm (Copeland 1993)
- A coupled Meyer-Peter-Müller (1948) and Toffaleti (1968) transport function

- Capabilities to calibrate selected sediment transport functions by adjusting coefficients and exponents. For example, the Wong and Parker (2006) correction can be applied to the Meyer-Peter-Müller (1948) bed load function.

Other benefits of the HEC-RAS software include widespread industry acceptance, public availability, ease of use, and a graphical user interfaces that facilitate data input and review of results. While HEC-RAS Version 4.2.0 was not available at the time the initial model selection was occurring (Tetra Tech 2013h), it is now believed that this software is most appropriate given the benefits identified above and given that it will allow for better integration with the Open Water Flow Routing Model (ISR Study 8.5 Section 4.3) which is also using the HEC-RAS modeling software for hydraulic analysis of the Middle and Lower Susitna River segments. If at any point in the model development and testing it is found that the upgraded version of HEC-RAS will not allow for successful bed evolution modeling of the Susitna River, the modeling approach will revert to using the previously selected HEC-6T software. Conversion of the HEC-RAS model inputs to HEC-6T model format can be easily accomplished requiring only minimal effort.

6.1.1.2. Two-Dimensional (2-D) Bed Evolution Model

During the model selection process, it was thought that SRH-2D may not be appropriate for the bed evolution modeling due to the limitation of 16,000 elements. The initial SRH-2D mesh developed for FA-104 (Whiskers Slough) has approximately 10,000 elements. FA-104 (Whiskers Slough) is a reasonably complex site with multiple side channels and the main channel has been extended approximately 2 miles upstream of the FA boundary. Given, the number of elements in the SRH-2D mesh is significantly less than 16,000 and the model has sufficient resolution, it is very likely mesh size will not be a limiting factor and SRH-2D remains a viable model for the study.

Initial indications of the 2-D Bed Evolution Model development indicate the quality and resolution of the survey data is good and is resulting in high quality 2-D models. In developing the TINS for the 7 Focus Areas that have been surveyed, the extents of the surveys will be reviewed to determine if there is need to extend the surveys upstream or downstream to provide better mesh resolution and better prediction of the hydraulic conditions in the vicinity of the FA boundaries. The TINS will also be reviewed to determine if there are any areas in which additional points need to be collected to adequately represent the geometry of the Focus Area.

6.1.2. Coordination with other Studies

Coordination with others studies in 2013 was ongoing and extensive involving primarily data collection and model development. The3 effort included internal coordination between the Fluvial Geomorphology Modeling below Watana Dam Study and the Geomorphology Study (Study 6.5) and external coordination with the Fish and Aquatics Instream Flow Study (Study 8.5), Riparian Instream Flow Study (Study 8.6), Ice Processes in the Susitna River (Study 7.6), Groundwater Study (Study 7.5), Water Quality Modeling Study (Study 5.6), and Characterization and Mapping of Aquatic Habitats (Study 9.9). The success of the coordination effort between the studies will be demonstrated by the Proof of Concept to be reported on in 2014. Additional discussion of coordination efforts is provided in Section 6.3.

6.1.3. Model Resolution and Mesh Size Considerations

Areas identified by the aquatic habitat team members are modeled at element resolution of approximately 6.5 feet (2 m), which resulted in meshes with a very large number of elements and in longer development times than is typical for the areal extent of the Focus Areas. During the development of the initial SRH-2D habitat mesh, different methods for constructing the meshes were tested, which has resulted in an efficient methodology for constructing the subsequent meshes.

No significant or unanticipated issues arose during the development of the initial SRH-2D habitat mesh. Development of the mesh size and extents has been coordinated with the Fish and Aquatics Instream Flow Study (Study 8.5) to ensure that the proper resolution is being obtained throughout the each Focus Area to meet fish and aquatic habitat modeling needs.

6.1.4. Focus Area Selection

The selected Focus Areas are adequate to represent the more complex (e.g. split flows, mid-channel bars, and continuous bank-attached floodplain segments) geomorphic regions within the Middle River. The simpler geomorphic regions, identified by a single laterally confined channel with limited sediment storage in mid-channel bars and non-continuous bank-attached floodplain segments, are adequately represented within the selected 1-D Bed Evolution model and do not require the 2-D Bed Evolution modeling being performed in the Focus Areas.

The Geomorphic Assessment Areas (GAAs) were developed in the Geomorphology Study (Study 6.5) because it was necessary to identify governing geologic controls in order to explain the genesis and spatial distribution of geomorphic features within Focus Areas. The GAAs have limits that extend beyond the limits of the Focus Areas. This expanded area is intended to include all geomorphic surfaces encompassed between upstream and downstream lateral constrictions such as bedrock, moraines, terraces and alluvial fans. The 2-D Bed Evolution model mesh extents may be expanded to align with the defined GAA boundaries. This may be performed if the expanded boundaries are required to adequately predict flow distribution at either the upstream or downstream boundary of the model.

6.1.5. Model Calibration and Validation

6.1.5.1. One-Dimensional (1-D) Bed Evolution Model

The development of the 1-D Bed Evolution Model is still underway, so calibration and validation of the hydraulics and sediment transport routines has not yet been completed. Results of initial calibration will be presented in the Proof of Concept effort being completed and reported on in 2014. The adequacy of data collected to support the calibration is discussed in Section 6.1.9.1.

6.1.5.2. Two-Dimensional (2-D) Bed Evolution Model

The compilation and review of calibration data is being finalized from the 2013 data collection effort; therefore model calibration and validation have not yet been performed. The initial SRH-2D simulations were computationally stable with excellent flow conservation, which supports the selection of SRH-2D for further model evaluation. No River2D runs have been conducted, and therefore, there are no observations to discuss. Results of initial calibration and model comparison will be presented in the Proof of Concept effort being completed and reported in 2014.

6.1.6. Tributary Delta Modeling

Of the 20 tributaries selected for modeling, reconnaissance was planned for 13 tributary deltas during the 2013 field season, three in the Lower River and 10 in the Middle River. Since the reconnaissance at Birch Creek could not be carried out due access not being granted by a private landowner, attempts for access are planned in a next year of study. Of the remaining 12 tributaries with efforts planned for 2013, only the unnamed tributary (PRM 115.4) was removed from the list of candidates based on observations made during the 2013 reconnaissance of low sediment production and an absence of a delta. This decision was agreed upon in conjunction with the Study of Fish Passage Barriers in the Middle and Upper Susitna River and Susitna Tributaries (Study 9.12).

6.1.7. Large Woody Debris Modeling

There is extensive data now available from the 2013 field season on large woody debris quantities and characteristics (ISR Study 6.5 Section 5.9). This data includes conditions before and after high September 2012 flows, which will be used in the next year of study to help quantify the variability of debris loading over a range of flow conditions.

6.1.8. Wintertime Modeling and Load-Following Operations

There are numerous observations of ice cover and breakup conditions made by the Ice Processes in the Susitna River Study (ISR Study 7.6) from the winter periods of 2010-2011 and 2012-2013 and anticipate additional useful information from the 2013-2014 winter. Observations of ice effects were also made by the Geomorphology (Study 6.5) and Riparian Instream Flow (Study 8.6) studies during the 2013 field season. These data will be used to further develop winter conditions models, especially as they relate to ice jam breakup conditions.

6.1.9. Field Data Collection Efforts

The field data collection efforts in 2013 were carried out to support various components of this study, as well as the Geomorphology Study (ISR Study 6.5). A significant amount of the data to be used by the Fluvial Geomorphology Study was collected by the Fish and Aquatics Instream Flow Study (Study 8.5).

6.1.9.1. 1-D Bed Evolution Model

The development and calibration of the 1-D Bed Evolution Model rely on various types of field data (Section 5.1.9.1). Field data collected in 2013 are largely adequate to support development and preliminary calibration of the model, but final determination of data adequacy will be made in the next year of study as the hydraulic and sediment transport/bed evolution models are calibrated.

Hydraulic Observations: It is expected that the characterizations of hydraulic roughness will be adequate for setting initial energy loss parameters (Manning's n-values). Categories of roughness based on observations generally followed surfaces delineated in the geomorphic mapping (ISR Study 6.5 Section 5.1.3.5.1) along the Middle River. Based on these observations, representative overbank roughness values (Table 5.1-3) were assigned to each geomorphic mapping unit, which are being used to assign preliminary roughness values to the 1-D and 2-D Bed Evolution models. These values are a primary calibration parameter, so the initial values will be adjusted as needed to achieve model calibration.

