6. GEOMORPHOLOGY

6.1. Introduction

The overall goal of the geomorphology studies below Watana Dam is to assess the potential effects of the proposed Project on the fluvial geomorphology of the Susitna River, with particular focus on providing information to assist in predicting Project impacts to aquatic and terrestrial habitat. In general, the geomorphology studies will focus on the likely trends and magnitudes of responses of a suite of geomorphic characteristics that make up and control the quantity, quality and distribution of riverine habitat downstream from the proposed dam.

Natural river channels tend toward a state of dynamic equilibrium with the upstream water and sediment supply by adjusting their physical characteristics to the imposed conditions (Chorley et al. 1984; Lane 1955). These physical characteristics, that include gradient, channel geometry, planform and boundary materials, form the habitat that is used by the aquatic and riparian organisms, and they occur and adjust at a variety of spatial and temporal scales. An understanding of whether and how they will change under Project conditions is critical to understanding potential Project impacts to the habitat. An understanding of the equilibrium status of the existing channel morphology provides a significant part of the basis for determining the distribution and characteristics of the existing habitat, and it also provides the baseline against which potential Project-induced impacts will be compared. A key question that must be answered in this regard is whether changes in morphology will occur in response to the Project that will influence the relative distribution or characteristics of the 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 quantity, distribution and quality of the habitat?

A suite of key indicators have been identified by the instream flow and riparian habitat specialists for assessing potential Project effects. These indicators are part of the Instream Flow Study (IFS) analytical framework (Section 8.5.4.1) developed to identify Project effects on aquatic and riparian resources. The framework is provided in Figure 6.1-1. These indicators in the IFS analytical framework include the following:

- Weighted-Useable-Area (WUA) versus flow relationships.
- Magnitude and frequency of breaching flows that provide connectivity between the main channels, secondary channels, and side sloughs.

- Hydraulic and geomorphic conditions that affect fish passage, particularly into tributaries along the study reach where changes in hydraulic energy in the mainstem associated with the Project could potentially impact the characteristics of tributary mouth bars.
- Changes in the magnitude and timing of flows under Project conditions that could affect other yet-to-be identified, ecologically important attributes, as quantified using Indicators of Hydrologic Alteration- (IHA) or Ecosystem Flow Component (EFC)-type analyses.
- Characteristics of spawning/incubation areas, particularly as they relate to mobilization and cleaning of fines from the spawning substrate, replenishment of suitably-sized spawning gravels, hydraulic conditions that provide aeration and prevent smothering of the redds due to fine sediment deposition during incubation, and the potential for dewatering due to lower stages during incubation.
- Characteristics of winter rearing habitat, including groundwater upwelling that affects water temperature, changes in stage that could affect connectivity with off-channel habitat, and the potential for changes in aggradation/degradation patterns in key habitat areas.
- Characteristics of the varial zone, including the frequency and duration of wetting and dewatering, the timing and rate of downramping, and the associated potential for stranding and trapping of fish and benthic macroinvertebrates.

Construction and operation of the Project has the potential to alter a suite of geomorphologically significant factors that are directly related to the above habitat indicators, including river flow, sediment gradations, transport and delivery, bank erosion rates, rates of bar, island and floodplain formation and large woody debris (LWD) recruitment and transport in the Susitna River. Changes to these processes may affect channel and floodplain geomorphic units and their interactions and, therefore, aquatic and terrestrial habitat for an as yet undefined distance downstream of the Watana Dam site. Since in-channel and channel-margin habitats are formed and maintained by the interaction of a range of flows with the boundary materials, it is necessary to develop a full understanding of the dynamics of the existing system, including the equilibrium status to provide a supportable basis for predicting Project impacts on channel, island/bar and floodplain morphology and dependent habitats downstream of the Watana Dam. Specific conditions that must be understood include how hydraulic conditions, bed mobility, bank erosion, LWD recruitment and aquatic habitat change over the range of river flows, and the relative stability (i.e., rate of change) of the river with respect to lateral erosion, aggradation/degradation, and island and bar formation in the identified geomorphic reaches over recent decades. Operation of the reservoir also has the potential to change the morphology and dynamics of streams and hillsides around the reservoir, as deltas form at the stream/reservoir interface, and the sides of the reservoir are exposed to erosion and beach formation. An understanding of existing (i.e., baseline) geomorphic conditions is needed for predicting the likely extent and nature of potential changes to river, hillside, and delta morphology that would occur due to Project operations.

The geomorphology effort consists of two studies. The Geomorphology Study (Section 6.5) will investigate historical and current geomorphology and geomorphic/geologic controls of the Susitna River by geomorphic reach using available information and additional information collected as part of the licensing effort. This study will identify existing morphology, historic changes in morphology over time along the Susitna River, and key physical processes governing the behavior of the river. This study will also provide an initial identification of potential Project effects within identified subreaches. In-channel (e.g., side channels, bars, islands) and channel margin (e.g. floodplain, side sloughs) geomorphic subunits are the foundations for the range of available habitats in the Susitna River, and thus, an analysis of river and floodplain morphology and morphologic change over time and space also provides a measure of the distribution and changes of habitats . The Fluvial Geomorphology Modeling Study (Section 6.6) will apply 1-D and 2-D hydraulic and bed evolution models to further quantify geomorphic processes in the existing river, equilibrium status of identified reaches and associated, potential Project effects on river geomorphology, and thus, habitats. An extensive data collection effort will be conducted as part of the Fluvial Geomorphology Modeling study. The understanding of the morphology and sedimentology of the system, and its governing physical processes gained from the integrated Geomorphology and Fluvial Geomorphology Modeling Studies will provide a rational basis for predicting and quantifying potential Project effects on habitat within the identified reaches of the Susitna River downstream of the Watana Dam site Studies in other resource areas, such as the instream flow studies (Section 8), will use this information to aid in quantifying Project effects for their resource areas. A key aspect of the integration between the various physical and biological studies will be the common use of the Focus Areas to jointly carry out integrated resource analysis.

The majority of the on-the-ground field data collection effort supporting both studies is encompassed in the Fluvial Geomorphology Modeling Study because the resulting data provides the information necessary to perform the 1-D and 2-D hydraulic and bed evolution modeling. The extensive field effort is described in the Bed Evolution Model Development, Coordination and Calibration Study component (Section 6.6.4.2). The exceptions are field data collection efforts described for the Bedload and Suspended Load Data Collection at Tsusena Creek, Gold Creek, and Sunshine Station on the Susitna River and the Chulitna River near Talkeetna (Section 6.5.4.2 to be performed by the USGS), Reservoir Geomorphology (Section 6.5.4.8), Large Woody Debris (Section 6.5.4.9), Geomorphology of Stream Crossings Along Transmission Line and Access Alignments (Section 6.5.4.10) study components of the Geomorphology Study. The coordination, integration, and interpretation of results between the Geomorphology Study and the Fluvial Geomorphology Modeling Study are described in Integration of Fluvial Geomorphology Modeling with the Geomorphology Study (Section6.6.5.11) and Coordination and Interpretation of Model Results (Section 6.6.4.3). The collection of aerial photography supporting both studies is being conducted as part of the Geomorphology Study under the Riverine Habitat versus Flow Relationship Middle Susitna River Segment (Section 6.5.4.5) and Riverine Habitat versus Flow Relationship Lower Susitna River Segment (Section 6.5.4.7) study components.

The geomorphology studies will be subject to revision and refinements in consultation with licensing participants as part of the continuing study program identified in the ILP. The impact assessments will inform development of any necessary protection, mitigation, and enhancement measures to be presented in the draft and final License Applications. A glossary of geomorphology terms is included in Attachment 6-1.

6.2. Nexus Between Project Construction / Existence / Operations and Effects on Resources to be Studied

Construction and operation of the Project have the potential to alter river flow, sediment transport and delivery, and large woody debris (LWD) recruitment and transport in the Susitna River. Changes to these processes may affect channel morphology and aquatic habitat downstream of the Watana Dam site. Operation of the reservoir also has the potential to change the geomorphology of streams and hillsides around the reservoir as deltas form at the stream/reservoir interface and the sides of the reservoir are exposed to erosion and beach formation. Understanding existing, baseline geomorphic conditions, how geomorphic conditions and thus, aquatic habitat change over a range of stream flows, and how stable/unstable the geomorphic conditions have been over recent decades provides baseline information needed for predicting the likely extent and nature of potential changes to the fluvial geomorphology and associated habitats that would occur due to Project operations.

Changes in the channel morphology may alter the presence, physical characteristics, and function of important riverine aquatic habitat types such as side channels and sloughs. For example, reduction in sediment supply has the potential to cause channel downcutting and coarsening of bed material. In contrast, reduction in peak flow magnitude and changes in timing can result in sediment deposition both in the mainstream and at tributary mouths. The regulated hydrology may affect the rates and timing of sediment transport that ultimately govern formation and maintenance of dynamic aquatic habitats, as well as access to these habitats. Analysis of the complex interactions of water and sediment with the channel and floodplain boundaries to evaluate existing conditions and potential Project effects requires development and application of a sediment transport model.

AEA's Susitna Water Quality and Sediment Transport Data Gap Analysis Report (URS 2011) indicated that further quantification of the sediment supply and transport capacity would help identify the sensitivity of the channel morphology (and associated aquatic habitats) to the effects of the proposed Project. The report indicated that information on sediment continuity could provide a basis for evaluating whether the Susitna River below the Chulitna River confluence is currently aggradational and/or would be at risk of becoming more strongly aggradational to a sufficient degree to alter aquatic habitats and hydraulic connectivity to these habitats. The report also pointed out that side channels and sloughs are of particular importance to fish habitat, and changes to the relationships between flow and stage at which the habitats are accessible could affect habitat. These relationships can be affected by not only distribution of flows, but also changes in the bed elevations due to sediment transport processes. Other impacts to the sediment transport regime could affect cleaning and maintenance of spawning gravels, hyporheic flows through redds, groundwater inflows, and hydraulic connectivity for out-migration to the main channel.

6.3. Resource Management Goals and Objectives

Several natural resources agencies have jurisdiction over aquatic species and their habitats in the Project area. These agencies will be using in part, the results of the Geomorphology Study, Instream Flow Study, and other fish and aquatic studies to satisfy their respective mandates. The following federal and state agencies and Alaska Native entities have identified their resource management goals, or provided comments in the context of FERC licensing, related to geomorphology, instream flow, and riparian resource issues.

6.3.1. National Marine Fisheries Service

The following text is an excerpt of the May 31, 2012, National Marine Fisheries Service (NMFS) letter and Geomorphology Study Request:

> *"NMFS is entrusted with federal jurisdiction over marine, estuarine, and anadromous fishery resources under the Magnuson-Stevens Fishery Conservation and Management Act (MSA) (16 U.S.C.§ 1801 et seq, the Anadromous Fish Conservation Act (16 U.S.C. 757a-757g; Pub. L. 89-304, as amended), and the Pacific Salmon Treaty Act (16.U.S.C. §3631, et seq.). Section 305(b) of the MSA requires federal agencies to consult with NMFS on all actions that adversely affect Essential Fish Habitat (EFH). Where, in the judgment of NMFS, the proposed action would adversely affect EFH, NMFS is required to make EFH Conservation Recommendations, Section 10(j) of the Federal Power Act (FPA) authorized NMFS to recommend license terms and conditions necessary to protect, mitigate damage to, and enhance fish and wildlife habitat affected by the project. Section 18 of the FPA provides NMFS authority to issue mandatory fishway prescriptions. In addition, NMFS has the responsibilities related to FERC proceedings derived from the Fish and Wildlife Coordination Act, Endangered Species Act, and the Marine Mammal Protection Act.*
>
> *NMFS resource management objectives derived from these authorities include:*
>
> - *Maintaining native and natural aquatic communities for their intrinsic and ecological value ant their benefits to people. This includes habitat protection and maintenance to ensure the health and survival of all species and natural communities.*
> - *Maintaining stream flow regimes sufficient to sustain native riparian and aquatic habitats in the project-affected stream reaches.*
> - *Maintaining the diversified use of fish and wildlife including commercial, recreational, scientific and educational purposes.*
> - *Protecting, conserving and enhancing native fishes and their habitats by maintaining their access to suitable and fully functioning habitats.*
> - *Identifying and implementing measures to protect, mitigate, or minimize direct, indirect and cumulative impacts to native anadromous fish resources, including related spawning, rearing and migration habitats and adjoining riparian habitats.*
> - *Maintaining riparian resources, channel conditions, and aquatic habitats.*
> - *Maintaining stream flow regimes sufficient to sustain desired conditions of native riparian, aquatic, and wetland habitats.*
> - *Protecting aquatic systems to which species are uniquely adapted."*

6.3.2. U.S. Fish and Wildlife Service

The following text is an excerpt of the May 31, 2012, U.S. Fish and Wildlife Service (USFWS) Geomorphology Study Request:

> *"The overarching resource management goal of the USFWS is described in our mission:*
>
> > *to conserve, protect, and enhance fish, wildlife, plants, and their habitats for the continuing benefit of the American people.*
>
> *The U.S. Fish and Wildlife Service (USFWS), is providing comments in accordance with provisions of the National Environmental Policy Act (NEPA) of 1969 (83 Stat. 852; 42 U.S.C. 4321 et seq.), Endangered Species Act (ESA) of 1973 (87 Stat. 884, as amended; 16 U.S.C. 1531 et seq.), Bald and Golden Eagle Protection Act (BGEPA) (54 Stat. 250, as amended, 16 U.S.C. 668a-d), Migratory Bird Treaty Act (MBTA) (40 Stat. 755, as amended; 16 U.S.C. 703 et seq.), Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 et seq.), and Federal Power Act (16 U.S.C. § 791 et seq.). .).*
>
> *Under Section 18 of the Federal Power Act (FPA), the National Marine Fisheries Service*
>
> *(NMFS) and USFWS have authority to issue mandatory fishway prescriptions for safe, timely, and effective fish passage. Under Section 10(j) of the FPA, NMFS and USFWS are authorized to recommend license conditions necessary to adequately and equitably protect, mitigate damages to, and enhance, fish and wildlife (including related spawning grounds and habitat) affected by the development, operation, and management of hydropower projects. Section 10(a)(1) of the FPA requires the Federal Energy Regulatory Commission to condition hydropower licenses to best improve or develop a waterway or waterways for the adequate protection, mitigation, and enhancement of fish and wildlife (including related spawning grounds and habitat) based on NMFS and USFWS recommendations and plans for affected waterways. Specific management goals are the protection of anadromous, trust fish species and their habitats.*
>
> *Consistent with our mission and with the legal authorities described above, our resource goal in this matter is to conserve existing fish and wildlife resources and their habitats in the Susitna River basin. With regard to fish passage, we will recommend scientifically-based and coordinated studies, collaborate with others, and ensure development of the best information possible to inform potential development of fishway prescriptions for this project pursuant to Section 18 of the Federal Power Act."*

6.3.3. Alaska Department of Fish and Game

The following text is an excerpt of the May 30, 2012, Alaska Department of Fish and Game (ADF&G) letter and Instream Flow Study Request:

> *"The Fish and Game Act requires the Alaska Department of Fish and Game to, among other responsibilities, "…manage, protect, maintain, improve, and extend the fish, game and aquatic plant resources of the state in the interest of the economy and general well-being of the state" (AS 16.05.020)."*

6.3.4. Alaska Native Entities

6.3.4.1. Chickaloon Village Traditional Council

The Chickaloon Native Village provided comments on Project licensing activities in a May 31, 2012, letter to the FERC. Chickaloon Native Village is a federally recognized Alaska Native tribe. Chickaloon Village is an Ahtna Athabascan Indian Tribe governed by the nine-member Chickaloon Village Traditional Council. The Chickaloon Village Traditional Council strives to increase traditional Ahtna Dene' practices for the betterment of all residents in the area. Preserving and restoring the region's natural resources is one way of supporting Ahtna culture and the regional ecosystem. Concerning the potential effects of the Project on the geomorphology of the Susitna River, the Chickaloon Native Village wrote:

> *"The whole sediment transport system of the Susitna River will be changed by the proposed dam. Only the smaller sediment particles will pass downstream, as the dam will trap the larger particles. Since the substrate size for salmon redds varies by salmon species, studies must be conducted to ensure that the appropriate sediment particle sizes will be present for the salmon spawning habitats."*

6.4. Summary of Consultation with Agencies, Alaska Native Entities, and Other Licensing Participants

The geomorphology study plans have been modified in response to comments from various agency reviewers, including NMFS, the Alaska Department of Environmental Conservation (ADEC), and USFWS. Consultation on the study plan occurred during licensing participant meetings on April 6, 2012, and during the June 14, 2012 Water Resources Technical Workgroup (TWG) meeting. At the June 2012 TWG meeting, study requests and comments from the various licensing participants were presented and discussed, and refinements were determined and agreed-upon to address modifications to the draft study plans. The ILP formal study plan presentation meeting was held for the Geomorphology Study on August 17, 2012. On September 14, 2012 a TWG meeting was held to present and discuss the preliminary selection of Focus Areas. On October 2, 2012, a TWG meeting was held to discuss instream flow modeling and included a discussion of the integration with the geomorphology studies. This meeting was followed by a one-and-one-half day field reconnaissance conducted on October 3 and 4, 2012 with agency representatives to tour three of the proposed Focus Areas and discuss riparian, groundwater, geomorphology, fish habitat sampling and modeling. The field reconnaissance was followed by a two hour informal debrief meeting on the afternoon of October 4, 2012. On October 22, a TWG meeting was held to update the agencies on progress in the development of the Revised Study Plan (RSP). As part of this meeting, comments received since the July filing of the Preliminary Study Plan (PSP) and associated responses and modifications being incorporated in the RSP were discussed.