The water-surface measurements, particularly those collected during the mid-August high-flow event, provide valuable data for calibration of the 1-D and 2-D Bed Evolution models. The water-surface elevation measurements, together with those collected by the Fish and Aquatics Instream Flow Study (Study 8.5), provide very good coverage along the Middle River downstream of PRM 146.6. Further discussion of the water-surface measurements is provided with water-surface measurements compiled from other studies in Section 6.1.9.4. Appendix D summarizes the water-surface elevations measured as part of Studies 6.5 and 6.6. It is recommended to continue collecting water-surface elevation measurements using the same methodology and, when possible (and safe), to collect water-surface elevations during high flow events of primary interest to the Geomorphology Studies as well as lower flows of primary interest to habitat modeling. Above certain levels, safety issues limit access to the river and the stage recorders become the primary means of collecting high flow water surfaces elevations.

Sediment Sampling:

Surface and subsurface sampling: Review of the surface and subsurface sediment sampling results presented in Appendix A indicates that it is sufficient for initial development of the 1-D and 2-D Bed Evolution models. The spacing and extent of the samples provides good coverage throughout the Lower Susitna River Segment and good coverage in the Middle Susitna River Segment to PRM 146.6. The results show consistent trends within the Segments that will provide data for the bed evolution models and for interpretation of physical processes.

Bank material sampling: The bank material sampling was mostly conducted in the Focus Areas in 2013 with 59 samples collected in the Focus Areas and 6 samples collected in the Middle River outside of the Focus Areas (Table 5.1-10, Appendix C). A full analysis of the bank samples has not been conducted; however, a preliminary review indicates that the bank materials are relatively consistent along Middle River with a median size (D_{50}) of about 0.1 mm, which corresponds to the very fine sand category. In addition, the preliminary review of the spatial distribution of the bank samples and the uniformity of the bank materials indicates the sampling method was more than sufficient to characterize the bank materials.

Pebble counts were conducted along the base of the banks to determine the gradation of the materials that composed the base core of the islands. A comparison of the base of bank materials with the bar head materials indicated that both had very similar gradations. It is therefore recommended that base of bank samples continue to be collected in a next year of study at about the same frequency as in 2013 or in locations where the gradation appears to be significantly different compared to nearby bar head samples.

In a next year of study, bank sampling will be conducted at the remaining 3 Focus Areas using the same techniques that were applied in 2013. Where necessary, additional bank material samples will be collected in areas outside of the focus areas to characterize any substantial changes in bank materials.

Winter sediment sampling: Underwater camera equipment was tested during the ice-covered period to determine: (1) if it is possible to obtain video of the channel bed, (2) the best combination of equipment, and (3) whether it is possible to develop a sediment gradation of the channel bed from the video images. The underwater camera techniques provided images that can be used to determine main channel streambed gradation, and these techniques will be used for application to a full scale field data collection campaign. Underwater video analysis is not possible during the open-water period due to poor visibility caused by fine sediment from glacial melt. During the underwater camera testing, water clarity was good and did not negatively impact the ability to acquire streambed images. Additionally, frazil ice and other moving material did not negatively impact the performance of this test work and resulting image quality. Main channel velocities were high, but did not prevent the submergence and operation of the underwater camera equipment. The 2013 effort indicated that it will be possible to develop bed-material gradation in the deeper portions of the channel during the winter period. It took approximately 1 day, including travel time to and from the site, to collect the video data at each transect.

Comparison of current and historical surface samples: The sediment samples collected during 2013 were compared to sediment samples collected in the 1980s. R&M Consultants (1985) presents gradations of bed-material samples collected to evaluate with-Project aggradation downstream of the Three Rivers Confluence. Armor layer and subsurface bed-material samples were collected during October 1984 at seven cross sections between the Three Rivers Confluence and the USGS gaging station at Sunshine (Table 6.1-1). R&M Consultants (1985) indicates five samples were biased toward the larger particle sizes because the sediment was chipped out of the frozen bed; the remaining two samples were considered representative because the armor layer was not frozen. The armor layer was reported as marginally developed at RM 87.7 (PRM 91.1), so it was not included in the comparison presented below.

Harza-Ebasco (1984) provides results of bed-material sampling from 46 mainstem and side channel locations along the Susitna River. Samples from submerged locations were collected with a 6-inch-diameter pipe dredge; samples located in less than about 1.5 feet of water were collected with a shovel. Size distributions were determined by sieve analyses. Table 6.1-2 provides the median bed-material size for the 18 surface/pavement samples collected from the mainstem Susitna River.

Appendix A provides the D_{50} values calculated for the surface samples collected in 2013. These samples were screened to remove locations not along the main channel of the Middle or Lower Susitna River Segments and plotted along with the D_{50} values from the 1980s sampling (Figure 6.1-1 and Figure 6.1-2).

In the Lower Susitna River Segment, the 1980s sampling was limited to the area upstream of the USGS gaging station at Sunshine. In this reach, the median D_{50} from the 1980s samples is about 50 mm and the median D_{50} from the 2013 samples is about 45 mm (Figure 6.1-1). This similarity indicates a general consistency in the median surficial bed material. Downstream of PRM 92, the 2013 samples have a median D_{50} of 33 mm, indicating a relatively consistent median surface sediment size downstream of the approximate location of the USGS gage at Sunshine. The median bed surface size, based only on the 2013 samples, is slightly finer downstream of PRM 92 than between PRM 92 and PRM 102.4. The general consistency of the 1980s and 2013 D_{50} values of the surface sediment samples from the mainstem channel provides support to the preliminary assessment of vertical stability based on comparisons of 1982 and 2013 thalweg profiles (ISR 6.5, Figure 5.1-2).

In the Middle Susitna River Segment, the median D_{50} of the 1980s samples is 53 mm and the median D_{50} of the 2013 samples is 59 mm (Figure 6.1-2). As with the Lower Susitna River Segment, this similarity indicates the potential for general consistency in the median surficial bed material over the 30 years between sampling periods.

6.1.9.2. Focus Areas

The data collected in the Focus Areas was conducted as part of the overall data collection effort in ISR Study 6.5 and 6.6 and has been described elsewhere in this report. The Geomorphology of the Focus Areas was mapped and characterized in Study 6.5 (ISR section 6.1.3). The bed-material sampling conducted has been described under the 1-D modeling effort (Section 6.1.9.1). Additional mapping of bed material performed in the Fish and Aquatics Instream Flow Study (Study 8.5) is discussed in Section 6.1.9.4). The bathymetric and topographic survey information (collected under Study 8.5) along with LiDAR to develop the geometry of the Focus Areas is discussed under Section 6.1.9.4 and 6.9.1.5, respectively. Water surface elevation measurements collected in this study to calibrate the hydraulics models are discussed in section 6.1.9.1. Model calibration information collected by the Fish and Aquatics Instream Flow Study, including water surface elevations and ADCP measurements of velocity and depth are discussed in Section 6.1.9.4 (Water surface elevations and ADCP measurements).

The data collected in the Focus Areas, including the bathymetric and topographic mapping, velocity, water surface elevations and sediment sampling, and bank observations has been high quality in terms of amount and spatial distribution of sampling, and appears to be sufficient for model development. The same data collection methodologies and techniques will be used at the 3 remaining Focus Areas in a next year of study. As the 2-D Bed Evolution Model development and calibration proceeds in 2014 as part of the Proof of Concept, any data gaps in the 2013 data collected at the 7 Focus Areas in 2013 will be identified and the data gaps filled by information collected in a next year of study.

6.1.9.3. Tributary Deltas

The channel geometry surveys and bed-material samples collected in 2013 from the 11 tributaries appear adequate to quantify the sediment loading delivered to the tributary deltas. These data have been used develop preliminary hydraulic models that will be used to calculate sediment loads. No data were collected at the unnamed tributary (PRM 115.4) based on the lack of an observed delta and the low sediment production potential from the contributing watershed. Since access across private lands to Birch Creek was not granted in 2013, no data could be collected; if access is not granted for future data collection, the sediment loading to the tributary delta will need to be estimated. As the tributary model development proceeds in 2014 as part of the Proof of Concept, any data gaps in the 2013 data collected at the 11 tributaries in 2013 will be identified and the data gaps filled by information collected in a next year of study.

6.1.9.4. Field Data from Other Studies

The development and calibration of the 1-D and 2-D Bed Evolution models rely heavily on field data collected from other studies. Both models will use surveyed water-surface elevations and measured flows to calibrate steady-state hydraulics (estimated flows will be used where measurement flows are unavailable). Measured flows in split channel reaches are useful in calibrating simulated split flows. Recorded flow and stage hydrographs will support properly representing the translation and attenuation of flow. Further calibration of the 2-D Bed Evolution and Hydraulic models will be based on measured velocities from ADCP data collected specifically for this purpose in the seven Focus Areas.