Summary tables of comments and responses from formal comment letters filed with FERC through November 14, 2012, are provided in Appendix 1. Copies of the formal FERC-filed comment letters are included in Appendix 2. In addition, a single comprehensive summary table of comments and responses from consultation, dated from PSP filing (July 16, 2012) through release of Interim Draft RSPs, is provided in Appendix 3. Copies of relevant informal consultation documentation are included in Appendix 4, grouped by resource area.

6.5. Geomorphology Study

6.5.1. General Description of the Proposed Study

6.5.1.1. Study Goals and Objectives

The overall goal of the Geomorphology Study is to characterize the geomorphology of the Susitna River, and to evaluate the effects of the Project on the geomorphology and dynamics of the river by predicting the trend and magnitude of geomorphic response. This will inform the analysis of potential Project-induced impacts to aquatic habitats. The results of this study, along with results of the Fluvial Geomorphology Modeling below Susitna-Watana Dam Study, will be used in combination with geomorphic principles and criteria/thresholds defining probable channel forms to predict the potential for alteration of channel morphology from Project operation. This information will be used to assist in determining whether protection, mitigation, or enhancement measures may be needed, and if so, what those measures may be. More specific goals of the Geomorphology Study are as follows:

- Determine how the river system functions under existing conditions.
- Determine how the current system forms and maintains a range of aquatic and channel margin habitats.
- Identify the magnitudes of changes in the controlling variables and how these will affect existing channel morphology in the identified reaches downstream of the dam and in the areas upstream of the dam affected by the reservoir.
- In an integrated effort with the Fluvial Geomorphology Modeling Study (Section 6.6) determine the likely changes to existing habitats through time and space.

In order to achieve the study goals, the following objectives are required:

- Geomorphically characterize the Project-affected river channels and floodplain including:
    - Delineate the Susitna River into geomorphically similar reaches.
    - Characterize and map relic geomorphic forms from past glaciation and debris flow events.
    - Characterize and map the geology of the Susitna River, identifying controlling features to channel and floodplain geomorphology.
    - Identify and describe the primary geomorphic processes that create, influence, and maintain mapped geomorphic features.
- Collect sediment transport data to supplement historical data to support the characterization of Susitna River sediment supply and transport.
- Determine sediment supply and transport in Middle and Lower Susitna River Segments.
- Assess geomorphic stability/change Middle and Lower Susitna River Segments.
- Characterize the surface area versus flow relationships for riverine macrohabitat types (1980s main channel, side channel, side sloughs, upland sloughs, tributaries and tributary mouths) over a range of flows in the Middle Susitna River Segment.

- Conduct a reconnaissance-level geomorphic assessment of potential Project effects on the Lower and Middle Susitna River Segments considering Project-related changes to stream flow and sediment supply and a conceptual framework for geomorphic reach response.
- Conduct a phased characterization of the surface area versus flow relationships for riverine macrohabitat types in the Lower Susitna River Segment including:
  - Delineation of aquatic macrohabitat per 1980s definitions for selected sites.
  - Comparison of 1980s versus existing macrohabitat areas and selected sites.
  - Estimate potential change in macrohabitat areas base on initial estimates of change in stage from Project operations.
  - Optional – If Focus Areas are extended into the Lower Susitna River Segment, perform development of macrohabitat wetted area versus flow relationships for additional sites and flows.
- Characterize the proposed Watana Reservoir geomorphology and changes resulting from conversion of the channel/valley to a reservoir.
- Assess large woody debris transport and recruitment, their influence on geomorphic forms and, in conjunction with the Fluvial Geomorphology Modeling Study, effects related to the Project.
- Characterize geomorphic conditions at stream crossings along access road/transmission line alignments.
- Integration with the Fluvial Geomorphology Modeling Study to develop estimates of Project effects on the creation and maintenance of the geomorphic features that comprise important aquatic and riparian macrohabitats and other key habitat indicators, with particular focus on side channels, side sloughs, and upland sloughs.

6.5.2. Existing Information and Need for Additional Information

An analysis of the Middle Susitna River Segment geomorphology and how aquatic habitat conditions change over a range of stream flows was performed in the 1980s using aerial photographic analysis (Trihey & Associates 1985). The AEA Susitna Water Quality and Sediment Transport Data Gap Analysis Report (URS 2011) states that "if additional information is collected, the existing information could provide a reference for evaluating temporal and spatial changes within the various reaches of the Susitna River." The gap analysis emphasizes that it is important to determine if the conditions represented by the data collected in the 1980s are still representative of current conditions and that at least a baseline comparison of current and 1980s-era morphological characteristics in each of the identified sub-reaches is required.

An analysis of the lower Susitna River Segment and how riverine habitat conditions change over a range of stream flows was performed in the 1980s using aerial photographic analysis (R&M Consultants, Inc. and Trihey & Associates 1985a). This study evaluated the response of riverine aquatic habitat to flows in the Lower Susitna River Segment between the Yentna River confluence (river mile [RM] 28.5) and Talkeetna (RM 98) (measured at Sunshine gage near RM 84) ranging from 13,900 cfs to 75,200 cfs. The study also included an evaluation of the morphologic stability of islands and side channels by comparing aerial photography between

1951 and 1983. As with the Middle Susitna River Segment information, it is important to determine if the conditions represented by the 1980s data are representative of current conditions. Such a comparison should include not only an identification of change, but should consider if the relative proportions of the various mesohabitat types have remained constant within a reach. If the relative proportions of the various mesohabitat types have remained constant in the various reaches, it provides a reasonable basis for using the 1980s data.

Considerable information is available from a variety of sources that will support the development and execution of the Geomorphology Study. Much of the available information is from the 1980s studies associated with the earlier efforts to develop the Susitna Hydroelectric Project (FERC No. 7114). In some cases, the older information will need to be replaced or supplemented with newer information because the Susitna River is a dynamic system and historical data such as cross-sections and aerial images in many areas will likely have changed considerably since they were collected in the 1980s. However, when compared with current information, these data provide valuable tools to understand the behavior and physical processes driving the geomorphology of the Susitna River. Comparability of the two sets of data will indicate that the fundamental relationships between channel form and fluvial process have remained constant and thus provide a basis for using the historical data. Additional data and analyses are needed to determine if historical data can be used to reflect current conditions and to address some of the data gaps identified in the AEA Susitna Water Quality and Sediment Transport Data Gaps Analysis Report (URS 2011). A more specific description of existing information and the need for additional information for each geomorphology study component are provided in the appropriate sections below.

6.5.3. Study Area

The study area for the Geomorphology Study is the Susitna River from its confluence with the Maclaren River (RM 260) downstream to the mouth at Cook Inlet (RM 0). The study area has been divided into three large-scale river segments:

- Upper Susitna River Segment: Maclaren River confluence (RM 260) downstream to the proposed Watana Dam site (RM 184).
- Middle Susitna River Segment: Proposed Watana Dam site (RM 184) downstream to the Three Rivers Confluence (RM 98).
- Lower Susitna River Segment: Three Rivers Confluence (RM 98) downstream to Cook Inlet (RM 0).

Each of the 11 study components that make up the Geomorphology Study has a component-specific study area often related to the three large-scale river segments identified above. The study area and river segments are shown on Figure 6.5-1. Identification of the study area that each study component addresses is provided in the discussion of each study component in Section 6.5.4, Study Methods.

6.5.4. Study Methods

The methods for each of the 11 Geomorphology Study components are presented in this section.

6.5.4.1. Study Component: Delineate Geomorphically Similar (Homogeneous) Reaches and Characterize the Geomorphology of the Susitna River

The goal of this study component is to geomorphically characterize the Project-affected river channels including determination of geomorphically similar reaches. Portions of this effort were performed in 2012 including development of the geomorphic classification system and initial delineation of geomorphic reaches. The study area is the length of the Susitna River from its mouth at Cook Inlet (RM 0), upstream to the proposed Watana Dam site (RM 184), and upstream of the proposed Watana Dam site, including the reservoir inundation zone and on upstream to the Maclaren River confluence (RM 260). The tributary mouths along the Susitna River and in the reservoir inundation zone that may be affected by the Project are also included in the study area.

One of the major factors that is relevant to the geomorphic characterization and subsequent classification of the Susitna River and the potential for the Project to affect geomorphology, and hence habitat, is changes in the volume of sediment in storage within discrete types of storage units, that can generally be separated into mid-channel and bank-attached units. Storage of sediment for varying durations within discreet types of storage zones is an integral part of any fluvial system (Schumm 1977; Montgomery and Buffington 1993). The types of sediment storage units and the rates of change within the storage zones provide a measure of the sediment flux within the system (Harvey et al. 2003; Harvey and Trabant 2006). Order-of-magnitude changes in sediment storage within a given reach of the river, or for the river as a whole, as well as the rates of change in the various types of sediment storage zones can be assessed by GIS-based comparisons of time-sequential aerial photography. Suitable aerial photography appears to be available for the 1950s, 1980s, and the present (2012).

On the Susitna River, the end members of a continuum could include long-duration sediment storage in vegetated islands and floodplains that persist for multiple decades at one end and short-duration sediment storage in braid bars that change on an almost daily basis at the other end of the continuum. Sediment storage is directly incorporated into the preliminary geomorphic classification developed for the Susitna River (Section 6.5.4.1.2.2.1). Within single channel (SC) reaches, sediment storage zones include unvegetated mid-channel bars, vegetated islands, and discontinuous and continuous vegetated floodplain segments. Within multiple channel (MC) reaches, sediment storage zones include unvegetated braid bars, vegetated islands, and floodplains.

6.5.4.1.1. Existing Information and Need for Additional Information

This effort will support the understanding of the conditions in the Susitna River by applying a geomorphic classification system based on form and process. It will also support efforts by other studies, including the Fish and Aquatics Instream Flow (Section 8.5), Riparian Instream Flow (Section 8.6), Characterization and Mapping of Aquatic Habitats (Section 9.9), and Ice Processes (Section 7.6) studies by providing a basis to stratify the river into reaches based on current morphology and their potential sensitivity to the Project. A delineation of the Susitna River into reaches was performed in the 1980s for the Middle Susitna River Segment (Trihey & Associates 1985) and the Lower Susitna River Segment(R&M Consultants, Inc. and Trihey & Associates 1985a).

6.5.4.1.2. Methods

This effort consists of identification of a geomorphic classification system, conducting the delineation of geomorphic reaches based on the identified classification system and characterization of the geomorphology of the Susitna River.

6.5.4.1.2.1. Identification and Development of Geomorphic Classification System

The first step in the geomorphic reach delineation effort is the identification of the system to be used to classify and delineate the reaches. Classification of the river segments is required to provide a basis for communication among the various disciplines and to identify relatively homogeneous river segments that can then be used as a basis for extrapolation of results and findings from more spatially-limited studies. Numerous river classifications exist (Leopold and Wolman 1957; Schumm 1963, 1968; Mollard 1973; Kellerhals et al. 1976; Brice 1981; Mosley 1987; Rosgen 1994, 1996; Thorne 1997; Montgomery and Buffington 1997; Vandenberghe 2001), but no single classification has been developed that meets the needs of all investigators. Several factors have prevented the achievement of an ideal geomorphic stream classification, and foremost among these has been the variability and complexity of rivers and streams (Mosley 1987; Juracek and Fitzpatrick 2003). Problems associated with the use of existing morphology as a basis for extrapolation (Schumm 1991) further complicates the ability to develop a robust classification (Juracek and Fitzpatrick 2003). For purposes of classifying the Susitna River, available classification systems are being reviewed, and a specific system is being developed that borrows elements from several classification systems. The classification scheme considers both form and process. Development of this system is being coordinated with the Fish and Aquatics Instream Flow Study (FA-IFS) (Section 8.5, Riparian Instream Flow Study (R-IFS) (Section 8.56, Ice Processes (Section 7.6), and Characterization and mapping of Aquatic Habitats (Section 9.9) so it is consistent with their needs. These studies may require further stratification to identify specific conditions of importance to their efforts, in which case these studies will further divide the river into subreaches. However, the overall reach delineations developed in the Geomorphology Study will be used consistently across all studies requiring geomorphic reach delineations.

6.5.4.1.2.2. Geomorphic Reach Delineation

The Lower Susitna River Segment (RM 0 to RM 98), the Middle Susitna River Segment (RM 98 to RM 184), and the Upper Susitna River Segment to the Maclaren River confluence (RM 184 to RM 260) will be delineated into large-scale geomorphic reaches (a few to many miles) with relatively homogeneous characteristics, including channel width, entrenchment, ratio, sinuosity, slope, geology/bed material, single/multiple channel, braiding index, and hydrology (inflow from major tributaries) for the purpose of stratifying the river into study segments. Stratification of the river into relatively homogeneous reaches will permit extrapolation of the results of sampled data at representative sites within the individual reaches.

Because there are several studies that required reach delineation for planning 2012 field activities, an initial delineation primarily based on readily available information (most recent high-quality aerials, bed profile from the 1980s, geomorphic descriptions from the 1980s, and geologic mapping) was developed in April 2012. As additional information is developed, such as current aerial photographs and transects, the delineation will be refined and the various morphometric parameters will be included in the delineation. Coordination with the Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3) Study is being conducted to obtain cross-section channel/floodplain data. Coordination with the Fish and Aquatics Instream Flow Study (FA-IFS)(Section 8.5), Riparian Instream Flow Study (R-IFS)(Section 8.6), Fluvial Geomorphic Modeling Study, and Ice Processes in the Susitna River Study (Ice Processes Study) (Section 7.6) is being conducted to ensure that the river stratification is performed at a scale appropriate for those studies.

A reconnaissance-level site visit of the Susitna River was conducted for a portion of the Susitna River in October, 2012. A more complete reconnaissance will be conducted in early 2013 after break-up. The 2012 reconnaissance was coordinated with other studies to provide an opportunity for multidisciplinary interaction. Representatives from the Fish and Aquatics Instream Flow Study (Section 8.5), Riparian Instream Flow Study (Section 8.6), Riparian Vegetation Study Downstream of Susitna-Watana Dam Study (Section 11.6) and Groundwater Study (Section 7.5) participated in the 2012 reconnaissance. The 2013 reconnaissance will take a similar multidisciplinary approach. For the 2013 reconnaissance it is anticipated that the Geomorphology Study team will be joined by representatives from the FA-IFS (Section 8.5), R-IFS (Section 8.6), Ice Processes Study (Section 7.6), and Characterization and Mapping of Aquatic Habitats Study (Section 9.9). The purpose of this site visit will be to provide key team members an overview of the river system. This will be extremely useful for all components of the geomorphology studies because it will permit team members to verify on the ground assessments that have been made from remotely sensed information.

6.5.4.1.2.2.1. 6.5.4.1.2.2.1 Initial Geomorphic Reach Classification System

Classification of the identified Upper, Middle and Lower Susitna River Segments into reasonably homogeneous reaches is required to provide a basis for extrapolation of the results of process-based analyses of existing conditions and predictions of likely geomorphic changes in response to the Project at selected study locations to those reaches. To support development of study plans for a variety of resource areas, an initial reach classification was performed with the information available in 2012. This classification will be reviewed and updated in 2013 if necessary as new information from the Geomorphology Study and Fluvial Geomorphology Modeling Study, as well as several other studies, becomes available. The initial geomorphic reach classification scheme is described below.

From a practical viewpoint, Schumm (2005) has suggested that rivers and streams can be divided into two principal types: regime and non-regime. Regime channels, which are defined as those that flow on and in sediments transported by the river during the present hydrologic regime, and whose morphology is controlled primarily by the interactions of the flow regime and the sediment supply (Leopold et al. 1964; Schumm 1977), can be further subdivided on the basis of patterns (straight, meandering, wandering, braided, anastomosing). Non-regime channels can be further subdivided into constrained, where the form of the channel is forced by non-alluvial factors such as bedrock, colluvium, glacial deposits or extreme flood deposits (Montgomery and Buffington 1997; Tinker and Wohl 1998; O'Connor and Grant 2003), or unstable, which can include degrading (Schumm et al. 1984; Darby and Simon 1999), aggrading (Schumm 1977) or avulsing (Schumm et al. 2000) channels.

Based on Schumm's (2005) classification scheme, the factors used in the initial geomorphic classification of the individual reaches of the Susitna River include the following:

1. Channel planform (single channel: straight, meandering; multiple channels: braided, anastomosing) – identified from topographic mapping, aerial photography
2. Constraints (bedrock, colluvium, moraines, alluvial fans, glaciolacustrine and glaciofluvial sediments) – identified from geologic mapping
3. Confinement (width of the floodplain and modern alluvium in relation to the width of the active channel(s)) – identified from geologic mapping, Light Detection and Ranging (LiDAR) based topography, hydraulic modeling
4. Gradient and bed materials – derived from various sources of survey data, 1980s data

Based on available information, the individual reaches within the three river segments were classified as follows:

Single Channel (SC):
SC1– Laterally confined with no sediment storage in bars, islands, or floodplain
SC2 – Laterally confined with limited sediment storage in mid-channel bars and non-continuous bank-attached floodplain segments
SC3 – Laterally confined with sediment storage in mid-channel bars, vegetated islands, and continuous floodplain segments

Multiple Channels (MC):
MC1 – Moderately wide floodplain with significant sediment storage in braid bars and vegetated islands
MC2 – Wide floodplain with significant sediment storage in braid bars and vegetated islands
MC3 – Wide floodplain width with vegetated floodplain segments separated by anastomosed channels with downstream base level controls
MC4 – Delta distributary channels

6.5.4.1.2.2.2. 6.5.4.1.2.2.2 Initial Geomorphic Delineation

Application of the classification scheme described above to the three river segments of the study area resulted in the geomorphic reaches and reach types presented in Table 6.5-1. Maps showing the geomorphic reaches are presented on Figure 6.5-2, 6.5-3, and 6.5-4 for the Upper, Middle, and Lower Susitna River segments, respectively. The Upper Susitna River Segment was divided into six reaches, with three reaches identified as SC1 reach type and three geomorphic reaches identified as SC2 reach type. The Middle Susitna River Segment was divided into eight reaches with one geomorphic reach classified as SC1 (Devils Canyon), five as SC2, one as SC3, and one as MC1/SC2 geomorphic reach types. The latter designation represents the fact that the downstream most geomorphic reach of the Middle Susitna River Segment, MR-8, is a transition reach from a single channel to multiple channel. The Lower Susitna River Segment was divided into six reaches with the upper two reaches classified as MC1, the next two reaches classified as MC3, the fifth reach classified as SC2, and the downstream-most reach classified as MC4.