Cross section surveys: To date, a total of 179 cross sections have been surveyed along the Lower and Middle Susitna River Segments, the Chulitna River, and the Talkeetna River. Of this total, 63 sections have been surveyed along the Lower River between PRM 29.9 and PRM 102.4, which corresponds to an average spacing of approximately 1.1 miles. While this spacing appears adequate for development and calibration of the 1-D Bed Evolution Model, 13 cross sections have been identified as candidates for future survey should the need arise (Table 6.1-3); further, if additional locations arise as a result of unsuccessful model calibration, additional candidates may be identified. Along the Middle River, between PRM 102.7 and PRM 187.2 (excluding Devils Canyon, geomorphic reach MR-4: PRM 166.1 to PRM 153.9), 104 cross sections have been surveyed, corresponding to an average spacing of approximately 0.7 miles. Similar to the method described for the Lower River, 17 candidate cross sections have been identified for future surveying should the need arise, or additional cross section survey needs may be identified. Due to lack of access upstream of PRM 146.1 during the 2013 field season, 15 Middle River cross sections planned for survey could not be surveyed. While only two cross sections were surveyed along the Chulitna River, no further surveys are planned because it is expected that geometry can reasonably be represented using LiDAR topography and estimated bathymetry (Tetra Tech 2013h). Four additional cross sections may be surveyed in the next year of study along the Talkeetna River if the 10 sections already surveyed are not adequate for model calibration.

Topographic and bathymetric surveys within Focus Areas: The bathymetric data collected as part of Study 8.5 was used to assign elevations to the FA-104 (Whiskers Creek) 2-D Bed Evolution Model. The bathymetric and topographic data were collected mostly along transects set perpendicular to the flow and at a spacing of approximately 200 feet. The combination of bathymetric and topographic data survey, together with the overbank LiDAR provides adequate resolution to develop the 2-D models.

A TIN developed from the bathymetric, land, and LiDAR survey data at FA-128 (Slough 8A) provides a good representation of the main channel bed, side channels, other lateral features, bars, islands, and floodplain. The TIN includes sufficient resolution to define the breaching elevations between the main channel and side channels.

As the 2-D Bed Evolution Model development and calibration proceeds in the next year of study, any data gaps in the topographic and bathymetric survey data collected at the 7 Focus Areas in 2013 will be identified and the data gaps filled by information collected in a next year of Study.

Water-surface elevation (WSE) measurements: Coupled measurements of WSE and flow provide the basis for calibrating steady-state hydraulics for the bed evolution models; these measurements are also used within the Fish and Aquatics Instream Flow Study to calibrate the Open-Water Flow Routing Model (ISR 8.5 Section 4.3). The method for calibrating the Open-Water Flow Routing Model uses coupled measurements of WSE and flow for categories of high, medium, and low flow. The thresholds between categories were calculated using the 61-year period of record for the months of June through September at the UGSG gaging stations at Gold Creek (Middle River) and at Sunshine (Lower River). Annual flow duration curves were developed for each gage, and the flows corresponding to the 33 percent exceedance (i.e., the threshold between high and medium flows) and the 67 percent exceedance (i.e., the threshold between the medium and low flows) were identified (Table 6.1-4). These thresholds were compared to estimates of the effective discharge and flows required to mobilize bed material as presented in ISR 6.5 Section 5.3.4 and Section 5.3.3, respectively (Table 6.1-4). The threshold flows developed for the Fish and Aquatics instream Flow Study are less applicable for calibration of the bed evolution models; what is more important is whether the coupled measurements are adequate to calibrate the simulated hydraulics under conditions when the bed is mobile and substantial sediment is in transport. Additional measurements of flow and WSE collected along the Middle River during high flows occurring between late August and early September 2013 were considered. All available coupled measurements of WSE and flow were screened using threshold conditions of bed mobilization and effective discharge (using calculations at the gaging stations as indicators for the whole river segments); illustrations of the screening are presented for the Lower Susitna River Segment in Figure 6.1-3 and for the Middle Susitna River Segment in Figure 6.1-4.

Based on the screening of the coupled WSE and flow measurements, it appears that the available measurements are adequate for calibrating the bed evolution models in the Middle River (downstream of PRM 146.6) for conditions when the bed is mobile and substantial sediment is in transport; however, in the Middle River upstream of PRM 146.6 and in the Lower River, additional measurements are recommended. These additional measurements should be targeted to flows as measured, respectively at the Gold Creek gage in excess of about 27,000 cfs and at the Sunshine gage in excess of about 70,000 cfs. Ideally these measurements can be coordinated with the needs of the Fish and Aquatics Instream Flow Study to obtain high-flow measurements in the Middle River (i.e., in excess of 24,000 cfs as measured at Gold Creek) and in the Lower River (i.e., in excess of 60,600 cfs as measured at the USGS gage at Sunshine).

Bed-material mapping: The bed-material (substrate) mapping data have not yet been reviewed, so no assessment of the data adequacy can be made. These data are supplemental to the bed-material sampling conducted in the Focus Areas as part of Studies 6.5 and 6.6. It is expected that these data, even though categorical in nature, will prove useful in characterizing grain roughness to specify roughness values the 1-D and 2-D Bed Evolution models.

Acoustic Doppler Current Profiler (ADCP) measurements: ADCP measurements were collected in 2013 at all 7 Focus Areas both lateral and longitudinal to flow paths. These measurements provide velocity and depths at points throughout the Focus Areas as well as a means to determine the flow within individual channel features within the Focus Areas. The ADCP flow measurements collected as part of ISR Study 8.5 are sufficiently accurate and spatially distributed to quantify the flows in the main channel and side channels at all of the Focus Areas. The discharge measurements will be used to calibrate the 1-D and 2-D Bed Evolution models by comparing the simulated flows to the measured data. The combination of longitudinal and lateral velocity profiles provide a large set of measurements to calibrate cell velocities in the 2-D Bed Evolution models at each Focus Area.

The raw ADCP measurements have not yet been processed to create depth-averaged ADCP data, which will include magnitude and direction, and will be used in the 2-D Bed Evolution and Hydraulic models calibration process. Table 6.1-5 summarizes the number of ADCP measurements and corresponding discharges collected in 2013 at the Focus Areas; Figure 6.1-5 is an example that illustrates the locations and extents of the ADCP measurements collected at FA-104 (Whiskers Slough).

Stage hydrographs: The stage hydrographs recorded at the USGS gaging stations at Tsusena Creek, Gold Creek, Sunshine, and Susitna Station will provide valuable calibration data for 1-D and 2-D Bed Evolution models. After calibrating the steady state hydraulics, the stage hydrographs will serve as a primary reference for calibrating the unsteady hydraulics.

Surface-water stage measurements were collected during 2013 at various locations along the Susitna River (ISR Study 8.5 Sections 4.3.1.1 and 4.4.1.1). Water levels and flows were measured at Curry (Gage ESS50 at PRM 124.1), below Lane Creek (Gage ESS45 at PRM 116.6), above Whiskers Creek (Gage ESS40 at PRM 107.2), below Twister Creek (Gage ESS30 at PRM 98.4), and at Susitna Station (ESS20 at PRM 29.9). When coupled with the USGS stage hydrographs, these surface-water stage measurements are expected to be adequate to calibrate the unsteady hydraulics simulated using the 1-D and 2-D Bed Evolution models; however, calibration of the preliminary models in early 2014 as part of the Proof of Concept will determine whether additional calibration data are recommended.

Sediment transport measurements: The sediment transport measurements collected by the USGS at gaging stations provide key information for calibrating and validating the simulated sediment transport and bed evolution. These data are summarized in Tetra Tech (2013a) and the Geomorphology Study (ISR Study 6.5 Section 5.2). These data when combined with the 1980s data collected by the USGS form an extensive data base that is sufficient to develop relationships for the sediment supply from the Susitna River upstream of the Watana Dam site and the major tributaries represented by the Chulitna, Talkeetna and Yentna rivers within the Study area. Further discussion of the adequacy of these data is provided in ISR Study 6.5 Section 6.2. It is noted that the USGS will continue to collect another year of sediment transport information in a next year of study.

6.1.9.5. LiDAR Verification and Acquisition

6.1.9.5.1. Su-Wa LiDAR Verification

The 2013 Su-Wa LiDAR meets 1-ft contour equivalence in open terrain (FVA) and 2-ft contour equivalence in brush and forested land areas (SVA). The RMSEz and 95% confidence levels of these data are approximately 0.25 and 0.5 ft for FVA, and 0.5 and 1.1 ft for SVA. These results indicate that the Su-Wa LiDAR meets project specifications for LiDAR acquisition. Due to unfavorable weather conditions, not all of the desired LiDAR was acquired. Therefore, the 2011 Mat-Su LiDAR was evaluated for suitability.