It should be kept in mind that as more information becomes available, the geomorphic reach delineations and classifications will be reevaluated and adjusted if necessary.

6.5.4.1.2.3. Geomorphic Characterization of the Susitna River

Based on information collected and developed in support of the reach delineation (Section 6.5.4.1.2.1), mapping of current and historical (1980s and 1950s) fluvial geomorphic features (Section 6.5.4.4) and as part of the field studies conducted in the Fluvial Geomorphology Modeling Study (Section 6.6.4.1.2.9), the geomorphology of the Middle and Lower Susitna River Segments will be characterized. The characterization will be directed toward identifying processes and controls that create, influence and maintain the fluvial geomorphic features that comprise the river and floodplain and represent the important aquatic habitats that may be affected by the Project. The role of large woody debris, ice processes, floodplain vegetation and extreme events as well as the more typical hydrologic events and sediment loading will be considered in development of the understanding of the processes that create and influence the geomorphic features of the Susitna River. Of particular importance will be the features that represent both the within-channel (bars, islands, side channels) and the off-channel macrohabitats (side channels, side sloughs and upland sloughs) and the meso- and micro-scale habitats within these features.

Using the available geologic mapping, topographic mapping, recent (2012) and historical (1980s and 1950s) aerial photographs and the 2011 Mat-Su LiDAR in conjunction with fieldwork conducted in 2013 during the Focus Area fieldwork the following will be mapped and characterized:

- Geology of the Susitna River corridor with identification of controlling features such as locations where the river is laterally confined or vertically controlled
- Relic geomorphic forms from past glaciation, paleofloods and debris flow events with particular attention paid to coarse grained deposits that can serve as lateral or vertical controls
- Identify from aerials and aerial reconnaissance major locations of recent and historic mass wasting
- Overlay the mapping of areas of frequent ice jam events from the Ice Processes Study (Section 7.6)
- Identification of coarse deposits at tributary confluences that may influence the profile of the Susitna River

Using this information as well as thalweg profiles generated from the cross-section and bathymetric surveys performed in 2012 and 2013, aerial photo analysis of channel change from the 1950s to 2012, bed material sampling, floodplain soil profiles, LWD mapping and characterization, dating of floodplain surfaces, an understanding of the fluvial processes that govern the behavior of the Middle and Lower Susitna River will be developed. This understanding will be reviewed and updated as various study results are made available. This would include information such as determination of flows required for bed material mobilization, effective discharge, comparison of 1980s and current cross-section profiles, sediment balance, and 1-D bed evolution modeling, This will provide a basis for developing a thorough understanding of the current river system dynamics and thus the framework for interpreting potential Project effects which will be derived from the results of modeling and other analyses that reflect the changes in the hydrologic and sediment supply regimes due to construction and operation of the Project.

6.5.4.1.2.4. Information Required

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

- Historical aerial photographs
- Information on bed material size
- Location and extent of lateral and vertical geologic controls
- Drainage areas of major tributaries
- Topographic mapping, including USGS survey quadrangle maps and LiDAR
- Geologic mapping
- 1980s cross-sections

The following additional information will need to be obtained to conduct this study:

- Current high resolution aerial photography
- Field observations made during a site reconnaissance
- Extended flow record for the Susitna River and tributaries being developed by USGS
- Current cross-sections
- Profile of the river (thalweg or water surface)
- Field data collected in the Fluvial Modeling Geomorphology Study

6.5.4.1.3. Study Products

The results of the Delineate Geomorphically Similar Reaches study component will be included in the Geomorphology Report. Information provided will include the following:

- A geomorphic classification system developed specifically for the Susitna River that considers both form and physical processes.
- A delineation of the Susitna River into reaches of similar geomorphic characteristics, which has been coordinated with other relevant studies (FA-IFS (Section 8.5), R-IFS (Section 8.6), Ice Processes (Section 7.6), and Characterization and Mapping of Habitat (Section 9.9) studies). The delineation will include broad large-scale reaches and further delineation into sub-reaches.
- Tables of morphometric parameters describing the physical characteristics of each reach developed from the analysis of aerial photographs, LiDAR, bed profiles, bed material samples, geologic mapping, and transect surveys.

In addition, an ArcGIS shapefile will be provided with the following information:

- Mapping of the segments and reaches overlaid on recent aerial photography and topographic mapping.

6.5.4.2. Study Component: Bedload and Suspended Load Data Collection at Tsusena Creek, Gold Creek, and Sunshine Gage Stations on the Susitna River, Chulitna River near Talkeetna and the Talkeetna River near Talkeetna

The goal of this study component is to empirically characterize the Susitna River sediment supply and transport conditions. This effort is being performed by USGS. The effort described is for 2012 and 2013. The effort in 2013 may be modified in 2013 based on experience gained from the 2012 work. The study covers the Susitna River from RM 84 (Sunshine Station) upstream to RM 182 (Tsusena Gage) and the Chulitna River and Talkeetna Rivers near their confluences with the Susitna River. Figure 6.5-5 identifies the location of the study gages and other existing and historical USGS gages in the Susitna River basin. The collection of the sediment transport data was completed in 2012 per the 2012 study plan. The data will be available from the USGS in early 2013. The Talkeetna River near Talkeetna was added for 2013 after review of 1980s data and after comments from agency review of the PSP. Suspended sediment and flow were collected at the Talkeetna by the USGS as part of the USGS National monitoring network.

6.5.4.2.1. Existing Information and Need for Additional Information

The collection of the data described in this study component will supplement sediment transport data collected in the 1980s. The additional data are needed to determine if historical data can be used to reflect current conditions or if there have been shifts in the rating curves that might be related to climate change, glacial surges, or other as yet unidentified causes and to address some of the data gaps identified in the Susitna Water Quality and Sediment Transport Data Gaps Analysis Report (URS 2011).

The USGS published a summary report on sediment transport data collected in the 1980s (USGS 1987). The data collected includes suspended sediment measurements and bedload measurements for the Susitna River near Talkeetna, Susitna River at Sunshine, Susitna River at Susitna Station, Chulitna River near Talkeetna, Talkeetna River near Talkeetna, and Yenta River near Susitna Station. The suspended load is divided into a silt/clay component and a sand component. The bedload transport is divided into two fractions: sand and gravel. The report also presents rating curves developed from data collected between 1981 through 1985. The USGS estimated the annual sediment load for Water Year 1985 for the various components of the sediment load by applying the rating curves to the mean daily flow record.

Table 6.5-2 presents the sediment loads estimated by the USGS for Water Year 1985 (October 1984 through September 1985). This information suggests that the Chulitna River contributes the majority of the sediment load at the Three Rivers Confluence. The relative contributions are 61 percent for the Chulitna River, 25 percent for the Susitna River, and 14 percent for the Talkeetna River. Of note is the relatively small amount of the gravel load contributed by the Susitna River to the Three Rivers Confluence (about 4 percent, compared to 83 percent from the Chulitna River and 13 percent from the Talkeetna River, based on the 1985 data).

This study will provide information on current transport conditions and support assessment of Project effects on sediment supply. Sediment data derived from the gages will be used to provide sediment inputs at model boundaries. This information will be used by several study components in this study as well as the Fluvial Geomorphology Modeling below Watana Dam Study.

6.5.4.2.2. Methods

The following scope of work was provided by USGS:

- Operate and maintain the stream gages.
- Maintain datum at the site.
- Record stage data every 15 minutes.
- Make discharge measurements during visits to maintain the stage-discharge rating curve and to define the winter hydrograph.
- Store the data in USGS databases.
- Collect at least five suspended sediment samples at Susitna River above Tsusena Creek, at Gold Creek, and at Sunshine; the Chulitna River near Talkeetna and the Talkeetna River near Talkeetna during the year for concentration and size analysis (collect in 2012 and 2013).
- Collect at least five bed material samples during the year at Susitna River above Tsusena Creek, at Gold Creek, and at Sunshine; and the Chulitna River near Talkeetna for bedload transport determination and size analysis (collect in 2012 and 2013, except Talkeetna River near Talkeetna will be collected in 2013 only).
- Collect at least five bedload samples during the year at Susitna River at Gold Creek, Susitna River at Sunshine, Susitna River above Tsusena Creek, and the Chulitna River near Talkeetna for bedload transport determination and size analysis (collect in 2012 and 2013, except Talkeetna River near Talkeetna will be collected in 2013 only).
- Operate and maintain the stream gages at the Susitna River near Denali and the Chulitna River near Talkeetna (2012 and 2013).
- Operate a stage-only gage at a site upstream from Deadman Creek. Logistics at this site may preclude continuous operation or telemetry of the information (2012 and 2013).
- Compile suspended and bedload data, including calculation of sediment transport ratings and daily loads, in a technical memorandum delivered to AEA during federal fiscal year (FFY) 2013 for the 2012 data and FFY 2014 for the 2013 data, and as early as March of the following year, if possible. Provisional results from sampling will be available as soon as lab data are available. Provisional results from sediment load computations will be made available as soon as possible.

The bedload and suspended sediment data will be combined with existing rating curves to identify the differences and similarities between the historical and current data sets. This information will be used to evaluate whether the historical data sets are representative of current conditions in the Susitna River at Gold Creek, the Susitna River at Sunshine, the Chulitna River near Talkeetna and the Talkeetna River near Talkeetna. If the historical data are not representative of current conditions, a decision will be made as to whether the 1980s data may be adjusted or shifted to represent current conditions or whether only the current data should be used in developing sediment transport relationships.

Based on review of the 1980s sediment transport data, including the information previously presented in Table 6.5-2, the Talkeetna River is a significant source of sediment to the Lower Susitna River Segment. Therefore, collection of sediment transport data for the Talkeetna River near Talkeetna will be conducted in 2013. This will allow for better understanding of the sediment transport balance in Geomorphic Reach LR-1 (the portion of the Susitna River between the Three Rivers Confluence and Sunshine Station).

6.5.4.2.3. Study Products

The results of the Bedload and Suspended Load Data Collection at Tsusena Creek, Gold Creek, and Sunshine Gage Stations on the Susitna River, and Chulitna River near Talkeetna and the Talkeetna River near Talkeetna and Sunshine gage stations study component will be included in the Geomorphology Report. Information provided will include the following:

- Calculation of discharge, suspended sediment discharge, and bedload discharge.
- Tabulation of all discharge, suspended sediment, bedload, and bed material sampling results.
- Data sheets reflecting field measurements.
- Comparison of historical and 2012 sediment transport measurements to determine if historical sediment transport rating curves can be expected to accurately represent current conditions.
- Narrative on data collection activities including description of methods, any difficulties encountered, and recommendations for data collection in 2013.
- Posting of near real-time stage and discharge data on the USGS website: http://waterdata.usgs.gov/ak/nwis/.
- Publication of the data in the USGS annual Water-Resources Data for the United States report (http://wdr.water.usgs.gov/).

In addition, an ArcGIS shapefile will be provided with the following information:

- Location of gage stations and measurement transects (if different from gage location).

6.5.4.3. Study Component: Sediment Supply and Transport Middle and Lower Susitna River Segments

The objective of this study component is to characterize the sediment supply and transport conditions in the Susitna River between the proposed Watana Dam site (RM 184) and the Susitna Station gage (RM 28). This includes the mainstem Susitna River and its tributaries. The Three Rivers Confluence (RM 98) separates the Middle Susitna River Segment from the Lower Susitna River Segment. Initial estimates for the Lower Susitna River Segment Sediment Balance are being developed in 2012 as part of the Reconnaissance-Level Assessment of Project Effects on Lower and Middle Susitna River Segment (Section 6.5.4.6). The remaining efforts, which include refined estimates of the Middle Susitna River Segment sediment balance, bed material mobilization, and effective discharge, will be conducted in 2013. The 2013 effort will provide estimates of sediment supply that will be used in the bed evolution modeling efforts described in Section 6.6.

6.5.4.3.1. Existing Information and Need for Additional Information

The Project will reduce sediment supply to the reach of the Susitna River downstream from the dam, and will also alter the timing and magnitude of the flows that transport the sediment. Information provided in the Pre-Application Document (PAD) (AEA 2011) suggests that peak flows may be reduced in magnitude and occur later in the season, and the flows will tend to be higher during the non-peak flow season under Project conditions. Sediment transport data are available along the mainstem Susitna River and several of the major tributaries between the proposed Watana Dam site (RM 184) and Susitna Station (RM 28) (URS 2011) that can be used to perform an initial evaluation of the sediment balance along the study reach under existing conditions. The results of this study component will provide the initial basis for assessing the potential for changes to the Middle and Lower Susitna River segments' sediment balance, and the associated changes to geomorphology, because it will permit quantification of the magnitude in the reduction of sediment supply below the dam. The studies will also support the Fluvial Geomorphology Modeling below Watana Dam Study through development of sediment supply information that will be required as input to the model.

6.5.4.3.2. Methods

The methods section is divided into five subsections: (1) Initial Lower Susitna River Segment Sediment Balance, (2) Middle Susitna River Segment Sediment Balance, (3) Characterization of Bed Material Mobilization, (4) Effective Discharge, and (5) Information Required.

Development of the sediment balance for both the Lower Susitna River Segment (RM 98 to RM 28) and Middle Susitna River Segment (RM 184 to RM 98) will consider various techniques to characterize the sediment supply to each reach, the sediment transport capacity through the reaches, and deposition/storage within the reaches. Sources of sediment supply are expected to include the mainstem Susitna River, contributing tributaries, and identified locations of mass wasting. Potential procedures to estimate sediment supply include the use of regional sediment supply relationships (e.g., regression equations based on watershed area) and calculation of differences in sediment loads between gaging stations. While it is recognized that the gages are spatially separated, the comparison of the loads at the gages will permit an assessment of whether there is significant storage or loss of sediment between gages. If the data indicate that there is little difference between the gages, then it can be reasonably concluded that there is sufficient supply of sediment within the reach between gages to support an assumption of transport capacity limitation rather than supply limitation. The sediment transport measurements collected by USGS, both historical and current, will be used to develop bedload and suspended load rating curves to facilitate translation of the periodic instantaneous measurements into yields over longer durations (e.g., monthly, seasonal, and annual). Since gradations of transported material will be available, the data will allow for differentiation of transport by size fraction.

The sediment balance will be quantified by developing sediment load versus water discharge rating curves for each portion of the sediment load (i.e., wash load, total bed material load, bedload) using the available data or transport capacity calculations based on the hydraulic modeling results, as appropriate. The rating curves will then be integrated over the relevant hydrographs to estimate the total sediment load, and the resulting total sediment loads will then be compared to determine if each segment of the reach between the locations represented by the rating curves is net aggradational (i.e., more sediment is delivered to the reach than is carried past the downstream boundary) or degradational (i.e., more sediment is carried out of the reach than is delivered from upstream and lateral sources).

Previous studies have documented the potential for bias in suspended load rating curves due to scatter in the relationship between sediment concentration or load and flow (Walling 1977a). Part of the scatter is often caused by hysteresis in the sediment load versus discharge relationship, where the loads on the rising limb are higher than on the falling limb due to availability of material and coarsening of the surface layer during the high-flow portion of the hydrograph (Topping et al. 2010). Bias is also introduced in performing linear least-squares regressions using logarithmically-transformed data and then back-transforming the predicted sediment loads to their arithmetic values (Walling 1977b; Thomas 1985; Ferguson 1986, Koch and Smillie 1986). The hysteresis effect can be accounted for by applying separate (or perhaps, shifting) rating curves through rising and falling limbs of flood hydrographs (Guy 1964; Walling 1974; Wright et al. 2010). Bias in the regression equations can be removed using the Minimum Variance Unbiased Estimator (MVUE) bias correction for normally distributed errors, or the Smearing Estimator (Duan 1983) when a non-normal error distribution is identified. These methods were recommended by Cohn and Gilroy (1991) and have been endorsed by the USGS Office of Surface Water (1992). Once the sediment measurements are available for review, the potential for bias in the sediment rating curves will be considered and addressed as appropriate.

The rating curves for the mainstem Susitna stations, for gaged tributary stations, and those developed for contributing ungaged areas between stations will be used to develop the sediment balance for the pre-Project hydrology for representative wet, average, and dry years and warm and cold Pacific Decadal Oscillation (PDO) phases. (The inclusion of the warm and cold PDO phases was requested by NOAA-NMFS and USFWS in the May 31, 2012, study requests; the rationale for the request was discussed at the June 14, 2012, Water Resources TWG meeting and it was agreed that the PDO phases would be included in the suite of representative annual hydrologic conditions.) The sediment balance will be calculated based on the assumption that the sediment load in the Susitna River is currently in a state of equilibrium. To develop the sediment balance for the post-Project condition, the historical (pre-Project) sediment rating curve developed for the river immediately below the Watana Dam site (Tsusena Creek) will be reduced by 100 percent for the bedload and 90 percent for the suspended load on a preliminary basis. If the reservoir trap efficiency analysis discussed below indicates that a substantially different amount of sediment will pass through the reservoir, the sediment load curves will be adjusted accordingly.