6.1.9.5.2. 2011 Mat-Su LiDAR Verification

The Matanuska-Susitna Borough 2011 LiDAR data acquisition was completed without the collection of ground survey points and the 2011 LiDAR point cloud was not ground-truthed (verified or indexed). For this study, the Mat-Su LiDAR verification was performed using available data from PRM 31 to PRM 147.The Lower and Middle Susitna River areas are undeveloped, which makes the identification of clear and open areas difficult. Most of the points identified and used for the Fundamental Vertical Accuracy test (FVA) are located on types of terrain (e.g. sandbars) that might not be considered for use in verification in normal conditions.

The result of the 2011 Matanuska-Susitna LiDAR verification shows that the FVA at the 95% confidence level is 2.4 ft and for SVA is approximately 1.6 ft.

6.1.9.5.3. 2011 Mat-Su LiDAR Indexing

Indexing (vertical datum adjustment) is common practice to adjust a LiDAR dataset to a vertical datum defined by survey points. The fundamental vertical accuracy of the LiDAR dataset after indexing is 1.8ft at a 95% confidence level. This is significantly higher than for the 2013 Su-Wa and would not meet Project specifications for new LiDAR acquisition. The fundamental vertical accuracy is determined through check points in open terrain. Supplemental vertical accuracy is approximately 1.7 ft at the 95% confidence interval.

For areas in vegetated terrain, the 95% confidence interval for vertical accuracy increases from 1.1 to 1.7 ft, and for open terrain it increases from 0.5 to 1.8 ft. This illustrates the more dynamic nature of in-channel features including bars, heads of islands, and bank lines, as compared with overbank areas including floodplains and terraces. The primary use of LiDAR was to extend cross sections outside the channel banks. Given the approximate 0.6 ft of potential accuracy improvement at the 95% confidence level, it may not be warranted to acquire additional LiDAR in vegetated areas. One in-channel area that required high density LiDAR was in the Chulitna River, where LiDAR was to be the primary source of in-channel data (Tetra Teach 2013h). LiDAR for this area was acquired in 2013.

Although improvements can be made in overbank and in-channel areas, in-channel areas can be surveyed efficiently using standard survey approaches. Therefore, in 2014, decisions will need to be made whether the existing LiDAR is adequate for Project use by the various study components. If the existing LiDAR is not deemed to be adequate then alternative methods will be considered in various study areas.

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

This section includes discussion of the current status of this study component. RSP Section 6.6.7 lists the primary studies that will provide information to the Fluvial Geomorphology Modeling below Watana Dam Study including a summary of the type of information. Based on numerous discussions with study leads and senior technical staff, information presented at TWG and other meetings, and review of study reports and technical memorandums, it appears that each study is on track to provide desired information.

6.2.1. Existing Conditions – Base Case Modeling

Reach-scale 1-D and local-scale 2-D Bed Evolution models are currently being developed for the Middle and Lower Susitna River segments and Focus Areas. The adequacy of the input data will be evaluated as part of the model development and calibrations, but no deficiencies are currently evident other than the inability to collect data upstream of PRM 146.1 during the 2013 field season. Data collection for the Middle Susitna River between PRM 146.1 and the Watana Dam site are planned for in a next year of study. The reach-scale modeling will include a 50-year periods of open water conditions comprised of a sequence of approximate 5 month periods (approximately May through September of each year). The actual start and end dates of each year will be evaluated based on the onset of ice cover conditions and breakup. For the 2-D Bed Evolution modeling, three representative years have been recommended and information on the selection of these years is included in Appendix E. Should other factors be identified adjustments to the recommended years can be made in 2014.

6.2.2. Future Conditions – with-Project Scenarios

The with-Project scenarios include maximum load-following, intermediate load-following, base-load, and a run-of-river. The Reservoir Operation Model (ISR Study 8.5 Section 4.3) will provide reservoir outflows for each of these scenarios to provide a upstream flow boundary to the 1-D Bed Evolution Model.

6.2.3. Uncertainty

The RSP Section 6.6.4.2.2.3 indicates that here is a wide range of information that can be used to identify and understand uncertainty related to the fluvial geomorphology modeling. In addition to sensitivity analysis, significant hydrologic variability is included in the 50-year flow record for 1-D Bed Evolution Model and in the representative years selected for the 2-D Bed Evolution models. The range of operational scenarios, including a range of load conditions and run-of-river, will also introduce significant hydrologic variability in the with-Project Scenarios.

The sensitivity analysis discussed in the RSP identified hydraulic roughness coefficients, magnitude and gradation of inflowing sediment loads, substrate size gradation, and dimensionless critical shear values as parameters to be varied. Hydraulic roughness is directly associated with flow velocity, which is the primary hydraulic variable related to sediment mobilization and transport. Base on the calibration results there will be sufficient information to evaluate the range of roughness values to include in the sensitivity analysis. There will also be sufficient information based on the number of bed-material samples to evaluate the degree sediment gradation needs to be included in the sensitivity analysis. Critical shear is intrinsic to the sediment transport equations being considered for this study component and will be evaluated during model calibration. Therefore, this variable may not be available for inclusion as part of the sensitivity analysis. Incoming sediment loads often have significant uncertainty and may impact the interpretation of results. Therefore, input sediment loads and roughness values are likely to be the primary parameters for the sensitivity analysis.

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

As shown in Figure 5.2-1, the reach-scale 1-D Bed Evolution Model provides information to the local-scale 2-D Bed Evolution Models. The information includes sediment loads and boundary conditions required by the 2-D Bed Evolution Models. Should the 1-D Bed Evolution Model show appreciable change at years 25 or 50, the downstream boundary conditions and the geometry of the 2-D Bed Evolution Models would need to reflect these changes. The synthesis is not only between the reach- and local-scale models, but also among the morphology modeling and other studies. As discussed in Section 4.3, the primary interdependencies include the Geomorphology, Ice Processes in the Susitna River, Riparian Instream Flow, and Fish and Aquatics Instream Flow (Open-water Flow Routing Model study component) studies.

6.3. Study Component: Coordination and Interpretation of Model Results

The effort conducted in 2013 was primary in the area of internal coordination and integration between the Fluvial Geomorphology Modeling below Watana Dam Study and the Geomorphology Study (Study 6.5) and external coordination with the Fish and Aquatics Instream Flow Study (Study 8.5), Riparian Instream Flow Study (Study 8.6), Ice Processes in the Susitna River Study (Study 7.6), Groundwater Study (Study 7.5), Water Quality Modeling Study (Study 5.6), and Characterization and Mapping of Aquatic Habitats (Study 9.9).

6.3.1. Integration of Geomorphology and Fluvial Geomorphology Modeling Study

This effort has been progressing well and the Geomorphology Study (Study 6.5) has provided the information needed by the Fluvial Geomorphology Modeling below Watana Dam Study to help guide the development of the 1-D and 2-D Bed Evolution models (Section 5.3.1). The bed evolution models are being developed incorporating the results of the Geomorphology Study, including geomorphic reach delineation (Tetra Tech 2013b), tributary and mainstem sediment supply (ISR Study 6.5 Section 4.3 and Tetra Tech 2013a), sediment-load analyses (Tetra Tech 2013a, Tetra Tech 2013c), effective discharge analyses (ISR 6.5 Section 4.3.2.4), preliminary system equilibrium and sensitivity analyses (ISR 6.5 Section 4.6.2.3 and Tetra Tech 2013c), LWD loading and distribution and reservoir sediment supply and trap efficiency (ISR Study 6.5 Section 4.8.2.1). Model results will be evaluated in terms of geomorphic processes as identified in geomorphic process models (Study 6.5 ISR Section 4.1.2.3.3) as well as spatial distribution of predicted changes and likely magnitude of geomorphic changes. Continuous coordination between the Fluvial Geomorphology Modeling below Watana Dam and Geomorphology studies ensures that the two studies are fully integrated.

6.3.2. Coordination of Results with Other Resource Studies

The coordination with the other modeling studies is also proceeding well through the efforts identified in Section 5.3.2. Coordination and integration with the other resource studies mentioned has centered on integration of the modeling efforts and in particular transfer of information between the various studies in terms of results from one study becoming input to another study. The modeling studies are jointly working on the Proof of Concept to develop the linkages between the various models and refine the development of the suite of results that will form a large part of the metrics that Project effects will be evaluated.

7. COMPLETING THE STUDY

[Section 7 appears in the Part C section of this ISR.]

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9. TABLES

Table 3.1-1. Schedule for the downstream study limit determination process for the Fluvial Geomorphology Modeling below Watana Dam 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	February 2013
TWG meeting for confirmation or adjustment of downstream geomorphology modeling limit – downstream study limit extended to PRM 29.9	February 2013
1-D Bed Evolution modeling and 2013 Geomorphology Study results and tech memo	2014
TWG meeting to reevaluate and confirm or adjust downstream modeling limit of PRM 29.9	2014
Collect additional data if need identified (Second Study Season)	Summer 2nd Study Season

Table 4.1-2. Average Annual Sediment Loading at USGS Gaging Stations (R&M Consultants, Inc. 1982b).

USGS Gaging Station	Average Annual Sediment Load (tons)		
	Suspended Sediment	Bed load[1]	Total Load
Susitna River near Cantwell	6,898,000	207,000	7,105,000
Susitna River at Gold Creek	7,731,000	232,000	7,963,000

Note:
1 Estimated as 3 percent of suspended sediment load

Table 4.1-2. Average Annual Sediment Loading at USGS Gaging Stations and Watana Dam (Harza-Ebasco 1984).

Location	Average Annual Sediment Load (tons)		
	Suspended Sediment	Bed load[1]	Total Load
Susitna River near Cantwell	5,660,000	170,000	5,830,000
Susitna River at Gold Creek	7,260,000	218,000	7,478,000
Watana Dam	6,530,000	196,000	6,726,000

Note:
1 Estimated as 3 percent of suspended-sediment load.

Table 4.1-3 Model input and results interactions among various Studies and study components.

Modeling Task	Input and Results	Hydrology	Sediment	Hydraulics	Channel & Floodplain Geometry
1-D Tributary Sediment Modeling	Input	Site speific[1]	bed material from site samples	site specific D/S stage-discharge	Existing at T = 0 (yr-0)[3]
	Results for:	Results for range of steady flows to develop sediment-rating curves at mouth of each tributary			
	1-/2-D Morph.	n/a	trib. Sediment-rating curves	n/a	n/a
	Aquatic Habitat (8.5)	n/a	n/a	V, D, WSE some trib. mouths	barrier/delta change some tribs.
	Fish Access(9.12)	n/a	n/a	V, D, WSE some trib. mouths	barrier/delta change some tribs.
1-D Bed Evolution Modeling (Reach-Scale)	Input	50-yrs Existing & 3 OS[1]	Existing & 3 OS[2]	stage-discharge at Susitna Sta.	Existing at T = 0 (yr-0)[3]
	Results for:	Results for continuous 50-year simulations throughout 1-D modeling domain			
	2-D Morphology	n/a	U/S sed. rating curves at FAs	D/S stage-discharge at FAs	main channel change
	1-D Ice(7.6)	n/a	n/a	stage-discharge at 3-Rivers	main channel change[4]
	Flow Routing(8.5)	n/a	n/a	n/a	main channel change[4]
	Aquatic Habitat(8.5)	n/a	substrate change[4]	stage-discharge relationships	main channel change[4]
	Riparian Habitat(8.6)	n/a	sediment supply to overbanks	stage-discharge relationships	bar/island/floodplain change
2-D Bed Evolution Modeling (Local-Scale)	Input	<1-yr wet, avg., dry with PDO, Existing & 3 OS[1]	U/S sed. rating curves at FAs for yrs-0,25,50 for Existing & 3 OS[5]	D/S stage-discharge at FAs for yrs-0,25,50 for Existing & 3 OS[5]	Existing (yr-0)[3], yrs-25,50[5] in main channel
	Results for:	Results for range of <1-yr simulations throughout FA modeling domain			
	2-D Hydraulic	n/a	Bed-material gradation change[4]	n/a	lateral feature trends
	2-D Ice(7.6)	n/a	n/a	n/a	lateral feature trends[4]
	Flow Routing(8.5)	n/a	n/a	n/a	n/a
	Aquatic Habitat(8.5)	n/a	substrate change[4]	n/a	barrier/delta change
	Riparian Habitat(8.6)	n/a	sediment supply to overbanks	n/a	bar/island/floodplain change
2-D Hydraulic Modeling (Local-Scale)	Input	Range of steady flows[6]	Bed-material gradation change[7]	D/S stage-discharge at FAs for yrs-0,25,50 for Existing & 3 OS[5]	Existing (yr-0)[3], yrs-25,50 main channel[5] and lateral features[7]
	Results for:	Results for range of steady flows throughout FA modeling domain			
	Ice, Flow Routing	n/a	n/a	n/a	n/a
	Aquatic Habitat(8.5)	n/a	n/a	V, D, WSE, etc. throughout FAs	n/a
	Riparian Habitat(8.6)	n/a	n/a	V, D, WSE, etc. throughout FAs	n/a

Notes: [1] From Open-Water Flow Routing Model development effort (Study 8.5 Section 4.3).
[2] From gage data (USGS), sediment transport study (ISR Study 6.5 Section 4.2 and Tetra Tech 2013a).
[3] From hydrographic survey, land-based survey, and LiDAR. (Studies 8.5 and 6.6, survey by Tetra Tech for some tributaries.)
[4] Only if magnitude of change is sufficiently large to warrant inclusion in other study aspects.
[5] From 1-D Bed Evolution Models (Reach-Scale).
[6] From habitat study requirements.
[7] From 2-D Bed Evolution Modeling trends (Local-Scale).
This table does not include all interactions involving Ice Processes and Large Woody Debris conditions related to bed evolution modeling.

Table 4.1-4. 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)
Reservoir Operation 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 Open-water Flow Routing Model is developed (Q1 2013)
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 field work (Q4 2013 ver. 2) and finalized (Q4 2nd Study year, ver. 3). Provides boundary conditions to 2-D Bed Evolution Model.
River1D Ice Processes Model	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 2nd Study year, ver. 2). The model will also provide water temperature, ice extents and ice thickness for the same period.
River1D Ice Processes Model River2D Focus Area Ice Models	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.
2-D 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	HEC-6T[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. Open-water Flow Routing Model will take precedence for 1-D hydraulics.
2-D Bed Evolution Model (Hydraulics and Sediment Transport)	6.6	TBD[2] (2014)	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 Open-water Flow Routing Model

Notes:

1 HEC-6T was selected. However, HEC-RAS version 4.2 has become available and is being evaluated for suitability on this project.

2 Candidate Models: SRH-2D and River-2D are being evaluated to determine which model is most suitable for this project.

Table 4.1-5. Calibration Datasets for 1-D and 2-D Bed Evolution Models.

Source	Type of data
Tetra Tech Inc.	water-surface elevations, high-water marks
Brailey Hydrologic Consultants	Water-surface elevations, ADCP velocity measurements
Geovera, LLC.	Water-surface elevations
U.S.G.S.	Flow data, stage data, sediment transport measurements, sediment gradations
R2 Resources, Inc.	Water-level loggers and stage

Table 4.1-6. Sieve bulk sample area dimensions.

D_{max} (mm)	Weight (lb)	Depth (ft)	Depth (in)	Square (ft)	Diameter (ft)
2	0.024	0.01	0.2	0.1	0.1
4	0.189	0.03	0.3	0.2	0.3
8	1.51	0.05	0.7	0.5	0.6
11.3	4.23	0.08	0.9	0.7	0.8
16	12.0	0.11	1.3	1.0	1.1
22.6	33.6	0.15	1.8	1.4	1.6
32	101	0.22	2.6	2.0	2.3
45	185	0.31	3.7	2.3	2.6
64	307	0.44	5.2	2.5	2.8
90	400	0.61	7.3	2.4	2.7
128	400	0.87	10.4	2.0	2.2
180	400	1.22	14.7	1.7	1.9
256	400	1.74	20.9	1.4	1.6
360	400	2.45	29.4	1.2	1.3

Table 4.1-7. 2013 Susitna-Watana airborne LiDAR data specifications.

Data Specification	Description
Point density	Minimum 8 points per square meter
Nominal point spacing	0.45 meter
Field of view	30° angle
Returns per pulse	4
Horizontal projection	NAD 1983 State Plane Alaska 4 FIPS 5004
Vertical projection	NAVD 88 – GEOID09
Horizontal accuracy (RMSEr)	≤ 17 cm (~0.56 ft)
Vertical accuracy (RMSEz)	≤ 9.25 cm (~0.30 ft)
LiDAR intensity values	0 to 255 (8 bits)
LiDAR files version	ASPRS LAS files version 1.2
Vertical and horizontal units	U.S. Survey Feet

Table 4.1-8. Comparison of NMAS/NSSDA Vertical Accuracy (ASPRS 2004).