6.5.4.3.2.1. Initial Sediment Balance (Lower Susitna River Segment)

The primary purpose of the Initial Sediment Balance evaluation for the Lower Susitna River Segment performed in 2012 is to help evaluate the potential for the Project to alter sediment transport conditions and channel response in the Lower Susitna River Segment. The results of this evaluation will provide the basis for assessing the need to perform additional 1-D and 2-D modeling and other studies related to potential channel change downstream from RM 75. The Lower Susitna River Segment Sediment Balance depends on the sediment supply from the Middle Susitna River Segment of the Susitna, the Chulitna and Talkeetna rivers, and other local tributaries along the reach, and the transport capacity along the reach. The total sediment supply to the Lower Susitna River Segment under pre-Project conditions is being evaluated using the sediment rating curves developed from the historical data (and 2012 data, if available) for the

Susitna River at Gold Creek and near Talkeetna gages on the mainstem, and the below canyon near Talkeetna and near Talkeetna gages on the Chulitna and Talkeetna rivers, respectively. The historical rating curves for the Sunshine and Susitna Station gages, updated with any new sediment transport data collected by USGS under the Bedload and Suspended Load Data Collection at Tsusena Creek, Gold Creek, and Sunshine Gage Stations on the Susitna River, the Chulitna River near Talkeetna and the Talkeetna River near Talkeetna (Section 6.5.4.2), are being used to estimate the sediment loads in the river in the vicinity of RM 84 and RM 26.

6.5.4.3.2.2. Middle Susitna River Segment Sediment Balance

A more detailed sediment balance will also be developed in 2013 for the Middle Susitna River Segment between the proposed Watana Dam site (RM 184) and the Three Rivers Confluence (RM 98/98.5) using the available data, and when available, the hydraulic and sediment transport modeling results for this portion of the study reach. Estimates of the contributions to the sediment supply from the Upper Susitna River Segment identified mass wasting locations, bank erosion, and contributing tributaries downstream of the dam will be an important aspect of this analysis. An estimate of the volume of sediment from bank erosion will be made utilizing a comparison of the channel location and area developed in the Assess Geomorphic Change Middle and Lower Susitna River Segments study component (see Section 6.5.4.4) and comparison of cross-sections surveyed in the 1980s and in 2012. The cross-sections may also be used to determine if there has been a loss or gain in sediment supply from aggradation or degradation of the bed in the Middle Susitna River Segment. Tributary sediment loading will be estimated as part of the Fluvial Geomorphology Modeling Study (see Section 6.6.4.1.2.6).

Potential procedures to estimate the Middle Susitna River Segment sediment supply include the use of watershed area and regional sediment supply relationships and the determination of the differences on a seasonal or annual basis between the sediment loads estimated for the Susitna River at the Tsusena Creek and Gold Creek gage locations. Past USGS sediment data may be available for Indian River and Portage Creek, which could also be used to assist in the estimation of the Middle Susitna River Segment sediment supply inputs. If data being collected by USGS for the Bedload and Suspended Load Data Collection at Tsusena Creek, Gold Creek, and Sunshine Gage Stations on the Susitna River, the Chulitna River near Talkeetna, and the Talkeetna River near Talkeetna are available in time for this analysis, the 2012 data from Tsusena Creek will be compared to the 2012 Gold Creek data to estimate the sediment inflow between these two locations. This will allow development of a sediment rating curve from the 1985 data for the Susitna River at Tsusena Creek (representative of sediment transport at the Watana Dam site).

6.5.4.3.2.3. Characterization of Bed Material Mobilization

Bedload transport, particularly for the gravel and cobble size-fractions, is the key process that determines the dynamic behavior of the river bed both in the mainstem and in the side channel that is important to fish habitat. In coarse-grained rivers such as the Susitna River, a coarse surface layer is present that is typically not mobile over the full range of flows; thus, significant bedload transport does not occur. An important part of the geomorphology study will involve quantification of the range of flows over which bed mobilization occurs, and the potential change in duration of those flows under Project conditions. The approximate discharge at which bedload mobilization begins in the Susitna River near the proposed dam and at selected locations in the Middle and Lower Susitna River Segments will be estimated using the USGS empirical sediment rating curves, incipient motion calculations (i.e., estimates of the critical discharge at which bed material begins to mobilize), and field observations. The resulting estimates of the critical discharge will be used to assess the frequency and duration of bed mobilization under the pre- and post-Project condition hydrology. This will be performed on both a monthly and annual basis at the selected locations for a range of flow years.

The concept of incipient motion as advanced by Shields (1936) relates the critical shear stress for particle motion (τ_c) to the dimensionless critical shear stress (τ^*_c) and the unit weight of sediment (γ_s), the unit weight of water (γ), and the median particle size of the bed material (D_{50}). One key limitation of this relation is the specification of τ^*_c (often referred to as the Shields parameter), which can range by a factor of three (Buffington and Montgomery 1997). The large range in published values for τ^*_c is caused largely by the difficulty in defining and identifying when bed material motion actually begins. To work around this limitation, Parker (Parker et al. 1982) defined a reference Shields stress (τ^*_r) that corresponds to a dimensionless transport rate $W^* = 0.002$, corresponding to a very low, but measurable transport rate. For this relationship, W^* is a function of the unit bedload and the total boundary shear stress, both of which are relatively simple parameters to calculate from field data if bedload and discharge measurements are included. (In the NOAA-NMFS and USFWS Study Plan Requests, it was proposed that the bed material mobilization analysis be calibrated based on the use of tracers. This topic was discussed at the Water Resources TWG held on June 14, 2012. AEA's consultants indicated that the use of tracers in a large river such as the Susitna would not be practical due to the difficulty in locating the tracers after mobilization. Therefore, the use of tracers is not included in the proposed study plan.)

Another limitation of the original Shields equation is that is does not consider hiding effects in substrate with a broad range of particle sizes. Hiding effects result in mobilization of the larger particles at lower shear stresses than would occur in uniform-sized substrate. This is due to the larger substrate projecting farther into the flow than if they were surrounded by similarly sized particles. Conversely, the smaller particles are mobilized at higher-than-expected shear stresses because they are sheltered by the larger particles. Meyer-Peter, Muller, and Einstein recognized this effect in developing their original bedload transport equations, and numerous researchers have continued to evaluate and provide relationships that account for this effect (Parker et al, 1982; Andrews 1978; Neill 1969; and many others). In a general sense, these relationships indicate that the original Shields equation only applies directly to the median (D_{50}) substrate size, and the substrate mixture is effectively immobile at shear stresses less than that required to mobilize the median size. These relationships do, however, indicate varying degrees of selective transport in which at least some of the finer particles mobilize at shear stresses less than that required to mobilize the median size. The strength of this effect is marginally different among the different relationships, most likely due to difference in the specific characteristics of material used to develop them. For purposes of this study, the Parker et al. (1982) relationship will most likely be used because it applies to relatively clean (i.e., low percentages of sand and finer material) gravel and cobble substrate. If it is found that the substrate in specific areas contains more than about 20 percent sand, the Wilcock and Crowe (2003) relationship will be used because it takes into account effects of large amounts of sand in increasing the mobility of the gravel/cobble fraction.

Because of the uncertainty in defining appropriate values of the Shields critical shear stress for the median particles size, bed material mobilization at various locations along the study reach will be characterized using the reference shear approach of Parker, following the methods of Mueller et al. (2005). Data collected by USGS, which will include the necessary series of coupled flow and bedload transport measurements, will be used to formulate a series of bedload rating curves. These curves will then provide a basis for estimating τ^* that corresponds to a dimensionless transport rate $W^* = 0.002$ for bed material mobilization.

6.5.4.3.2.4. Effective Discharge

The concept of effective discharge, as advanced by Wolman and Miller (1960), relates the frequency and magnitude of various discharges to their ability to do geomorphic work by transporting sediment. They concluded that events of moderate magnitude and frequency transport the most sediment over the long-term, and these flows are the most effective in forming and maintaining the planform and geometry of the channel. Andrews (1980) defined the effective discharge as "*the increment of discharge that transports the largest fraction of the annual sediment load over a period of years.*"

Estimates of the potential change in effective discharge between historic and post-Project conditions provides a basis for predicting whether the bankfull channel capacity will change due to the Project, and if so, the likely trajectory and magnitude of the changes. The concept of effective discharge, as advanced by Wolman and Miller (1960), relates the frequency and magnitude of various discharges to their ability to do geomorphic work by transporting sediment. They concluded that events of moderate magnitude and frequency transport the most sediment over the long-term, and these flows are the most effective in forming and maintaining the planform and geometry of the channel.

Alluvial rivers adjust their shape in response to flows that transport sediment. Numerous authors have attempted to relate the effective discharge to the concepts of dominant discharge, channel-forming discharge, and bankfull discharge, and it is often assumed that these discharges are roughly equivalent and correspond to approximately the mean annual flood peak (Benson and Thomas 1966; Pickup 1976; Pickup and Warner 1976; Andrews 1980, 1986; Nolan et al. 1987; Andrews and Nankervis 1995). Quantification of the range of flows that transport the most sediment provides useful information to assess the current state of adjustment of the channel and to evaluate the potential effects of increased discharge and sediment delivery on channel behavior. Although various investigators have used only the suspended sediment load and the total sediment load to compute the effective discharge, the bed material load should generally be used when evaluating the linkage between sediment loads and channel morphology because it is the bed material load that has the most influence on the morphology of the channel (Schumm 1963; Biedenharn et al. 2000).

For purposes of this study, the effective discharge will be computed for the Susitna River below Tsusena Creek, at Gold Creek, and at Sunshine. This will be performed by dividing the full range of flows at each location into at least 30 logarithmic classes (Biedenharn et al. 2000) and then computing the sediment transport capacity at the average discharge within each flow class using the previously described rating curves. The bed material transport in each flow class over the long-term will be determined by multiplying the individual transport rates by the corresponding flow duration, which is derived from mean daily flow duration curves. The effective discharge is the flow, or range of flows, where the incremental bed material transport is greatest. Effective discharges will be determined for both the pre- and post-Project conditions. If the post-Project value is lower than the pre-Project value, it provides an indication that the morphology of the channel will change because there is a reasonably well identified relationship between the effective discharge and the size of the channel.

6.5.4.3.2.5. Information Required

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

- Current and historical aerial photographs.
- Historical suspended sediment and bedload data for the Susitna River and contributing tributaries.
- Flow records for the Susitna River and contributing tributaries.

The following additional information will need to be obtained to conduct this study:

- Suspended and bedload data for the Susitna River at Tsusena Creek and Gold Creek being performed by USGS.
- Extended flow record for the Susitna River and gaged tributaries within the study area being developed by USGS.
- Estimated flows for the ungaged tributaries within the study area.
- Extended flow records for the Susitna River and tributaries being developed by USGS.
- Collection of bed material samples throughout the Middle and Lower River Segments, as well as contributing tributaries.
- Hydraulic conditions in the Susitna River from the Hydraulic Routing Model.
- Surveys of channel geometry for contributing tributaries to simulate hydraulic conditions.

6.5.4.3.3. Study Products

The results of the Sediment Supply and Transport Middle and Lower Susitna River Segments study component will be included in the Geomorphology Report. Information provided will include the following:

- Tabular and graphical summary of available discharge and sediment transport data.
- Description of procedures used to develop sediment transport rating curves from suspended load and bedload data, including development of curves for specific sediment size-classes.
- Graphical and numerical relationships for sediment discharge rating curves.
- Narrative describing procedures used to perform effective discharge and bed mobilization calculations.
- Determination of total sediment load delivered to the Susitna River for pre- and post-Project conditions (the latter based on preliminary assumption that 100 percent bedload

and 90 percent of suspended load will be trapped behind the Project dam; this estimate can be refined if the trap efficiency analysis indicates substantially different results).

- Estimate of Middle Susitna River Segment sediment supply inputs from local tributaries and other sources.
- Tabular and graphical representation and comparison of the duration and frequency of bed material mobilization in the Middle and Lower Susitna River Segments for pre- and post-Project conditions.
- Estimates of the effective discharge for the pre- and post-Project conditions, and the likely effects on channel morphology.
- Estimates of the overall sediment transport balance along the reach and the likely effects on channel morphology, particularly with respect to aggradation/degradation trends and changes in braiding potential. In reaches with net sediment deficit, results from the bed mobilization analysis will also be considered in assessing degradation tendencies.

6.5.4.4. Study Component: Assess Geomorphic Change Middle and Lower Susitna River Segments

The goal of this study component is to compare existing, 1980s and 1950s geomorphic feature data from aerial photo analysis to characterize channel stability and change and the distribution of geomorphic features under unregulated flow conditions. The effort will include use of the best available aerial photographs from the 1950s to provide a longer range assessment of channel change. The acquisition of the current aerials for the Middle Susitna River Segment was initiated in 2012 as part of the Aquatic Habitat and Geomorphic Mapping of the Middle Susitna River Segment Using Aerial Photography study (Section 6.5.4.5) and for the Lower Susitna River Segment as part of the Riverine Habitat Area versus Flow Lower Susitna River Segment (Section 6.5.4.7). Digitization of the geomorphic features from the 1980s and 2012 aerial, determination of geomorphic feature areas, and qualitative assessment of channel change were conducted in 2012 for the flows that aerials could be obtained. Due to a combination of weather and flows conditions, not all aerials originally planned for acquisition in 2012 were obtained. The acquisition of the aerials is discussed further in Sections 6.5.4.4.2.1 and 6.5.4.4.2.2. The remainder of the effort described will be conducted in 2013. The study area extends from the mouth of the Susitna River (RM 0) at Cook Inlet to the proposed Watana Dam site (RM 184).

6.5.4.4.1. Existing Information and Need for Additional Information

An analysis of the Middle Susitna River Reach geomorphology and how aquatic habitat conditions changed over a range of stream flows was performed in the 1980s using aerial photographic analysis (Trihey & Associates 1985). A similar analysis was performed for the Lower Susitna River Segment (R&M Consultants, Inc. and Trihey & Associates 1985a). The1980s Lower Susitna River Segment study also included an evaluation of the morphologic stability of islands and side channels by comparing aerial photography between 1951 and 1983. An analysis of channel changes of the Middle River was presented in *Geomorphic Change in the Middle Susitna River Since 1949* (Labelle et al. 1985). In this document, aerial photographs and other data from the late 1940s through the early 1980s was evaluated to determine historical change in the Middle Susitna River Segment including the important off-channel macrohabitats identified in the 1980s studies (side channels, side sloughs, and upland sloughs).

The AEA Susitna Water Quality and Sediment Transport Data Gap Analysis Report (URS 2011) states that "if additional information is collected, the existing information could provide a reference for evaluating temporal and spatial changes within the various reaches of the Susitna River." The gap analysis emphasizes that it is important to determine if the conditions represented by the data collected in the 1980s are still representative of current conditions and that at least a baseline comparison of current and 1980s-era morphological characteristics in each of the identified sub-reaches is required.

Understanding existing geomorphic conditions and how laterally stable/unstable the channels have been over recent decades provides a baseline set of information needed to provide a context for predicting the likely extent and nature of potential changes that will occur due to the Project. Results of this study may also be used in the Riparian Instream Flow (Section 8.6) and Ice Processes (Section 7.6) studies to provide the surface areas of bars likely to become vegetated in the absence of ice-cover formation. This would be accomplished by evaluating the areas of exposed bars within river segments over a range of flows and developing exposed bar area discharge curves that could then be used to assess the impacts of the Project flows on bar inundation by both flows and ice. Increases in areas that would be both inundation- and ice-free are likely to permit vegetation establishment and persistence.

Determination of the rate that area occupied by the channel is converted to floodplain and islands, and area occupied by floodplain and islands is converted to channel will provide information useful in identifying LWD recruitment rates and characterizing floodplain dynamics important to the Riparian Instream Flow Study (Section 8.6). Therefore, a "turnover" analysis is included as part of this study component.

6.5.4.4.2. Methods

This study component has been divided into the Middle and Lower Susitna River Segments because the available information differs. The analysis of geomorphic change will be conducted for a single representative discharge.

6.5.4.4.2.1. Middle Susitna River Segment

The orthorectified digital images of the historical 1983 black and white aerial photographs for the Middle River at a flow of 12,500 cfs were acquired for the area from RM 98 to RM 150 (RM 150 was the limit of the coverage from the 1980s effort). Additional historical aerials were acquired to allow delineation of the geomorphic features from RM 150 to 184. The September 6, 1983, aerials flown at a flow of 12,500 cfs, as measured at the Gold Creek Gage, were used for the historical condition. From RM 98 to RM 150, color aerials from July 19–20, 1980, at flows ranging between 31,800 and 35,900 cfs (as measured at Gold Creek), not collected as part of the original Susitna Project effort, were used to digitize geomorphic features from RM 150 to RM 184. The 1980s orthorectified digital images of historical aerials were also acquired for the Upper River from RM 184 to RM 260. The aerials from RM 184 to RM 252 were from the same July19–20, 1980 acquisition as the RM 150 to RM 184 aerials. From RM 252 to RM 260, color aerials from August 24, 1981 were obtained. The flow at Gold Creek on this date was 35,000 cfs.

Acquisition of the 2012 aerials was targeted at a flow of 12,500 cfs; however, due to a combination of late season high flows and poor weather, the actual 2012 aerials were collected at flows of 13,300 cfs for RM 98 to RM 135 and 18,100 cfs for RM 136 to RM 184. Table 6.5-3 summarizes the 2012 aerial photo data collection effort for the Lower, Middle, and Upper Susitna River segments and indicates the RMs and discharges at which various sets of photos were obtained. The higher flow for the RM 136 to RM 184 should not create problems with digitizing geomorphic features, except that the areas of the gravel bars will require adjustment prior to comparison with 1980s information for use in 2013. Completion of aerial collection at the targeted flows will be performed in 2013, so the final information is expected to be based on flows closer to the target of 12,500 cfs.

In 2012, for the both the 1983 and 2012 aerials, each feature was digitized as a polygon (without slivers) using ArcGIS software. Associated metadata were developed for both sets of digitized geomorphic features. The primary geomorphic features that are visible between the 1980s and current images, including the main channel, side channels, and sloughs were digitized from the aerial database just described. In addition, the presence and extent of mid-channel bars, vegetated bar areas, and changes at tributary deltas were digitized.

The information developed from digitizing the aerials is being used to analyze and compare the geomorphology for 1980s and current conditions. From RM 98 to RM 184, Geographic Information System (GIS) software is being used to compare the 2012 versus 1980s total surface area associated with each geomorphic feature. Results will be compiled into tables and graphs, as appropriate, to show the difference in surface areas of the feature types between 2012 and the 1980s photography. The lead geomorphologist has trained the staff performing the digitization to ensure appropriate application of the geomorphic definitions. Since this 34-mile river segment below the proposed Watana Dam site (RM 150 to RM 184) was not analyzed in the 1980s, the historical aerials are at a higher discharge, 30,000 cfs compared to 12,500 cfs, and the area of exposed gravel will not be comparable to the 2012 aerials at a lower flow without adjustment. It may be more appropriate to compare this 1980s RM 150 to RM 184 information with the results of the 2012 aerials collected at 23,200 cfs. A final decision on the 2012 aerials used from RM 150 to 184 for comparison with the 1980s will be made in 2013 after the 2013 supplemental aerial photo acquisition effort is conducted. (The 2013 supplemental aerial photo acquisition effort will be performed to fill in flow rates and areas that were scheduled for collection in 2012 but were not collected due to a combination of weather and flow conditions.)

In 2013, orthorectified digital versions of historical 1950s aerials will be acquired and the geomorphic features digitized. Acquisition of these aerials and performing the effort is dependent on locating a set of historical aerials from the 1950s or early 1960s that are of sufficient quality to provide for meaningful comparison between the other two datasets (1980s and current).

The change in channel planform over the length of the river (main channel location, side channel location, bars, channel and side channel width, channel and side channel location) will first be qualitatively assessed between the 1980s and 2012. This will be performed to assist in selection of the proposed Focus Areas. The geomorphic reach delineations will be reviewed in terms of the information on channel change and geomorphic reach limits adjusted if necessary to properly characterize channel stability. Reaches will be identified that are relatively stable versus those that are more dynamic. Reaches that would be most susceptible to channel change (e.g., width or planform change) with changes in the flow or sediment regime resulting from the Project or Project operations will be qualitatively identified because these are currently the most dynamic.

In 2013, a quantitative evaluation of channel change in the Middle River will be performed by conducting a “turnover” analysis (Note: the turnover analysis was added to the RSP as a result of comments on the PSP from the EPA submitted November 14, 2012). The digitized maps of the geomorphic features will be used to determine how much of the area covered by water in the 1950s and 1980s is land in 2012 versus still covered by water, taking into account river stage for the aerials not collected at ~12,500 cfs, and how much of the area covered by water today was land versus covered by water in the 1980s and 1950s. This analysis will be performed on a geomorphic reach basis. This information will be used to calculate a “turnover rate” (water to land and land to water, in acres per year) for each reach, for the periods between the 1950s and the1980s, and between the 1980s and 2012 aerial imagery. The resulting reach-scale data will be used to define the reach-scale turnover rate values. The resulting quantitative data on turnover rate will be compared with hydrologic conditions, events at upstream glaciers, and other potential factors such as the occurrence of earthquakes to determine potential differences in the turnover rates from the two periods. Spatially, the turnover rates will be compared between reaches and channel types to determine if there is a difference in turnover between the various reaches and associated channel types.

Depending upon the results of the riverine geomorphic analysis, additional historical photographic analysis may be requested as part of future geomorphic studies, but this additional analysis is not included at this time. Additional analysis of historical aerial photographs and the corresponding flows that occurred between 1950s and 2012 could be pertinent if substantial changes in the riverine habitat types (surface area, locations, etc.) are identified during comparison of the 2012, 1980s, and 1950s photography. A decision on whether to acquire additional aerials will be made in Q4 2013. While the long-term changes in river morphology are the result of a range of flows, if significant changes are identified between pairs of aerial photographs, review of the hydrologic record frequently identifies events that are more than likely to have been morphogenetically significant. This type of additional aerial photo analysis could provide more specific information on the flow magnitude(s) and other conditions (for example, ice formation) that may cause substantial geomorphic channel adjustments.

6.5.4.4.2.2. Lower Susitna River Segment

In 2012, orthorectified digital images of the 36,600-cfs (as measured at Sunshine Station) September 6, 1983, set of Lower Susitna River Segment aerial photographs were obtained for the Lower Susitna River Segment from RM 0 to RM 98. Acquisition of 2012 aerials for the Lower Susitna River Segment at a targeted flow of approximately 36,600 cfs was planned. Due to a combination of weather and flows conditions, the Lower River aerials were acquired at several different times for flows ranging from 38,100 cfs to 46,900 cfs. For determining geomorphic features, these flows are considered to be within the target range.

The extent of the side channels, main channel, anabranches and braid plain in the Lower Susitna River Segment, including the Three Rivers Confluence area, were digitized for both the 1980s and 2012 aerials. Planform shifts of the main channel and side channels are being identified between the 1983 and current aerial photography. This work was performed in 2012 to help in confirmation or adjustment of the downstream study limit for the Fluvial Modeling Geomorphology Study. Geomorphic features that are visible between the 1983 and 2012 images, including the presence and extent of individual side channels, side channel complexes, vegetated islands or bar complexes, and tributary deltas, were mapped and characterized. In areas where the mainstem channel consists of a dynamic braid plain mostly void of stabilizing vegetation, the effort was directed at defining the edges of the active channel rather than detailing the myriad of channels within the active area. Portions of the area within the braid plain were identified as bar island complexes and side channel complexes. Major sloughs and side channels along the Lower Susitna River Segment margins were included in the digitizing effort.

In 2013, orthorectified digital versions of historical 1950s aerials will be acquired and the geomorphic features digitized. Acquisition of these aerials and performing the effort is dependent on locating a set of historical aerials from the 1950s or early 1960s that are of sufficient quality to provide for meaningful comparison between the other two datasets (1980s and current). The geomorphic change over the length of the river (main channel location, side channel location, bars, channel and side channel width, channel and side channel location) will be qualitatively assessed between the 1980s and current conditions. Reaches will be identified that are relatively stable versus those that are more dynamic. Reaches that would be most susceptible to channel change (e.g., width or planform change) with changes in the flow or sediment regime resulting from the Project or Project operations will be qualitatively identified.

In 2013, a quantitative evaluation of channel change in the Lower River will be performed by conducting a “turnover” analysis (Note: the turnover analysis was added to the RSP as a result of comments on the PSP from the EPA submitted November 14, 2012). The digitized maps of the geomorphic features will be used to determine how much of the area covered by water in the 1950s and 1980s is land in 2012 versus still covered by water, taking into account river stage for the aerials not collected at ~36,600 cfs, and how much of the area covered by water today was land versus covered by water in the 1980s and 1950s. This analysis will be performed on a geomorphic reach basis. This information will be used to calculate a “turnover rate” (water to land and land to water, in acres per year) for each reach for the periods between the 1950s and the1980s, and between the 1980s and 2012 aerial imagery. The resulting reach-scale data will be used to define the reach-scale turnover rate values. The resulting quantitative data on turnover rate will be compared with hydrologic conditions, events at upstream glaciers, and other potential factors such as the occurrence of earthquakes to determine potential differences in the turnover rates from the two periods. Spatially, the turnover rates will be compared between reaches and channel types to determine if there is a difference in turnover between the various reaches and associated channel types.

Depending on the results of the riverine geomorphic analysis, additional historical photographic analysis may be requested as part of future geomorphic studies, but this additional analysis is not included at this time. Additional analysis of historical aerial photographs and the corresponding flows that occurred between the 1950s and 2012 could be pertinent if substantial changes in the riverine habitat types (surface area, locations, etc.) are identified during comparison of the 2012, 1980s and 1950s photography. While the long-term changes in river morphology are the result of a range of flows, if significant changes are identified between pairs of aerial photographs, review of the hydrologic record frequently identifies events that are more than likely to have been morphogenetically significant. This type of additional aerial photo analysis could provide more specific information on the flow magnitude(s) and other conditions (for example, ice formation) that may cause substantial geomorphic channel adjustments. A decision on whether to acquire additional aerials will be made in Q4 2013.

6.5.4.4.2.3. Information Required

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

- Historical 1980s orthorectified aerial photographs for the Middle and Lower Susitna River Segments.
- Historical 1950s orthorectified aerial photographs for the Middle and Lower Susitna River Segments.

The following additional information will be needed to conduct this study:

- Obtain recent or develop 2012 orthorectified aerial photos in the Middle and Lower Susitna River Segments at a flow similar to the historic aerials (12,500 cfs Middle Susitna River Segment and 36,600 cfs Lower Susitna River Segment) (acquired in 2012).
- Supplemental aerials Middle River to be collected in 2013 for any areas with gaps in 2012 coverage at the 12,500 cfs target flow.

6.5.4.4.3. Study Products

The results of the Assess Geomorphic Change Middle and Lower Susitna River Segment component will be included in the Geomorphology Report. Information provided will include the following (Note: 1950s products are dependent on suitable aerials being available from the 1950s):

- Maps showing riverine geomorphic features outlined in the Middle and Lower Susitna River Segments for the 1950s, 1980s, and 2012 for flows of approximately 12,500 cfs and 36,600 cfs, respectively.
- Maps showing the distribution of all riverine geomorphic features for the three dates and for the Middle and Lower Susitna River Segments.
- Overlay map of 1950s, 1980s, and 2012 riverine geomorphic features to qualitatively assess the level of change in the channel morphology over the past three decades.
- Tabular and graphical representation of the areas for each riverine geomorphic feature type by geomorphic reaches within the Middle and Lower Susitna River Segments.
- Qualitative assessment of the level of geomorphic change within each geomorphic reach over the lengths of the Middle and Lower Susitna River Segments including identification of stable versus non-stable areas.
- Quantitative assessment of geomorphic change based on conducting a turnover rate analysis identifying the area of channel converted to land and land converted to channel for the periods of 1950s to 1980s and 1980s to 2012.

In addition, an ArcGIS shapefile will be provided with the following information:

- 1950s, 1980s, and 2012 orthorectified aerial imagery on GIS layer for the Middle and Lower Susitna River Segments.
- Digitized polygons for each riverine habitat feature type in the Middle and Lower Susitna River Segments.

6.5.4.5. Study Component: Riverine Habitat versus Flow Relationship Middle Susitna River Segment

The goal of this study component is to delineate existing and 1980s riverine macrohabitat types and develop wetted habitat area data over a range of flows to quantify riverine macrohabitat surface area versus flow relationships. The habitat areas will be determined for the riverine macrohabitats as defined in the 1980s (main channel, side channel, side slough, upland slough, tributary mouth and tributary).

It is noted that the macrohabitats being delineated in this study component is one of five levels of nested and tiered habitat classification being applied to the Middle Susitna River Segment. The system is presented in Table 9.9-4 of the Characterization and Mapping of Aquatic Habitats (Section 9.9). The classification levels include rivers segment, geomorphic reach, macrohabitats, mesohabitat, and edge habitat. The Geomorphology Study has defined the Susitna River segments and geomorphic reaches. The effort in this section will map approximately 50 percent of the macrohabitat in the Middle River. The results will be provided to the habitat characterization study (Section 9.9) to add macrohabitat subcategories not defined in the 1980s classification scheme. These include split main channel, multiple split main channel, backwater, and beaver complex. The habitat characterization study (Section 9.9) will also conduct the mapping for the fourth and fifth levels of the classification scheme.

The study area extends from the Three Rivers Confluence area (RM 98) to the Watana Dam site (RM 184). Sixteen study sites representing approximately 50 percent of the river studied in the 1980s were studied in the 2012 study. Due to a combination of weather and flow conditions, not all aerials intended to be acquired in 2012 were flown (Table 6.4-3 summaries the 2012 aerial photo acquisition). Therefore, development of the riverine habitat area versus flow relationships for the current condition will continue into 2013. The 2012 effort does supply the information necessary for reach stratification and selection of proposed Focus Areas in the Middle River. Additionally, all or part of the remaining portion of the Middle Susitna River Segment may be studied in 2013–2014, depending on the outcome and recommendations from the 2012 study as well as the finalization of instream flow Focus Areas.

6.5.4.5.1. Existing Information and Need for Additional Information

An analysis of the Middle Susitna River Segment and how riverine habitat conditions change over a range of stream flows was performed in the 1980s using aerial photographic analysis (Trihey & Associates 1985). This study evaluated the response of riverine aquatic habitat to flows in the Middle Susitna River Segment between the Three Rivers Confluence (RM 98) and Devils Canyon (RM 150) ranging from 5,100 cfs to 23,000 cfs (measured at Gold Creek gage [approximately RM 134]).

Understanding existing geomorphic conditions, how aquatic macrohabitat changes over a range of stream flows, and how stable/unstable the geomorphic conditions have been over recent decades provides a baseline set of information needed to provide a context for predicting the likely extent and nature of potential changes that will occur due to the Project. Results of this study will also provide the basis for macrohabitat mapping to support the Fish and Aquatics Instream Flow Study (Section 8.5) and will be used in the Ice Processes Study (Section 7.6) to provide the surface areas of bars likely to become vegetated in the absence of ice-cover formation.

6.5.4.5.2. Methods

Aerial photography obtained in 2012 were combined with 1980s and other information to create a digital, spatial representation (i.e., GIS database) of riverine habitat. The result was intended to be a quantification of the area of the riverine habitat types for three flow conditions for the historical 1980s condition and the current 2012 condition. Due to a combination of weather and flow conditions, only portions of two out of the three flows were collected (aerials for high and medium flows were collected, but no aerial low flows were collected). A supplemental data collection effort will be conducted in 2013 to complete the acquisition of aerials for all three flows for the entire Middle Susitna River Segment.

The results for the information available in 2012 will be analyzed and presented in January 2013 as riverine habitat versus area relationships at three spatial levels: for the Middle Susitna River Segment, for the geomorphic reaches in the Middle Susitna River Segment, and for individual habitat study sites (This includes all ten proposed Focus Areas and seven additional sites studied in the 1980s that are not proposed Focus Areas). Comparison between the results from the 1980s and 2012 are being made. The historical information is only being developed for the reach from RM 98 to RM 150 because the delineation of habitat in the Devils Canyon section, RM 150 to RM 184, was not performed in the 1980s.

The methods for this study component have been divided into three tasks: aerial photography, digitize riverine habitat types, and riverine habitat analysis.

6.5.4.5.2.1. Aerial Photography

Portions of new color aerial photography of the Middle Susitna River Segment (RM 98 to RM 184) at stream flows corresponding to those analyzed in the Trihey & Associates study (1985) (stream flow at the Gold Creek gage [15292000]) were obtained in 2012 to provide the foundation for the aquatic habitat and geomorphic mapping of the Middle Susitna River Segment, as well as to provide a resource for other studies. The aerials collected included RM 98 to RM 107 at 23,200 cfs, RM 98 to RM 135 at 13,300 cfs, and RM 136 to RM 184 at 18,100 cfs.

It was the intent of the study plan to obtain three sets of aerial photography in 2012 at the following approximate discharges: 23,000 cfs; 12,500 cfs; and 5,100 cfs. (Note: seven sets of aerial photographs were flown and evaluated in the 1985 study at the stream flows of 5,100 cfs; 7,400 cfs; 10,600 cfs; 12,500 cfs; 16,000 cfs; 18,000 cfs; and 23,000 cfs). The combination of weather conditions and river flows only allowed the 23,000 cfs and a portion of the 12,500 cfs set of aerials to be collected in 2012. No aerials were obtained for the lowest flow of 5,100 cfs as ice and snow cover formed prior to the Susitna River dropping to this level. In order to provide a complete set of current aerial imagery, the 23,000 cfs aerials were collected for the entire study are from RM 0 to RM 260. The aerial photography was collected in 2012 at a scale of 1:12,000 and with a pixel resolution of 1 foot or better. Images to be collected in 2013 will be flown at the same scale and resolution. The flow levels intended to be collected in 2013 will be the remainder of the 12,500 cfs acquisition and all of the 5,100 cfs acquisition. If weather and discharge conditions have not occurred that allowed for collection of the aerials at the specified discharges by September 1 of 2013, a more opportunistic approach to obtaining the aerials will be instituted and alternate flows may be substituted for the 12,500 cfs and 5,100 cfs discharges to insure that a medium and low flow set of images are collected by the end of 2013.

Digital orthorectified images of the 1980s 12,500 cfs aerial photos will be obtained to serve as the base map for overlaying the digitized riverine habitat types from the1980s map book (Trihey and Associates 1985).

6.5.4.5.2.2. Digitize Riverine Habitat Types

For the 2012 effort, 17 study sites totaling 26.3 river miles were selected from the 1980s effort The 17 sites represent over 50 percent of the 49 miles (RM 100 to RM 149) of the Middle Susitna River Segment with aquatic habitat delineated in the 1980s. The selected sites are listed in Table 6.5-4. Selection of the sites was based on consideration of habitat and geomorphic characteristics of the reach and a visual qualitative side-by-side comparison of the aerials to ensure that the selected reaches were also representative of the level of change that has occurred over the period of comparison. The sites include the seven proposed Focus Areas, as identified in Section 6.6.1.2.4, in this portion of the Middle Susitna River Segment. Aerial photography for both 1980s and present condition was obtained for the entire reach so that additional areas may be digitized in the future if warranted.

The Middle Susitna River Segment upstream of RM 150 was not studied in the 1980s; however, the current habitat features are to be delineated on 50 percent of the portion of the Segment encompassing Geomorphic Reaches MR-1 and MR-2. Six sites were selected, representing a variety of conditions and totaling 9.0 miles of the total 17.5 miles of combined Geomorphic Reaches MR-1 and MR-2. These sites include three proposed Focus Areas identified in Section 6.6.4.1.2.4. and represent approximately 50 percent of Geomorphic Reaches MR-1 and MR-2.