NMAS Equivalent Contour Interval (ft)	NSSDA RMSEz (ft)	NSSDA Vertical Accuracy at 95% confidence level (ft)	Required Accuracy for Reference Data for "Tested to Meet" (ft)
0.5	0.15	0.30	0.10
1	0.30	0.60	0.20
2	0.61	1.19	0.40
3*	0.92*	1.79*	0.60*
4	1.22	2.38	0.79
5	1.52	2.98	0.99
10	3.04	5.96	1.98

Notes:
* Average of 2 and 4 ft equivalent contour interval rows in ASPRS 2004.

Table 4.3-1: Primary output variables for which values are taken directly from the 1-D and 2-D Bed Evolution models and relevance to other studies.

Variable	Description of Model Output	Spatial Resolution	Relevance to Other Studies
1-D Bed Evolution 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 Bed Evolution 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 4.3-2: 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 Bed Evolution models.

Variable	Description	Spatial Resolution	Relevance to Other Studies
1-D Bed Evolution 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 Bed Evolution 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 5.1-1 Potential 1-D Bed Evolution Models.

Characteristics & Evaluation Criteria	Software				
	HEC-RAS Ver. 4.1.0	HEC-RAS Ver. 4.2.0	SRH-1D	MIKE 11	HEC-6T
General					
Commercial/cost (if applicable)	○	○	○	● / $8,000	● / $3,000
Full or quasi-unsteady for sediment transport simulation	Quasi	Both	Both	Full	Quasi
Ice for fixed bed	●	●	○	○	○
Ice for moveable bed	●	●	○	○	○
Number of transport equations supported	7	8	13	10	18
Supports user-defined transport equation	○	●[1]	○	○	●
Closed-loop capability	○	●	●	●	●
Experience with model	H	H	L	M	H
Model Size Limitations					
Number of cross sections	NL	NL	NL	NL	5,000
Number of hydrograph ordinates	40,000	40,000	NL	NL	5,000
Number of sediment sizes	20	20	NL	NL	20
Sediment Sizes Supported					
Wash load (silt and clay)	●	●	●	●	●
Considers settling and resuspension	●	●	●	●	●
Sand	●	●	●	●	●
Gravel and cobble	●W	●W	●P,W	●	●P,W

● = Yes; ○ = No; H = High; M = Moderate; L = Low; NL = No Limit

P = Parker (1990), W = Wilcock & Crowe (2003) sediment transport functions

[1] The user can calibrate coefficients and exponents of certain transport functions, thereby creating user-defined equations

Table 5.1-2 Potential 2-D Bed Evolution Models Selected for Final Evaluation.

Evaluation Criteria	Model	
	SRH-2D	**River2D**
Proprietary/cost (if applicable)	○	○
Unsteady flow capability	●	●
Ice for fixed bed	○	●
Ice for moveable bed	○	●
Number of transport equations supported	6	2
Supports user defined transport equation	○	○
Relative execution speed	M	S
Model stability	H	H
Experience with model	H	M
Moveable boundary simulation	●	●
Finite element (FE) / Finite Volume (FV)	FV	FE
Grid structure: Flexible Mesh (FM)	●	●
# of mesh elements	Hydrodynamic>200,000, Sed. Transport <16,000	Hydrodynamic>100,000, Sed. Transport >100,000
Wash load (silts, clays)	○	○
Suspended Load	●	○
Considers settling	●	○
Sand	●	●
Gravel and cobble	●	●

Notes: ● = Yes; ○ = No; F = Fast; M = Moderate; S = Slow; L = Low

Table 5.1-3 Tributary Modeling.

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

*Tributaries that will be analyzed in 2013.

Table 5.1-4 Initial Manning's Roughness Coefficients for 1-D and 2-D Bed Evolution Models.

Description*	Abbreviation	Initial Manning's Roughness Coefficient
Bed Rock	KF	0.05
Channel	FAN	0.04
Fan	MCGB & SCGB	0.08
Gravel Bar	GD	0.05
Grano Diorite	MC	0.15
Main Channel	MFP	0.03
Mature Floodplain	MORAINE	0.17
Moraine	OCH	0.17
Overbank Channel	OFP	0.12
Overbank Floodplain	OUTWASH TCE	0.15
Outwash Terrace	PC	0.17
Paleo Channel	RRRR	0.12
Rail Road Riprap	SC	0.05
Side Channel	SS	0.03
Side Slough	TCE	0.03
Terrace	TR	0.17
Tributary	US	0.035
Upland Slough	VB	0.04
Vegetated Bar	YFP	0.12
Young Floodplain	KF	0.15

*Descriptions correspond to geomorphic mapping

Table 5.1-5. Sources and Types of Data Used to Develop the 2-D Models.

Source	Type of data
Tetra Tech Inc.	water-surface elevation, high-water mark, bed-material gradations (surface + subsurface), tributary sediment loads
Brailey Hydrologic Consultants	Bathymetry, water-surface elevation, high-water mark, velocity measurements
Keystone Aerial Surveys, Inc.	LiDAR Survey
Geovera, LLC.	Overbank topography and channel surveys
U.S.G.S.	Flow data, stage data, sediment transport measurements, sediment gradations
Bill Miller Ecological	Channel substrate mapping
R2 Resources, Inc.	HEC-RAS model
Fish and Aquatics IFS Team	Mapping showing the fine mesh areas for the 2-D model development

Table 5.1-6: Focus Areas in the Middle Susitna River Segment.

Focus Area ID	Common Name	Downstream PRM	Upstream PRM	Geomorphic Reach	Reach Type
FA-184	Watana Dam	184.7	185.7	MR-1	SC2
FA-173	Stephan Lake Complex	173.6	175.4	MR-2	SC2
FA-151	Portage Creek	151.8	152.3	MR-5	SC2
FA-144	Slough 21	144.4	145.7	MR-6	SC3
FA-141	Indian River	141.8	143.4	MR-6	SC3
FA-138	Gold Creek	138.5	140.0	MR-6	SC3
FA-128	Slough 8A	128.1	129.7	MR-6	SC3
FA-115	Slough 6A	115.3	116.5	MR-7	SC2
FA-113	Oxbow I	113.6	115.3	MR-7	SC2
FA-104	Whiskers Slough	104.8	106.0	MR-8	MC1/SC3

Table 5.1-7: Upstream and Downstream PRM boundaries for Geomorphic Assessment Areas.

Geomorphic Assessment Area	PRM		Length
	Downstream	Upstream	mile
GAA-Whiskers Slough	104.2	107.4	3.2
GAA-Oxbow I	113.6	115.3	1.7
GAA-Slough 6A	115.3	117.3	2.0
GAA-Slough 8A	128.1	130.4	2.3
GAA-Gold Creek	137	140.1	3.1
GAA-Indian River	140.1	143.6	3.5
GAA-Slough 21	143.6	146.1	2.5

Table 5.1-8 Tributary Modeling Results.

Tributary Name	PRM	Reconnaissance Conducted/ Planned	Model Developed	No. Cross Sections	Modeled Channel Length (ft)	Average Channel Width (ft)	Average Channel Slope (ft/ft)
Tsusena Creek	184.6	Next Study Season	n/a	n/a	n/a	n/a	n/a
Fog Creek	179.3	Next Study Season	n/a	n/a	n/a	n/a	n/a
Unnamed	174.3	Next Study Season	n/a	n/a	n/a	n/a	n/a
Unnamed	173.8	Next Study Season	n/a	n/a	n/a	n/a	n/a
Portage Creek	152.3	Next Study Season	n/a	n/a	n/a	n/a	n/a
Unnamed*	144.6	2013	HEC-RAS	4	151	31	0.038
Indian River*	142.1	2013	HEC-RAS	5	511	120	0.010
Gold Creek*	140.1	2013	HEC-RAS	4	194	37	0.022
Skull Creek*	128.1	2013	HEC-RAS	5	143	53	0.030
Lane Creek*	117.2	2013	HEC-RAS	5	167	32	0.009
Unnamed*	115.4	2013	No[2]	n/a	n/a	n/a	n/a
Gash Creek*	115.0	2013	HEC-RAS	5	112	8	0.013
Slash Creek*	114.9	2013	HEC-RAS	5	67	8	0.018
Unnamed*	113.7	2013	HEC-RAS	6	66	26	0.044
Whiskers Creek*	105.1	2013	HEC-RAS	5	90	30	0.002
Trapper Creek*	94.5	2013	HEC-RAS	10	n/a[3]	n/a[3]	n/a[3]
Birch Creek*	92.5	Next Study Season[1]	n/a	n/a	n/a	n/a	n/a
Sheep Creek	69.5	Next Study Season	n/a	n/a	n/a	n/a	n/a
Caswell Creek	67.0	Next Study Season	n/a	n/a	n/a	n/a	n/a
Deshka River*	45.0	2013	HEC-RAS	10	30,500	220	0.0005

Notes:

* Tributaries that will be analyzed in 2013.