Coordination has occurred and will continue to occur with AEA's Spatial Data Contractor to digitize (within the aerial photography analysis study reaches) the riverine habitat types from RM 98 to RM 150 defined in the 1980s from hard copy maps found in the Middle Susitna River Segment Assessment Report (Trihey & Associates 1985). Each habitat type has been digitized as a polygon (without slivers). The digitized habitat types are overlaid on a digital orthorectified image of the 1980s 12,500 cfs black and white aerial. The habitat types were classified into the following categories: main channel, side channel, side sloughs, upland sloughs, and tributary mouths.

In 2012, riverine habitat types for the identified study sites were delineated and digitized from the 2012 aerials at the selected 23,000 cfs and for portions sites of the 12,500 cfs. Sites included the 17 sites identified for the 1980s digitization effort as well as six additional sites between RM 166.5 and RM 184, identified in coordination with the FA-IFS (Section 8.5), the R-IFS (Section 8.6), Ice Processes Study (Section 7.6), and other pertinent studies. The habitat types were digitized from the orthorectified photography using ArcGIS software (each habitat type must be a polygon without slivers). Riverine habitat was classified using the same classification categories used in the Trihey & Associates study (1985) main channel, side channel, side sloughs, upland sloughs, and tributary mouths.

In 2013, the digitization of the riverine habitat types and determination of the areas will be completed. This will include acquisition of the remaining portions of the 12,500 cfs and all of the 5,100 cfs orthorectified aerial photos.

6.5.4.5.2.3. Riverine Habitat Analysis

The information developed in the previous task are being used to develop relationships for riverine habitat versus flow for the specified reaches and habitat study sites. The relationships will be developed for both 1980s and 2012 and 2013 aerials. The riverine habitat type surface area versus flow relationships between the 1980s and current conditions are being compared at both a site and reach scale to determine if changes in the relationships have occurred. The comparison can only be performed for a portion of the reach, since the 1980s study did not cover the entire Middle Susitna River Segment. This effort will be completed in December 2012 and reported on in January 2012 for the 23,000 cfs and the portion of the 12,500 cfs aerials collected in 2012.

From RM 98 to RM 150, GIS software was used to compare the 2012/2013 versus 1980s total surface area associated with each delineated riverine habitat type at each measured flow. Results are being compiled into tables and graphs, as appropriate, to show the difference in surfaces area of the feature types between 2012/2013 and the 1980s photography and to show the change in riverine habitat types versus flow. To ensure accurate comparison to the 1980s data set, not only are the same approximate flows be compared, but the same definitions are being used for each of the riverine habitat features that are delineated (see above). The Lead Geomorphologist has provided training to the staff performing the delineation to ensure appropriate application of the habitat definitions.

Since the 34-mile river segment below the proposed Watana Dam site (RM 150 to RM 184) was not analyzed in the 1980s, this portion of the river is a new assessment (2012/2013 photography only) that will not be compared to past studies. However, the methods for analyzing riverine habitat types over the range of flows remain the same as for the downstream reach (23,000 cfs; 12,500 cfs; and 5,100 cfs). For Geomorphic Reaches MR-3 and MR-4, which include Devils Canyon and the river immediately upstream, no habitat sites have been selected for study. This reach has a high level of lateral and vertical control, the areas associated with riverine habitat types have likely experienced little change. Results of the study component Assess Geomorphic Change Middle and Lower Susitna River Segments (Section 6.5.4.4) will determine whether there has been change in geomorphic features in this portion of the Middle Susitna River Segment.

Habitat features are being compared and contrasted quantitatively and a qualitative assessment will be made of the similarity of the sites in 2012/2013 compared to the 1980s in order to assess the stability of the study sites. The results for the sites with 2012 aerials will be reported on in January 2013. A decision will also be made as to whether the remaining portions of the Middle Susitna River Segment, beyond the original selected study sites analyzed in 2012, will be digitized and analyzed in 2013–2014.

6.5.4.5.2.4. Information Required

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

- Historical 1980s orthorectified aerial photographs for the Middle Susitna River Segment.
- USGS flow records for the past 10 years for the Susitna River at Gold Creek.

The following additional information will be needed to conduct this study:

- Obtain (fly) 2012/2013 orthorectified aerial photos in the Middle Susitna River Segment at 5,100; 12,500; and 23,000 cfs (corresponds to 1980s flow) (partially completed in 2012).
- Obtain orthorectified digital images of 1980s black and white aerial photos in the Middle Susitna River Segment at 12,500 cfs base map aerial (completed in 2012).

6.5.4.5.3. Study Products

The results of the Riverine Habitat Versus Flow Relationship Middle Susitna River Segment component will be included in the Geomorphology Report. Information provided will include the following:

- Tabulation of the riverine habitat types versus flow on a reach and individual site basis for the 1980s and 2012/2013 conditions.
- Graphical representation of the riverine habitat type area versus flow relationships by reaches for both the 1980s and 2012/2013 data.
- Assessment of the change and similarity in riverine habitat types between the 1980s and 2012 and conclusions on site stability to aid the Instream Flow Study in site selection and determination of the applicability of the 1980s data to represent current conditions.

In addition, an ArcGIS shapefile will be provided with the following information:

- Orthorectified 2012/2013 aerial imagery of the Middle Susitna River Segment at 5,100 cfs; 12,500 cfs; and 23,000 cfs.
- Orthorectified 1983 aerial imagery of the Middle Susitna River Segment from RM 98 to RM 150 at 12,500 cfs.
- Digitized polygons representing the 1980s riverine habitat types for the Middle Susitna River Segment at 5,100 cfs; 12,600 cfs; and 23,000 cfs from RM 98 to RM 150 (Middle Susitna River Segment below Devils Canyon).
- Digitized polygons representing the current (2012/2013) riverine habitat types for the Middle Susitna River Segment at 5,100 cfs; 12,500 cfs; and 23,000 cfs from RM 98 to RM 150 (Middle Susitna River Segment below Devils Canyon) and RM 150 to 184 (Middle Susitna River Segment in Devils Canyon and above Devils Canyon).

6.5.4.6. Study Component: Reconnaissance-Level Assessment of Project Effects on Lower and Middle Susitna River Segments

The goal of the Reconnaissance-Level Assessment of Project Effects on Lower and Middle Susitna River Segments study component is to utilize comparison of pre- and post-Project flows and sediment transport conditions to estimate the likelihood for potential post-Project channel change in the Lower and Middle Susitna River Segments. The study area for this effort is the Lower Susitna River Segment from RM 98 to RM 0 and the Middle Susitna River Segment from RM 184 to RM 98. The initial effort involves the Lower River and was started in 2012 and will be completed in early 2013. The results of this effort will help determine what additional analysis of Project effects may be warranted in the Lower Susitna River Segment for the 2013–2014 studies. The initial Middle River assessment will be performed in Q3 2013. Continued application of the framework to both the Lower and Middle Susitna River segments as additional information on with-Project hydrology, sediment transport, and the geomorphology of the system are developed by the various studies will provide additional context for identification of Project effects including interpretation of and integration with the Fluvial Geomorphology Modeling Study results.

6.5.4.6.1. Existing Information and Need for Additional Information

An analysis of the Lower Susitna River Segment and how riverine habitat conditions change over a range of stream flows was performed in the 1980s using aerial photographic analysis (R&M Consultants, Inc. and Trihey and Associates 1985a). This study evaluated the response of riverine aquatic habitat to flows in the Lower Susitna River Segment reach between the Yentna River confluence (RM 28.5) and Talkeetna (RM 98) (measured at Sunshine gage [approximately RM 84]) ranging from 13,900 cfs to 75,200 cfs. The study also included an evaluation of the morphologic stability of islands and side channels by comparing aerial photography between 1951 and 1983.

In another study, 13 tributaries to the lower Susitna River were evaluated for access by spawning salmon under existing and with proposed stream flows for the original hydroelectric project (R&M Consultants, Inc. and Trihey and Associates 1985b). The study contains information regarding fish run timing, mainstem and tributary hydrology, and morphology. Based on the results of this study, it was concluded that passage for adult salmon was not restricted under natural flow conditions nor was it expected to become restricted under the proposed Project operations.

An analysis of channel changes of the Middle River was presented in *Geomorphic Change in the Middle Susitna River Since 1949* (Labelle et al. 1985). In this document, aerial photographs and other data from the late 1940s through the early 1980s was evaluated to determine historical change in the Middle Susitna River Segment including the important off-channel macrohabitats identified in the 1980s studies (side channels, side sloughs, and upland sloughs).

The AEA Susitna Water Quality and Sediment Transport Data Gap Analysis Report (URS 2011) states that “if additional information is collected, the existing information could provide a reference for evaluating temporal and spatial changes within the various reaches of the Susitna River.” The gap analysis emphasizes that it is important to determine if the conditions represented by the data collected in the 1980s are still representative of current conditions, and that at least a baseline comparison of current and 1980s morphological characteristics in each of the identified subreaches is required.

Results of this study in Q1 of 2013 will provide the initial basis for assessing the potential for changes to the Lower Susitna River Segment reach morphology due to the Project in order to help inform the evaluation of the downstream limit for the Fluvial Geomorphology Modeling Study. Additional studies will be planned for 2013–2014 to continue further downstream in the Lower River if the results of this study identify a potential for important aquatic habitat and channel adjustments in response to the Project below RM 84. In addition to providing the initial assessment for informing the evaluation of the downstream limit for the Fluvial Geomorphology Modeling Study, the assessments presented in this study component will also assist in the overall evaluation of Project effects. This is why the effort was extended upstream to include the Middle

Susitna River Segment in response to comments filed November 14, 2012 by NMFS and USFWS on the PSP (NMFS and USFWS).

The Stream Flow Assessment portion of this study component includes a concurrent flow and stage analysis for the Susitna River in the area of the Talkeetna and Chulitna confluences. This analysis was added in response to a comment filed November 14, 2012 on the PSP concerning the potential for Project to affect erosion in the area of the Town of Talkeetna (Teich, Cathy).

Issues associated with geomorphic resources in the Lower and Middle Susitna River Segments for which information appears to be insufficient were identified in the PAD (AEA 2011), including the following:

- G16: Potential effects of reduced sediment load and changes to sediment transport as a result of Project operations within the Lower Susitna River Segment.
- F19: The degree to which Project operations affect flow regimes, sediment transport, temperature, and water quality that result in changes to seasonal availability and quality of aquatic habitats, including primary and secondary productivity.

6.5.4.6.2. Methods

6.5.4.6.2.1. Stream Flow Assessment

Pre-Project and available post-Project hydrologic data are being compared in 2012 and the results will be reported on in January 2013. This includes a comparison of the monthly and annual flow duration curves (exceedance plots) and plots/tables of flows by month (maximum, average, median, minimum) for the Susitna River at Gold Creek, Susitna River at the Sunshine and Susitna Station gaging stations. These analyses are being conducted for the major tributaries provided in the extended record including the Chulitna River near Talkeetna, the Talkeetna River near Talkeetna, and the Yentna River near Susitna Station. In 2013, additional hydrologic indicators may be used to further illustrate and quantify the comparison between pre- and post-Project stream flows. The pre-Project data analysis includes the 61-year extended record prepared by USGS. The post-Project condition is based on initial runs of the Operations Model and the Initial Flow Routing Model developed by the engineering studies. The Operations Model provides Project releases and the routing model provides estimates of hourly flow and stage from the base of the dam at RM 184 to the downstream limit of the model near RM 84.

Using the extended record currently prepared by USGS, a flood-frequency and flood-duration analysis for pre- and post-Project annual peak flows is being performed. The flood-frequency analysis is being performed using standard hydrologic practices and guidelines as recommended by USGS (1982). The pre-Project analysis was completed in November 2012 and the post-Project analysis will be completed by the end of December 2012. The results of both analyses were be compared and reported on in January 2013.

A concurrent flow and stage analysis will be conducted in Q4 of 2013 to determine the potential for Project-induced changes in flows and stage on the Susitna River that may have the potential to alter the erosion patterns in the area of the town of Talkeetna. A technical memorandum will be prepared identifying the analysis procedures and results. If this initial analysis indicates that the changes in flows and stage on the Susitna River may be sufficient to alter the flow patterns during peak flows on the Talkeetna and Chulitna rivers, then a plan will be developed to further study this potential Project effect in 2014. It is expected that if implemented, this additional effort would include extending a branch of the Mainstem (Open-water) Flow Routing Model up the Talkeetna River and possibly the Chulitna River. As part of this effort, 2012 aerial photos acquired prior to the September 2012 high flows and after the high flows will be evaluated to determine the extent of erosion from the September 2012 high flow event. This aerial photo comparison will provide an indication of current erosion that is typical of a high flow event for pre-Project conditions.

6.5.4.6.2.2. Sediment Transport Assessment

The sediment transport data collected by USGS (See Section 6.5.4.2) are used to develop bedload, total bed material, and wash load rating curves to facilitate translation of the periodic instantaneous measurements into yields over longer durations (e.g., monthly, seasonal, and annual). This information is being used to perform an overall sediment balance for each component of the sediment load. This information will be developed as part of the Sediment Supply and Transport Middle and Lower Susitna River Segment study (see Section 6.5.4.3). The initial sediment balance will be completed in December 2012 and reported on in January 2013 to inform the review of the downstream study limit (See Section 6.6.3.2) with more detailed work effort conducted throughout 2013 and 2014 to support the Fluvial Geomorphology Modeling Study (Section 6.6).

6.5.4.6.2.3. Integrate Sediment Transport and Flow Results into Conceptual Framework for Identification of Geomorphic Reach Response

Prediction of Project-induced changes to river morphology in an alluvial river is fundamentally based on the magnitudes and directions of change in the driving variables, hydrology, and sediment supply. Initial, qualitative assessment of change can be based on Lane's (1955) equality:

$Q_w.S \sim Q_s.D_{50}$,

where Q_w is the flow, S is the slope, Q_s is the sediment transport and D_{50} is the median size of the bed material. A change in any one of the variables will require a change in the others to maintain the balance.

Use of the expansion of Lane's relation by Schumm (1977) allows the response to the changes in driving variables to be expressed in terms of channel morphometric parameters such as channel width (b), depth (d), slope (S), meander wavelength (λ), width-depth ratio (F) and sinuosity (P). For example, a potential range of changes in response to the Project in the vicinity of the Three Rivers Confluence where flows will be reduced and sediment supply could be effectively increased could be expressed as follows:

$Q_w^-, Q_s^+ \sim b^\pm, d^-, \lambda^\pm, S^+, P^-, F^+$

where + represents an increase, – represents a decrease and ± represents indeterminacy.

Application of these qualitative relations assumes that the river is alluvial and that the form and characteristics of the channel are the result only of the interaction of the flows and the sediment load. Where non-fluvial factors such as bedrock outcrop or coarse-grained paleo-flood deposits limit the adjustability of the channel, the ability to predict the direction and magnitude of channel change in response to changes in the water and sediment load below dams is reduced (Miller 1995; Grant and Swanson 1995; Grant et al. 2003).

Using the data developed for the pre- and post-Project flood frequency, flood duration, and sediment load, the geomorphic response of the Susitna River in a conceptual framework along the longitudinal profile of the river system from the Lower and Middle Susitna River Segments will be predicted. The work will be initially performed for the Lower River Segment and completed in January of 2013 in order to support evaluation of the downstream study limit for the Fluvial Geomorphology Modeling Study (Section 6.6.3.2). The initial effort on the Middle River will be performed in Q3 of 2013. The conceptual framework developed by Grant et al. (2003) that relies on the dimensionless variables of the ratio of sediment supply below the dam to that above the dam and the fractional change in frequency of sediment transporting flows is being used to predict the nature and magnitude of the response of the geomorphic reaches in the Lower and Middle Susitna River Segments. Other analytical approaches are also being considered to evaluate potential for geomorphic adjustments of the reaches in the river segments due to the Project. These include an evaluation of morphologic changes based on changes to the degree and intensity of braiding using Germanoski's (1989) modified braiding index (MBI) that has been used to predict channel responses to anthropomorphically-induced changes in Alaskan, glacial-fed rivers including the Toklat, Robertson, and Gerstle Rivers (Germanoski 2001). As demonstrated by Germanoski and Schumm (1993), Germanoski and Harvey (1993), and Harvey and Trabant (2006), the following are the expected directions of responses in the MBI values to significant changes in bed material gradation and sediment supply:

- If the D50 increases and there is a supply of sediment, then MBI increases.
- If the D50 increases and there is a significant decrease in the supply of sediment, then MBI decreases.
- If the bed aggrades, then MBI increases.
- If the bed degrades, then MBI decreases.

Specific MBI values for braided reaches of the Susitna River under existing conditions are being developed from aerial photography, and the likely changes in values in response to the Project will be assessed. Prediction of the direction, if not the magnitude of changes, provide useful information for assessing likely Project effects on geomorphic features that form instream habitats. It also provides context to assist in interpreting and assessing the validity of results from the bed evolution models and other analytical tools.

6.5.4.6.2.4. Literature Review on Downstream Effects of Dams

To assist in the assessment of potential Project effects on the geomorphology of the Susitna River, a search and review of literature on the downstream effects of dams will be conducted. There is considerable literature on this topic for dams within the United States as well as around the world. Grant et al. (2003) identified in the previous section in one such reference, with others including, but not limited to Sabo et al. (2012), Clipperton et al. (2003), Schmidt and Wilcock (2000), Shields et al. (2000), Freidman et al. (1998), Collier et al. (1996), and Williams and Wolman (1984). Efforts will be made to locate information on specific dams within the region and in other similar cold region environments around the world. Information could be used to extend or complement field studies as well as reduce the uncertainty associated with study results and conclusions.

6.5.4.6.2.5. Information Required

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

- Historical suspended sediment and bedload data for the Susitna River.
- Flow records for the Susitna River.
- Characterization of bed material from previous studies.

The following additional information will need to be obtained to conduct this study:

- Suspended and bedload data for the Susitna River at Tsusena Creek and Gold Creek being performed by USGS.
- Extended flow record for the Susitna River and gaged tributaries within the study area being developed by USGS.
- Channel morphologic data for existing conditions including, width, depth, width/depth ratios, and MBIs.