1 Private landowner did not allow access in 2013, will try for access again in the next study season.

2 Excluded from modeling based on observations during 2013 reconnaissance of low sediment production and absence of a delta.

3 Modeling is in development, so these results are not yet available.

Table 5.1-9. Summary of the number of bank observations along the Susitna River and tributaries in 2013.

Location	Cross Section Roughness Observations	Water-Surface Elevation Measurements	Bank Profiles
Susitna River	20	20	30
Focus Areas	8	8	6

Table 5.1-10. Summary of the number of sediment samples collected along the Susitna River and tributaries in 2013.

Location	Susitna River			
	Pebble Counts	Pebble Count/Sub-Surface Sample	Bulk Samples	Bank Samples
Lower River	0	16	0	0
Middle River (Excluding FA's)	5	22	1	6
FA104	9	5	2	14
FA113	4	8	0	9
FA115	8	4	0	5
FA128	5	1	0	8
FA138	6	5	0	10
FA141	7	3	0	5
FA144	12	6	0	6
Location	**Tributaries**			
	Pebble Counts	**Pebble Count/Sub-Surface Sample**	**Bulk Samples**	**Bank Samples**
Trappers Creek	7	0	1	0
Indian River	2	1	0	0
Yentna River	1	2	0	0
Chulitna River	0	5	0	0
Deshka River	1	0	8	0
Talkeetna River	0	5	0	0
Slash Creek	0	0	1	0
Gash Creek	1	0	1	0

Table 5.1-11. Sediment sampling conducted at the Tributary Delta study sites.

Tributary	PRM	Surface Sample/ Pebble Count				Subsurface Sample			
		Size (mm)			Sand Cover[1]	Size (mm)			Less Than 2mm[2]
		D_{16}	D_{50}	D_{84}	%	D_{16}	D_{50}	D_{84}	%
Whiskers Creek	105.1	19	34	54	0	0.45	12	24	33
UNT 113.7	113.7	27	90	457	0	0.10	3	103	48
Slash Creek	114.9	n/a	n/a	n/a	n/a	2	12	27	17
Gash Creek	115.2	12	24	46	2	2	19	102	18
Lane Creek	117.2	25	57	116	0	3	31	117	14
Skull Creek	128.1	23	69	223	0	2	23	80	16
Gold Creek	140.1	31	85	177	1	2	21	59	18
Indian River	142.1	35	75	162	0	0.6	19	49	27
UNT 144.6	144.6	27	83	179	0	2	24	59	15

[1] Value is the percent of the surface that was covered with a layer of sand and finer material.

[2] Value represents the percent of the subsurface sample that was less than 2 mm which is the upper limit of sand.

Table 5.1-12. Cross Sections Surveyed through 2013 Field Season.

Lower Susitna River Segment						Middle Susitna River Segment							
PRM	Date[1]	PRM	Date[1]	PRM	Date[1]	PRM	Date[1]	PRM	Date[1]	PRM	Date[1]	PRM	Date[1]
29.9	C	69.2	C	94.0	C	102.7	A	120.3	C	134.3	A,B	146.2	C
31.6	C	71.0	C	94.8	C	103.5	A	120.7	A	134.7	C	146.6	A
32.4	C	73.1	C	96.2	C	104.1	A	121.4	C	135.0	A	148.3	A
33.7	C	74.1	C	97.0	A	104.7	A	122.1	C	135.7	C	151.1	A
34.8	C	75.0	C	98.4	A,B	105.3	A	122.7	A	136.2	A	152.1	A,B
36.4	C	75.9	C	99.9	C	106.1	A	122.8	A	136.7	A	152.9	A
38.3	C	77.0	C	100.7	C	106.6	C	123.2	C	137.2	C	153.7	A
39.5	C	78.0	C	101.4	A,B	107.1	A	123.7	A	137.6	A,B	168.1	A
40.4	C	79.0	C	102.1	C	107.8	C	124.1	A,B	138.1	A	170.1	A
41.3	C	80.0	A	n/a	n/a	108.3	A	124.5	C	138.4	C	173.1	A
44.5	C	80.7	C	n/a	n/a	109.0	C	125.0	C	138.7	A	174.9	A
45.6	C	81.4	C	n/a	n/a	110.5	A,B	125.4	A	139.0	A	176.5	A
46.3	C	82.3	A	n/a	n/a	111.9	A	125.8	C	139.8	A	178.5	A
47.1	C	83.0	A	n/a	n/a	112.5	C	126.1	A	140.0	A,B	179.5	A
47.9	C	84.4	A	n/a	n/a	113.1	C	126.5	C	140.5	C	181.6	A
49.0	C	85.4	A	n/a	n/a	113.6	A,B	126.8	A,B	140.8	C	182.9	A
52.1	C	86.3	A	n/a	n/a	114.4	A	127.8	C	141.2	C	183.3	A
54.2	C	87.1	A	n/a	n/a	115.4	A	128.1	A	141.7	A	184.4	A
55.4	C	87.6	C	n/a	n/a	115.7	A	129.7	A,B	141.9	A	184.9	A
57.8	C	88.0	C	n/a	n/a	116.3	A	130.5	C	142.2	A,B	185.2	A
59.1	C	88.4	A	n/a	n/a	116.6	A	130.9	C	143.0	A	185.5	A
60.3	C	89.5	C	n/a	n/a	117.1	C	131.4	A	143.5	A	186.2	A
62.7	C	90.2	C	n/a	n/a	117.4	A	132.1	C	143.9	C	187.2	A
64.6	C	91.0	A	n/a	n/a	117.9	C	132.6	A	144.3	A	n/a	n/a
66.1	C	91.6	A	n/a	n/a	118.4	A	133.3	A	144.9	A	n/a	n/a
67.2	C	92.3	C	n/a	n/a	119.0	C	133.8	A	145.5	A	n/a	n/a
68.2	C	93.2	C	n/a	n/a	119.9	A,B	134.1	A	145.7	A,B	n/a	n/a

Note:
A = 2012field season; B = 2012 post-flood (end of September through early October); C = 2013 field season

Table 5.1-13. Water-Surface Elevation (WSE) measurements collected during the Focus Area topographic surveys by Fish and Aquatics Instream Flow (ISR Section 8.5).

Location	No. of WSE measurements	Comment
FA-104	846	WSE's collected along main-channel, side channels and upland sloughs. Date of surveys and corresponding discharges need to be determined
FA-113	358	
FA-115	439	
FA-138	759	
FA-128	899	
FA-141	578	
FA-144	377	

Table 5.1-14. Water surface elevations measurements collected for model calibration as part of the ADCP survey by Fish and Aquatics Instream Flow (ISR Section 8.5).

Location	No. of WSE measurements	Date	Approximate flow at time of measurements, cfs
FA-104	24	12-July-2013	17,500
FA-113	28	10-11 July, 2013	20,040
FA-115	19	10-July-2013	21,690
FA-128	64	2-July-2013	24,710
FA-138	21	1-July-2013	25,000
FA-141	19	30-June-2013	24,750
FA-144	20	29-June-2013	26,020

Table 5.1-15. Summary of 2012-2013 data collected at ESS stations[a].

Station	PRM	Water Level	Water Temperature	Air Temperature	Camera Images	Land Access Granted	Priority	Studies Using Data
ESS80	225.0	Complete	Complete	Complete	Yes	Yes	B	Engineering, Upper Basin DGGS
ESS70	187.1	Missing 2013	Missing 2013	Complete	Yes	No	A	IFS, Ice Processes, Geomorphology, Water quality, Engineering, Upper Basin DGGS, Groundwater
ESS65	176.5	Missing 2013	Missing 2013	Complete	Yes	No	A	IFS, Ice Processes, Geomorphology, Water Quality
ESS60	168.1	Missing 2013	Missing 2013	Complete	Yes	No	A	IFS, Ice Processes, Geomorphology, Water Quality
ESS55	152.2	Missing 2013	Missing 2013	Complete	Yes	No	A	IFS, Ice Processes, Geomorphology, Water quality, Groundwater
ESS50	124.1	Partial 2013	Partial 2013	Complete	Yes	Yes	A	IFS, Ice Processes, Geomorphology, Water quality, Groundwater
ESS45	116.6	Partial 2013	Partial 2013	Complete	Yes	Yes	A	IFS, Ice Processes, Geomorphology, Water quality, Groundwater
ESS40	107.2	Partial 2013	Partial 2013	Complete	Yes	Yes	A	IFS, Ice Processes, Geomorphology, Water quality, Groundwater
ESS35	102.1	Missing 2013	Partial 2013	Complete	Yes	Yes	C	IFS, Ice Processes, Geomorphology, Water quality, Groundwater
ESS30	98.4	Complete	Complete	Complete	Yes	Yes	B	IFS, Ice Processes, Geomorphology, Water quality, Groundwater

Notes:

a Table copied from ISR Study 8.5

Table 5.1-16. Priority Area 01 South vertical accuracy tests results for 2013 LiDAR.

LiDAR Vertical Accuracy Test	Cover type	# Survey points	Max (US Feet)	Min (US Feet)	Mean (US Feet)	STD (US Feet)	RMSEz (US Feet)	Vertical accuracy at 95% confidence level (US Feet)	# Outlier s
Fundamental Vertical Accuracy Test	Open terrain	39	0.545	-0.728	-0.015	0.275	0.272	0.533	0
Supplemental Vertical Accuracy Test	Brush land/Low vegetation	24	1.048	-1.100	-0.316	0.546	0.619	1.213	1
	Forest land	23	0.500	-1.141	-0.344	0.429	0.542	1.062	0
Consolidated Vertical Accuracy Test	All land cover types	86	1.048	-1.141	-0.191	0.427	0.465	0.911	1

Table 5.1-17. Priority Area 02 South, 03 and 04 vertical accuracy tests results for 2013 LiDAR.

LiDAR Vertical Accuracy Test	Cover type	# Survey points	Max (US Feet)	Min (US Feet)	Mean (US Feet)	STD (US Feet)	RMSEz (US Feet)	Vertical accuracy at 95% confidence level (US Feet)	# Outliers
Fundamental Vertical Accuracy Test	Open terrain	21	0.432	-0.473	0.004	0.215	0.209	0.410	0
Supplemental Vertical Accuracy Test	Brush land/Low vegetation	21	1.071	-0.601	0.189	0.473	0.499	0.978	0
	Forest land	19	1.640	-0.918	0.041	0.571	0.557	1.091	0
Consolidated Vertical Accuracy Test	All land cover types	61	1.071	-0.918	0.053	0.391	0.391	0.766	1

Table 5.1-18. 2011 Matanuska-Susitna LiDAR vertical accuracy verification results.

LiDAR Vertical Accuracy Test	Cover type	# Survey points	Max (US Feet)	Min (US Feet)	Mean (US Feet)	STD (US Feet)	RMSEz (US Feet)	Vertical accuracy at 95% confidence level (US Feet)	# Outliers
Fundamental Vertical Accuracy Test	Open terrain	174	3.830	-2.840	0.728	0.991	1.227	2.405	2
Supplemental Vertical Accuracy Test	Brush land/Low vegetation	174	2.256	-1.709	0.368	0.703	0.791	1.550	3
	Forest land	174	3.504	-3.101	0.029	0.830	0.828	1.623	2
Consolidated Vertical Accuracy Test	All land cover types	522	2.822	-2.840	0.361	0.844	0.917	1.797	10

Table 5.1-19. 2011 Matanuska-Susitna LiDAR comparison to obtain average elevation difference.

Cover type	# Survey points	Max (US Feet)	Min (US Feet)	Mean (US Feet)	STD (US Feet)	RMSEz (US Feet)	Vertical accuracy at 95% confidence level (US Feet)	# Outliers
Open terrain	525	3.291	-2.559	0.673	0.952	1.165	2.283	16

Table 5.1-20. 2011 Matanuska-Susitna LiDAR vertical accuracy verification results after indexing.

LiDAR Vertical Accuracy Test	Cover type	# Survey points	Max (US Feet)	Min (US Feet)	Mean (US Feet)	STD (US Feet)	RMSEz (US Feet)	Vertical accuracy at 95% confidence level (US Feet)	# Outliers
Fundamental Vertical Accuracy Test	Open terrain	174	2.668	-2.754	0.095	0.916	0.918	1.799	4
Supplemental Vertical Accuracy Test	Brush land/Low vegetation	174	1.701	-2.038	-0.268	0.714	0.761	1.492	2
	Forest land	174	2.577	-2.682	-0.615	0.710	0.937	1.837	6
Consolidated Vertical Accuracy Test	All land cover types	522	2.836	-2.754	-0.254	0.858	0.894	1.752	9

Table 6.1-1. Lower Susitna River Bed-material Samples Collected in 1984 (R&M Consultants 1985).

1984 RM	2013 PRM	Armor Layer Sample Number	D_{50} (mm)[1]
97.1	100.4	6	38
95.9	99.3	7	46
93.1	96.3	3	32
91.8	95.4	6	55
90.6	93.3	5	55
87.7	91.1	6	11
86.3	90.3	5	55

Note:
1 Visually interpolated from gradation curves presented in R&M Consultants (1985)

Table 6.1-2. Middle Susitna River Bed-material Samples Collected in 1983 (Harza-Ebasco 1984).

Location	2013 PRM	D_{50} (mm)
LRX-1.0, left channel, center[1]	100.6	70
LRX-1.0, right channel, center[1]	100.6	50
LRX-2.3, near left bank	102.1	24
LRX-3.3, near left bank	102.8	58
LRX-3.3, near right bank	102.8	64
LRX-4, East bank, pavement	103.2	30
LRX-4, site 1, pavement	103.2	30
LRX-4, site 2, pavement	103.2	20
LRX-7.0, right channel	105.4	50
Near RM 109.3, pavement	113.0	65
Upstream of Lane Creek, pavement	117.3	58
Near LRX-18.2, Site 1, pavement	118.2	54
Near LRX-18.2, Site 2, pavement	118.8	10
Near Slough 10, pavement	137.0	20
LRX-42, center	138.6	52
Right channel Slough 11, pavement	139.0	60
LRX-45, center	140.0	65
LRX-51, center	142.3	70

Table 6.1-3. Candidate Cross Sections Surveys for the Next Study Season.

Lower Susitna River Segment		Middle Susitna River Segment	
PRM	PRM	PRM	PRM
30.8	88.9	109.7	170.8
33.0	95.3	111.2	172.2
42.5	97.8	119.5	175.9
51.1	99.1	127.4	177.3
56.8	n/a	140.2	179.0
61.7	n/a	141.5	180.1
63.7	n/a	148.8	183.8
70.1	n/a	153.3	186.7
83.5	n/a	167.4	n/a

Table 6.1-4. Flow thresholds for evaluating coupled measurements of flow and WSE.

Note:

USGS Gaging Station	Fish and Aquatics Instream Flow Study (ISR 8.5)		Geomorphology Study (ISR 6.5)	
	Low/Medium Flow Threshold (cfs)	Medium/High Flow Threshold (cfs)	Flow Required for Bed Mobilization (cfs)	Effective Discharge (cfs)
Susitna River at Sunshine (Lower River)	45,500	60,600	16,000	66,000
Susitna River at Gold Creek (Middle River)	17,700	24,000	25,000	27,000

Table 6.1-5. ADCP Discharge Measurements Collected at the Focus Areas in 2013.

Focus Area	Number of Transects	Date	Discharge cfs)[1]		Date	Discharge (cfs)[1]
FA-144	5	6/29/2013	~26,000		9/7/2013	~26,500
FA-141	5	6/30/2013	~25,000		9/8/2013	~29,500
FA-138	5	7/1/2013	~25,000		9/6/2013	~29,000
FA-128	5	7/2/2013	~24,750		9/10/2013	~26,200
FA-115	5	7/10/2013	~21,750		9/13/2013	~30,750
FA-113	7	7/11/2013	~19,750		9/14/2013	~25,500
FA-104	4	7/12/2013	~17,500		9/15/2013	~21,500

Note:

1 The discharges varied over the survey period. Representative discharges for the survey period were developed from ISR Study Plan Section 8.5.4.4.1.1 (Figures 5.1-5a to 5.1-5g & 5.1-6a to 5.1-6g).

10. FIGURES

[See separate file for figures.]

PART A - APPENDIX A: BED-MATERIAL SAMPLES

[See separate file for appendix.]

PART A - APPENDIX B: BED-MATERIAL SAMPLE LOCATIONS IN FOCUS AREAS

[See separate file for appendix.]

PART A - APPENDIX C: BANK-MATERIAL SAMPLES

[See separate file for appendix.]

PART A - APPENDIX D: WATER SURFACE MEASUREMENTS

[See separate file for appendix.]

PART A - APPENDIX E: EVALUATION OF 50-YEAR SIMULATION PERIOD, PACIFIC DECADAL OSCILLATION, AND SELECTION OF REPRESENTATIVE ANNUAL HYDROGRAPHS

[See separate file for appendix.]

PART A - ATTACHMENT A: FIELD REPORT, FIELD ASSESSMENT OF UNDERWATER CAMERA PILOT TEST FOR SEDIMENT GRAIN SIZE DISTRIBUTION

[See separate file for attachment.]