6.5.4.6.3. Study Products

The results of the Reconnaissance-Level Assessment of Project Effects on Lower Susitna River Segment Channel Sediment component will be included in the Geomorphology Report. Information provided will include the following:

- Pre- and post-Project comparison of hydrologic parameters for the Susitna River at Sunshine and at Susitna Station, including:
  - Monthly and annual flow duration curves
  - Annual peak flow frequency
  - Monthly flow statistics (maximum, average, median, minimum)
- Summary of changes in sediment transport for pre- and post-Project conditions in the Lower Susitna River Segment.
- Results of the assessment of anticipated Project effects on the Lower Susitna River Segment based on the analytical framework in Grant et al. (2003) and other indicators of potential channel change such as the MBI by Germanoski (1989).

6.5.4.7. Study Component: Riverine Habitat Area versus Flow Lower Susitna River Segment

The goal of this study component is to conduct an initial assessment of the potential for Project effects associated with changes in stage to alter Lower Susitna River Segment riverine habitat. This effort was conducted in 2012. If the decision is made to continue detailed studies of Project effects into the Lower Susitna River, then this effort will be expanded to include mapping of the 1980s aquatic macrohabitat type in the Lower Susitna River Segment and the development of the wetted macrohabitat versus flow relationships.

6.5.4.7.1. Existing Information and Need for Additional Information

An analysis of the Lower Susitna River Segment and how riverine habitat conditions change over a range of stream flows was performed in the 1980s using aerial photographic analysis (R&M Consultants, Inc. and Trihey and Associates 1985a). This study evaluated the response of riverine aquatic habitat to flows in the Lower Susitna River Segment reach between the Yentna River confluence (RM 28.5) and Talkeetna (RM 98) (measured at Sunshine gage at approximately RM 84) ranging from 13,900 cfs to 75,200 cfs. Results of this study will provide the initial basis for assessing the potential for changes to the Lower Susitna River Segment reach morphology due to the Project. Additional studies will be planned for 2013–2014 if the results of this study and other studies identify a potential for important aquatic habitat and channel adjustments in response to the Project.

6.5.4.7.2. Methods

This study component is divided into three tasks: Riverine Habitat-Flow Relationship Assessment, Synthesis of the 1980s Aquatic Habitat Information, and Contingency Analysis to Compare Wetted Channel Area. The third task is optional and dependent on a determination if comparison of riverine habitat in the Lower Susitna River Segment under pre- and post-Project flows is warranted for additional flow conditions and determination of whether aquatic resource studies need to be continued further downstream in the Lower Susitna River Segment.

6.5.4.7.2.1. Change in River Stage Assessment

A tabular and graphical comparison of the change in water surface elevations associated with the results of the pre- and post-Project stream flow assessment (Section 6.5.6.2.1) was developed using the stage-discharge relationships (rating curves) for the Sunshine and Susitna Station gaging stations. This comparison included monthly and annual stage duration curves (exceedance plots) and plots/tables of stage by month (maximum, average, median, minimum). Additional parameters to describe and compare the pre- and post-Project water surface elevations may be performed in 2013. A graphical plot of a representative cross-section at each gaging station was developed with a summary of the changes in stage (water surface elevation) for the two flow regimes. If possible, the location of the active channel and the floodplain will also be identified on the cross-section. Changes in stage will be related to exposure of bars through the previously developed bar area discharge curves, thereby providing the link between both vegetation and ice impact assessments. The stage change information was also used to estimate and compare the areas of the various riverine habitat types for the existing and with-Project conditions over a range of flow frequencies.

The availability of USGS winter gage data with respect to discharge and ice elevation/thickness was investigated. Coordination with the Ice Processes (Section 7.6) occurred to obtain information on ice elevation/thickness. This information was summarized and will be analyzed in Q1 2013 to make an initial assessment of discharge effects on ice elevation.

6.5.4.7.2.2. Synthesis of the 1980s Aquatic Habitat Information

A synthesis/summary of the 1980s Response of Aquatic Habitat Surface Area to Mainstem Discharge Relationships in the Yentna to Talkeetna Reach of the Susitna River (R&M Consultants, Inc. and Trihey & Associates 1985a) was performed and will be provided with the

January 2013 technical memorandum. A synthesis/summary of the Assessment of Access by Spawning Salmon into Tributaries of the Lower Susitna River (R&M Consultants, Inc. and Trihey & Associates, 1985b) was also performed and will be included in the January 2103 technical memorandum. Data have been summarized with respect to the anticipated pre- and post-Project flow changes, where applicable.

6.5.4.7.2.3. Site Selection and Stability Assessment

Five sites in the Lower Susitna River Segment were selected from the Yentna to Talkeetna reach map book (R&M Consultants, Inc. and Trihey and Associates 1985a) at the approximately 36,600 cfs flow at Sunshine Gage to study in 2012. These sites were selected in coordination with the FA-IFS and the R-IFS. A side-by-side comparison of the sites using the 1983 36,600-cfs aerials and the 2011 aerials from the Mat-Su Borough LiDAR project were used to qualitatively assess site stability. Only sites that had been relatively stable during the period from the 1980s to present were selected. The five sites selected were: Side Channel IV-4 (SC IV-4), Willow Creek (SC III-1), Goose Creek (SC II-4), Montana Creek (SC II-1) and Sunshine Slough (SC I-5).

6.5.4.7.2.4. Aerial Photography Analysis, Riverine Habitat Study Sites (RM 28 to RM 98)

Using GIS and the September 6, 1983 aerials for the 36,600-cfs flow, mainstem and side channel riverine habitat was digitized from the 1985 map book (R&M Consultants, Inc. and Trihey & Associates 1985a) for the selected sites. Each area associated with a habitat type was digitized as a polygon (without slivers). To provide a comparison with current conditions, aerials flown at approximately 36,600 cfs were obtained (actual flows ranged from 38,100 cfs to 46,900 cfs). The current wetted areas of the riverine habitat types, as defined in the 1980s analysis, were delineated for the selected sites.

In January 2013, the difference in wetted surface area of the main channel and side channel riverine habitats (as defined in R&M Consultants, Inc. and Trihey & Associates 1985a) will be compared between the 1983 and current conditions. The areas of the riverine habitat types, along with the initial 2012 results of the Assess Geomorphic Change Middle and Lower Susitna River Segments study component (Section 6.5.4.4), will be compared and contrasted quantitatively, and a qualitative assessment will be made of the similarity of the 1980s sites compared to the 2012 sites. The assessment of site stability will help determine the applicability of Lower Susitna River Segment riverine habitat information developed in the 1980s to supplement information being developed in the current Project studies.

6.5.4.7.2.5. Additional Aerial Photography Analysis, Riverine Habitat Study Sites (RM 28 to RM 98)

Based on the results of the comparison of riverine habitat areas at the selected study sites for the Lower Susitna River Segment and results of the Assess Geomorphic Change Middle and Lower Susitna River Segments study component (Section 6.5.4.4), a determination of whether to perform a similar effort and comparison for up to two additional discharges will be made (discharges corresponding to the analysis of wetted habitat areas in the Lower Susitna River Segment include 75,200 cfs; 59,100 cfs; 36,600 cfs; 21,100 cfs; and 13,900 cfs). This decision will be made in coordination with the FA-IFS (Section 8.5), R-IFS (Section 8.6), Ice Processes Study (Section 7.6), Characterization and Mapping of Aquatic Habitats Study (Section 9.9), and licensing participants.

If the decision is made to analyze riverine habitat at two additional discharges, the flows will be selected and the associated habitat areas digitized from the 1985 map book. New aerial photographs will be obtained at the selected discharges. If a decision is made to extend studies further downstream in the Lower Susitna River Segment, additional sites for delineation may be selected. The process, schedule, and criteria for extending the studies further in the Lower Susitna River Segment is described in Section 6.6.3.2 based on geomorphic criteria and in Section 8.5.3 based on results of the Mainstem (Open-water) Flow Routing Model. The geomorphic criteria will be evaluated in Q1 2013 and again in Q1 2014. The Mainstem Flow Routing Model trigger will be evaluated in Q1 2013.

The riverine habitat types at the selected sites will be delineated and digitized on these images to represent the current condition. The difference in wetted surface area of the main channel and side channel riverine habitats will be compared between the 1983 and current conditions for the two additional discharges. Additional sites for delineation of existing aquatic macrohabitat beyond those identified in the 1980s may be included in the optional effort if results of the interim flow and fish and aquatics studies require this information. (The USFWS Study Plan Request included digitizing the riverine habitat types for three flows in the Lower Susitna River Segment. This topic was discussed at the Water Resources TWG meeting held on June 14, 2012. It was explained that the current proposal by AEA is to digitize riverine habitat for a single flow in 2012, then based on decisions on whether to continue Focus Area studies into the Lower Susitna River Segment and how far those studies would be carried downstream, the optional aerial photo analysis identified in this task would be performed in 2013. USFWS agreed at the meeting that this approach was appropriate.)

6.5.4.7.2.6. Information Required

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

- Historical 1980s orthorectified aerial photographs for the Lower Susitna River Segment.
- USGS flow record for the Sunshine and Susitna Station gages including measurement notes, rating curves, stage shifts, cross-sections, and information on ice thickness.

The following additional information will need to be obtained to conduct this study:

- Results of Study Component, Assess Geomorphic Change Middle and Lower Susitna River Segments (Section 6.5.4.4).

6.5.4.7.3. Study Products

The results of the Riverine Habitat Area versus Flow Lower Susitna River Segment component will be included in the Geomorphology Report. Information provided will include the following:

- Comparison of pre- and post-Project stage at the Susitna River at Sunshine and the Susitna Station gages associated with the flow duration curves (monthly and annual) and monthly statistics.

- Summary of available USGS measurements of ice elevation/thickness to identify the need to perform analysis of the discharge effect on ice elevation.
- Narrative describing the synthesis of the 1980s aquatic habitat versus flow relationships and the anticipated post-Project flow changes.
- Results for the selected flow of the comparison of the riverine habitat areas, by type, for the selected sites for 1980s and current aerial imagery.

In addition, an ArcGIS shapefile will be provided with the following information:

- Digitized polygons of the 1980s and current riverine habitat surface areas at the selected sites.

6.5.4.8. Study Component: Reservoir Geomorphology

The goal of this study component is to characterize changes resulting from conversion of the channel and portions of the river valley to a reservoir. For the majority of this study component (Sections 6.5.4.8.2.1, 6.5.4.8.2.2 and 6.5.8.4.3) the study area extends from the proposed Watana Dam site (RM 184) upstream to include the reservoir inundation zone and the portion of the river potentially affected by backwater and delta formation in the river, which is currently assumed to correspond to approximately five miles above the reservoir maximum pool (at approximately RM 238). This portion of the proposed study area is shown in Figure 6.5-6. For the Bank and Boat Wave Erosion downstream of Watana Dam (Section 6.5.4.8.2.4) portion of the study component, the study area extends from the proposed Watana Dam (RM 184) downstream to the Three Rivers Confluence (RM 98). This study area corresponds to the entire Middle Susitna River Segment. Specific objectives of the Reservoir Geomorphology study component include the following:

- Estimate reservoir sediment trap efficiency and reservoir longevity.
- Estimate the Susitna River and inflow tributary delta formation with respect to potential effects on upstream fish passage.
- Estimate erosion and beach formation in the Watana Reservoir drawdown zone and shoreline area.
- Evaluate the resistance of the Susitna River banks to boat wave erosion under Project operations and if the assessment indicates the lower portion of the bank is not sufficiently armored and/or boat activity may cause an increase in erosion of the upper part of the bank, the magnitude of the potential effects will be estimated.

6.5.4.8.1. Existing Information and Need for Additional Information

Construction and operation of the proposed Project will impound a reservoir for approximately 41.5 miles upstream from the dam. The reservoir will likely trap essentially all of the coarse sediment load and much of the fine sediment load that enters the impoundment from the upstream Susitna River. The coarse sediment load will form a delta at the head of the reservoir that will be re-worked by seasonal fluctuations of the reservoir elevation.

Similar to the mainstem Susitna River delta at the head of the reservoir, deltas of varying size will likely form where tributaries enter the reservoir. The amount and distribution of sediment deposits may affect the connectivity of the surface flows between the reservoir and the tributary channels, which may, in turn, block fish passage into the tributaries. The available information does not contain data describing the magnitude and size distribution of the annual sediment loads from the tributaries that enter the reservoir, a potentially significant data gap.

Operation of the Project would result in seasonal and daily water-level fluctuations in Watana Reservoir, which will result in beach formation and erosion and/or mass wasting of soils within the impoundment. The results of the erosion potential portion of this study will provide information on the extent of these processes and the potential for alterations to Project operations or erosion control measures to reduce erosion and mass wasting.

6.5.4.8.2. Methods

The methods are divided into three areas: reservoir trap efficiency and sediment accumulation rates, delta formation, and reservoir erosion. (In the Study Plan comments, NOAA-NMFS and USFWS requested that a description of reservoir sediment removal procedures be included in the Geomorphology effort. At the Water Resources TWG meeting held June 14, 2012, AEA's consultants indicated that there are no plans for removal of sediment deposited in the reservoir because no feasible procedures for accomplishing this on a large reservoir with a substantial permanent pool currently exist. The reservoir will have a finite life as a result of sedimentation and this will be estimated as part of the Reservoir Geomorphology study component.

6.5.4.8.2.1. Reservoir Trap Efficiency and Sediment Accumulation Rates

Inflowing sediment loads from the mainstem Susitna River will be determined by integrating the bedload and suspended load equations developed for the Susitna River at Tsusena Creek over the extended hydrologic record for the Susitna River. Due to the short record at this station, the information collected at Vee Canyon and the bedload and suspended load data collected at Gold Creek will be used to further refine Tsusena sediment rating curves. The methods described in the Empirically Characterize Susitna River Sediment Supply and Transport study component will be used to develop the incoming sediment load.

Sediment loading from the significant tributaries within the reservoir may also affect reservoir life. The reservoir tributary loading will be accounted for in the sediment load data collected for the Susitna River at Tsusena Creek. Similarly, if the sediment loading from the reservoir perimeter is substantial, it will be incorporated into the analysis. Potential additional sediment loading resulting from glacial surge will be investigated in the Glacier and Runoff Changes Study (Section 7.7.4.4, Analyze Potential Changes in Sediment Delivery to Watana Reservoir). If this investigation indicates that the increased sediment load can actually be delivered in substantial quantities to Watana Reservoir, more detailed analyses of the increased loading will be performed and a sediment loading scenario accounting for glacial surge will be added to the reservoir trap efficiency and sediment accumulation analysis. This would include an estimate of the reduction in reservoir life that could result from sediment loading associated with periodic glacial surges.

Due to the relatively large storage capacity of the proposed reservoir, it is reasonable to assume that all sand and coarser sediment size fractions delivered to the reservoir will be trapped, while a substantial amount of the fine-grained, colloidal sediments associated primarily with glacial outwash will pass through the reservoir into the downstream river. When applied over a long-term horizon, the amount of trapped sediment can be used to evaluate the impacts of sedimentation on reservoir storage capacity. If the analysis indicates that a substantial amount of fine sediment will deposit in the reservoir, consolidation of the deposits will also be considered in the analysis. (Note that consolidation of sands and gravels is minimal.) Potential methods for estimating the trap efficiency of the fine sediment include the relationships from Einstein (1965) and Li and Shen (1975). The latter method may be the most appropriate because it accounts for the tendency of suspended particles to be carried upward in the water column due to turbulence. Estimates of the trap efficiency for the fine sediment will be made using the Brune (1953) method. The Brune (1953) method that was recommended by Strand and Pemberton (1987) for use in large or normally-ponded reservoirs (Morris et al. 2007) can be used to check the reasonableness of results obtained from the other methods, although this method does not provide a means of separating the behavior of different particle sizes in the inflowing load. Chen (1975) may also be another method to check the reasonableness of the trap efficiency determination. The Churchill (1948) method is also commonly used to estimate reservoir trap efficiency; however, this method is more applicable for settling basins, small reservoirs, and flood-retarding structures and should probably not be used for this study. The proposed methods will provide a basis for estimating the quantity of the various size fractions that either pass through or are trapped in the reservoir. If the initial analyses indicate that a more sophisticated approach is necessary to obtain reasonable trap efficiencies, consideration will be given to using a numerical model such as Environmental Fluid Dynamics Code (EFDC) (Hamrick 1992) model to refine the estimates.

6.5.4.8.2.2. Delta Formation

Estimation of the formation of deltas on the mainstem Susitna River and its tributaries as they enter the proposed Watana Reservoir will require estimation of sediment load. Although the USGS measurements in the Bedload and Suspended Load Data Collection at Tsusena Creek, Gold Creek, and Sunshine Gage Stations study component target three locations along the Susitna River, sediment transport estimates will be needed at additional locations, including ungaged tributaries. Because of the potential impacts on fish movement into the tributaries, ungaged tributaries that require study will be identified in coordination with the Fish studies. In these locations, reconnaissance will be performed to characterize the sediment transport regime and to identify appropriate methods of calculating yields. In cases where bed material delivery to the proposed reservoir could produce deltas with the potential to affect upstream fish migration, surveys of tributary channel geometry and bed material gradations based on samples collected during the reconnaissance will be coupled with selected bed material transport functions to calculate sediment yield rating curves. Long-term flow hydrographs synthesized for the ungaged tributaries will be needed from other studies for each of the selected tributaries to calculate sediment yields. Alternate approaches to quantifying sediment yield, such as previous studies of regional sediment yields (Guymon 1974) may also be considered.

To estimate the development of the deltas, the sediment yield results can be coupled with the physical constraints imposed by Project operations (i.e., variation in lake levels) on the topset and foreset slopes of the deltas to simulate growth and development of deltas throughout the period of the license (USBR 1987; Morris and Fan 1998). The volume of sediments deposited will be distributed within the topographic constraints of the reservoir fluctuation zone identified for the period when mainstem and tributaries are delivering significant sediment load.

Consideration will be given to which portion of the sediment load would form the delta deposits based on settling characteristics.

6.5.4.8.2.3. Reservoir Erosion

Erosion and mass wasting potential will be assessed within the reservoir fluctuation zone and along the shoreline for 100 vertical feet above the proposed full pool elevation. The following potential erosion processes will be evaluated:

- Mass wasting.
- Surface erosion from sheetwash.
- Wave erosion (wind and boat wakes if motorized boat recreation is permitted).
- Solifluction, freeze-thaw, and thawing of permafrost.
- Beach/bank development at full pool.
- Erosion by ice movement on the reservoir surface.

The following existing spatial data will be collected:

- Topography (LiDAR as available).
- Geo-rectified aerial photography and recent stereo pairs to evaluate existing mass wasting sites.
- Geologic and soil mapping, including work done for the Susitna Hydroelectric Project (Acres 1982) and subsequent mapping by USGS and the Alaska Division of Geologic and Geophysical Surveys. This task will be coordinated with the Geology and Soils Study.
- Vegetation mapping; this task will be coordinated with the Botanical Resources Study.

In addition, the following information will be obtained from other resource study leads:

- Expected reservoir surface elevation fluctuations (seasonal, daily, maximum hourly lowering rate) from the Project Operation Study.
- Expected motorized watercraft recreational use data (if any, from the Recreation and Aesthetic Resources Study).
- Daily air temperature (maximum/minimum) and wind (speed, direction) data from the Water Quality Modeling Study (Section 5.6).
- Expected ice development and movement within the reservoir from the Ice Processes Study (Section 7.6).

The existing spatial data will be evaluated to determine if sufficient geologic and soil data are available to evaluate erosion and mass wasting potential. The mass wasting work will be coordinated with the Geology and Soils Study and geotechnical investigations of the dam site and reservoir area that are planned under the geotechnical exploration and testing program. The geotechnical investigations for the dam site and reservoir will cover large, deep rotational and block failures; the Reservoir Erosion Study will cover shallow translational slides (added in response to the FERC comment letter dated May 31, 2012). The initial investigation will be completed by spring 2013. If additional soil/geologic mapping or data on soil characteristics are needed, field mapping and sample collection will occur during summer 2013 in coordination with the Geology and Soils, and Geotechnical studies. This work could include mapping or collection of soil properties of interest in representative areas, including soil texture, depth, permafrost presence/absence, infiltration capacity, and cohesion.

The spatial data (topography, geology, soils, vegetation) will be used to prepare an erosion and mass wasting hazard map of the reservoir shoreline and inundation area. Areas with similar slope, soil, aspect, and potential wave fetch will be delineated. Areas above and below the full pool elevation will be mapped separately.

The erosion potential for representative erosion/mass wasting hazard polygons will be evaluated as follows:

- Mass wasting – evaluate potential for mass wasting based on slope gradient, soil properties, and anticipated pore pressures/fluctuations. This work will be carried out in coordination with the geotechnical investigation of the dam site and reservoir area. A GIS-based model such as SHALSTAB may be used to analyze shallow translational slides if sufficient data exist.
- Surface erosion from sheetwash – estimate surface erosion potential using WEPP and/or RUSLE.
- Wind (aeolian) erosion from exposed reservoir and delta surfaces and the floodplain downstream of Watana Dam – evaluate using the USDA-NRCS WEQ (Wind Erosion Equation) or WEPS (Wind Erosion Production System) to provide information on dust production for the recreation and aesthetics studies (in response to request by USDOI-NPS in a letter dated May 24, 2012).
- Wave erosion (wind and boat wakes if motorized boat recreation is permitted) – estimate erosive energy of waves based on methods in Finlayson (2006) and Sherwood (2006).
- Solifluction, freeze-thaw, and thawing of permafrost – evaluate potential based on soil properties, seasonal reservoir water elevations, and daily maximum/minimum temperatures.
- Beach/bank development at full pool – use the beach development model in Penner (Penner 1993; Penner and Boals 2000).
- Erosion by ice movement on the reservoir surface – evaluate potential for ice erosion based on reservoir elevation and coordination with the Ice Processes Study (Section 7.6).

6.5.4.8.2.4. Bank and Boat Wave Erosion downstream of Watana Dam

It has been suggested that Project operations may cause increased bank erosion, i.e., cumulative to ongoing erosion associated with boat waves, particularly during load-following operations. (This effort was added based on requests from the agencies at the Water Resources TWG meeting on June 14, 2012.) Load-following will primarily occur during the winter months when flows are relatively low (in the range of 5,000 cfs to 14,500 cfs). Boat activity is relatively infrequent (or not present due to ice conditions) during this period; thus, cumulative impacts of these two processes are very unlikely. Based on preliminary information, it appears that the lower portion of the bank that would be affected by the load-following operations is well armored with cobble-sized material; thus, additional erosion due to the load-following alone is unlikely. The Project may reduce flows and the associated river stage during the runoff period in late spring and summer. During the initial phases of the study, data will be collected to assess the amount of armoring of the portion of the banks that will be affected by load-following to assess whether or not bank erosion in this zone is likely. In addition, the bank material characteristics in the range of stages during the periods of frequent boat activity will be assessed under existing conditions and Project operations to determine if changes associated with the Project could cause an increase in bank erosion. If the information indicates the lower portion of the bank is not sufficiently armored and/or boat activity may cause an increase in erosion of the upper part of the bank, the magnitude of the potential effects will be investigated. Factors that may be considered include the following:

- The potential effects of rapid changes in stage, and the associated pore-water pressures on bank stability during the load-following period.
- The typical wave climate and frequency of use of the types of boats that operate in the reach (it is assumed that the boat types and frequency of use will be available from the Recreation studies).
- The change in erosion potential associated with the boat waves due to the change in stage under Project operations during the period of primary boat activity.

6.5.4.8.3. Study Products

The results of the Reservoir Geomorphology component will be included in the Geomorphology Report. Information provided will include the following:

- Determination of average annual trap efficiencies for sediment by general size characterization (clays, silts, sands, and gravels).
- Estimate of average annual sediment loading to the reservoir from the potential primary sources including the upstream Susitna River, reservoir tributaries, and shoreline erosion.
- Estimate of reservoir life based on extrapolation of the sedimentation rate.
- Sediment outflow rating curves to serve as downstream supply for the Fluvial Geomorphology Modeling Study.
- Discussion of the tributary delta formation processes and characterization of the estimated size, vertical extent, and morphology (topset and foreset slopes) of the deltas at the selected tributary mouths.
- Discussion of potential erosion areas within the proposed reservoir, including erosion type, relative erosion potential, Project-related factors affecting erosion, and potential mitigation measures.
- Map showing reservoir erosion hazard areas (completed in coordination with the Geology and Soils and Geotechnical studies).

In addition, an ArcGIS shapefile will be provided with the following information:

- Identification of all tributaries studied for potential tributary delta formation.
- Estimated footprint of delta formation for the selected tributaries.

- Reservoir erosion hazard map units.

6.5.4.9. Study Component: Large Woody Debris

The goal of this study component is to assess the potential for Project construction and operations to affect the input, transport, and storage of large woody debris in the Susitna River. Specific objectives include the following:

- Evaluation of large woody debris recruitment in the Middle and Lower Susitna River Segments' channels (including upstream of Watana Reservoir).
- Characterization of the presence, extent, and function of large woody debris downstream of the Watana Dam site.
- Estimation of the amount of large woody debris that will be captured in the reservoir and potential downstream effects of Project operation.
- Work in conjunction with the Fluvial Geomorphology Modeling Study to estimate potential Project effects on large woody debris recruitment and associated changes in the processes that create and influence the geomorphic features linked to important aquatic habitats of the Middle and Lower Susitna River Segments.

The study area for the Large Woody Debris study component includes the Susitna River from the mouth (RM 0) upstream to the confluence with the Maclaren River (RM 260).

6.5.4.9.1. Existing Information and Need for Additional Information

The role of large woody debris in the development of channel morphology and aquatic habitat has been widely studied in meandering and anastomosing channels. Large wood and wood jams can create pool habitat, affect mid-channel island and bar development, and create and maintain anastomosing channel patterns and side channels (Abbe and Montgomery 1996, 2003; Fetherston et al. 1995; Montgomery et al. 2003; Dudley et al. 1998; Collins et al. 2012). In addition, large wood can provide cover and holding habitat for fish and help create habitat and hydraulic diversity (summary in Durst and Ferguson 2000). Despite the wealth of large woody debris research, little is known of the role of large woody debris in the morphology and aquatic biology of braided, glacial rivers. Large woody debris may play a role in island formation and stabilization, as well as side channel and slough avulsion and bank erosion, although the role of large woody debris in altering hydraulics in the lower Susitna River may be limited due to the size of the river (J. Mouw, ADF&G, personal communication, May 14, 2012).

Construction and operation of the Project has the potential to change the input, transport, stability, and storage of large woody debris downstream of the Watana Dam site by changes to the flow regime, ice processes, and riparian stand development, and interruption of wood transport through the reservoir. An assessment of the source, transport, and storage of large woody debris in the Susitna River and the role of large woody debris in channel form and aquatic habitat is needed to evaluate the magnitude of these effects. Construction and operation of the Project will likely alter large woody debris input and transport downstream of the Watana Dam site. An assessment of the source, transport, and storage of large woody debris in the Susitna River and the role of large woody debris in channel form and aquatic habitat would provide data on the current status of large wood in the river which, in conjunction with data from the studies of hydrology, geomorphology, riparian and aquatic habitat, and ice processes, would be used to determine the potential effects of Project operations on large wood resources. The information can also be used to determine whether protection, mitigation and enhancement (PM&E) measures are necessary, such as a large woody debris management plan and handling of wood that accumulates in the reservoir.

6.5.4.9.2. Methods

Available recent and historic high-resolution aerial photography will be used to assess large woody debris characteristics in the Susitna River between the mouth and the Maclaren River. It is anticipated that large woody debris input, transport, and storage characteristics will vary along the length of the river. Four reaches have been initially delineated with distinct characteristics: downstream of the Three Rivers Confluence; between the Three Rivers Confluence and Devils Canyon; Devils Canyon; and upstream of Devils Canyon. However, the Geomorphic Reaches delineated in the Delineate Geomorphically Similar (Homogenous) Reaches (Section 6.5.4.1) study component will be used as a basis for final reach determination.

Large woody debris will be inventoried to the extent practical on the aerial photographs. Information regarding the sources of large woody debris, locations of large woody debris in the river channel, and the relationship of large woody debris to channel or slough habitat and geomorphic features will be collected and correlated with bank erosion and riparian vegetation mapping from the geomorphology mapping and riparian habitat mapping studies to identify potential recruitment methods (Mouw 2011; Ott et al. 2001). If adequate historic aerial photographs are available, the stability of large wood pieces and jams between photo years will be assessed in representative areas of the river.

It is likely not possible to identify all wood on the aerial photographs. As a supplement to large woody debris information obtained from aerial photographs, a reconnaissance assessment of large woody debris in the Susitna River between the proposed Watana Dam Site and Willow was made in coordination with aquatic/riparian habitat mapping June 2012. This assessment suggested that the primary large woody debris input mechanisms in the Middle Susitna River are wind throw, wind snap, ice snap, and bank erosion. Wood was observed in association with scour pool, islands heads, side channels, and channel margins. The Chulitna River appears to provide a large amount of woody debris to the Susitna River downstream from Three Rivers, where the Susitna becomes braided with both stable, racked log jams and single non-stable piece of wood.

Field studies of large woody debris will take place during 2013–2014 to (1) verify the large wood data collected from the aerial photographs at 4–5 representative sites in each of the four reaches discussed above, and (2) provide more detailed field information on large wood input, stable/key piece size, large wood/aquatic habitat function, and large wood stability in the river within each of the Focus Areas. It is anticipated that the following types of large woody debris data will be collected as part of a field inventory of large wood in 2013–2014:

- GPS location (to correlate with geomorphology, aquatic, and riparian habitat mapping from other studies).
- Wood size class (diameter, length, volume).
- Root wad status of attachment.

- Single piece, accumulation, or log jam.
- Decay class.
- Species if known.
- Input mechanism if known (windthrow, bank erosion, ice processes, etc.).
- Channel location (side; mid channel; side channel inlet, middle, outlet; associated with island or bar – and where on island or bar, etc.).
- Wood orientation in channel.
- In wetted or bankfull channel or potential input (leaning over bankfull channel).
- Function (scour pool, bar forming, island forming, side channel inlet protection, bank protection, aquatic cover, etc.) and associated geomorphic features.
- For log accumulations and jams: key piece size.
- Area/grain size of any associated sediment deposits.

The aerial photograph and field inventories of large wood will be used to determine large wood input processes, large wood transport and storage, and how large wood is functioning in the Susitna River to influence geomorphic, riparian, and aquatic habitat processes. Based on estimated large wood input and transport upstream of the Watana Dam site, the potential effects of reservoir operation on trapping upstream large wood will be assessed. In addition, the potential for operation of the Project to alter large wood input and transport downstream of the dam site will be analyzed. Modeling of the interaction between large woody debris and bedload transport/geomorphic processes will take place at selected Focus Areas utilizing the 2-D models described in Section 6.6. The analysis will require coordination with other geomorphology component studies, and the sediment transport, ice processes, riparian habitat, aquatic habitat, and instream flow studies.

6.5.4.9.3. Study Products

The results of the large woody debris component will be included in the Geomorphology Report. Information provided will include the following:

- Existing large woody debris input mechanisms and source areas.
- Existing large woody debris loading by geomorphic zone.
- Observations and discussion of how large woody debris is currently functioning in the Susitna River, including a discussion of interactions with riparian and aquatic/fish habitat, geomorphic processes (sediment transport/channel forming processes), ice processes, and flows.
- Discussion of potential for Project construction and operation to affect large woody debris input and transport in the Susitna River.
- Map showing current large woody debris loading.

In addition, an ArcGIS shapefile will be provided with the following information:

- Location of large woody debris mapped from aerial photographs and during field visits.

6.5.4.10. Study Component: Geomorphology of Stream Crossings along Transmission Lines and Access Alignments

The goals of this study component are to characterize the existing geomorphic conditions at stream crossings along access road/transmission line alignments and to determine potential geomorphic changes resulting from construction, operation, and maintenance of the roads and stream crossing structures.

6.5.4.10.1. Existing Information and Need for Additional Information

Development of the Watana Dam will require road transportation from either the Denali Highway or the railroad near Gold Creek or Chulitna to the dam site as well as a transmission line from the powerhouse to an existing transmission line intertie. Construction, use, and maintenance of the roads and transmission lines have the potential to affect stream geomorphology if stream crossing structures constrict flow or alter transport of sediment or large wood, or if sediment is delivered to the streams from erosion of the road prism.

Three different access/transmission alignments are currently being considered (Figure 6.5-7). Work currently underway may refine or change the number of alignments that are finally considered for the project, and may include upgrades to existing road systems (e.g., Denali Highway). The Geomorphology of Stream Crossings along Transmission Lines and Access Alignments study area will include the corridors that are under consideration at the beginning of the study work in 2013.

The three alignments currently under consideration are designated as Denali, Chulitna, and Gold Creek. The Alaska Department of Transportation and Public Facilities (ADOT&PF) evaluated potential access corridors, including the Denali and Chulitna options (HDR 2011). The analysis considered the number of stream crossings as one criterion, among many others, during the screening process, but a detailed analysis of the geomorphic effects of the stream crossings on bedload transport, large woody debris, and channel functions was not conducted.

A road in the Denali alignment would cross Seattle Creek and Brushkana Creek, two major drainages within the Nenana River watershed, and Deadman Creek within the Susitna River watershed. A road in this alignment would require a total of 15 stream crossings. A Gold Creek access alignment would require 23 stream crossings. The major streams that would be crossed by the Gold Creek access alignment include Gold Creek, Fog Creek, and Cheechako Creek. Smaller streams crossed include tributaries to Prairee and Jack Long creeks, and a number of unnamed tributaries to the Susitna River. A road in the Chulitna alignment would require about 30 stream crossings including the Indian River, and Thoroughfare, Portage, Devils, Tsusena, and Deadman creeks. The Chulitna alignment would also cross 10 small, unnamed tributaries of Portage Creek, three small tributaries of Devils Creek, seven smaller tributaries to the Upper Susitna River Segment, and two tributaries of Tsusena Creek. Construction of Project access roads and transmission lines would require stream crossing structures. Stream crossing structures have the potential to affect stream geomorphology in the following ways:

- Altering hydraulics upstream and downstream of the crossing if flow is constricted. This can lead to sediment deposition upstream of the crossing or bank erosion/channel incision downstream.
- Altering migration of streams across a floodplain.

- Inhibiting movement of large woody debris.
- Increasing sediment delivered to a stream if road erosion is occurring near stream crossings.

Data collected during this study will help determine the potential for proposed stream crossings to affect stream hydraulics, morphology, sediment transport, and large woody debris transport. This analysis will also provide data needed for design of appropriate stream crossing structures and PM&E measures to minimize effects.

6.5.4.10.2. Methods

The following data would be obtained from existing sources:

- Topography at stream crossings.
- Aerial photography of stream crossings.
- Crossing design – information on the culvert or bridge characteristics planned at each crossing will be obtained from Project engineering designs (HDR 2011 and subsequent reports).
- Road design – information on the proposed road prism in the vicinity of stream crossings will be obtained from Project engineering designs, including surfacing, gradient, expected traffic levels, and road prism width.

A field assessment of each stream crossing along routes being considered will be made during the summer of 2013. Fieldwork will be carried out in conjunction with the Aquatic Resources Study (Access Alignment, Transmission Alignment and Construction Area component), if possible. The following geomorphic information will be collected for each stream crossing:

- Stream characteristics – gradient, wetted and bankfull width, and depth.
- Substrate characteristics – existing substrate size and description of relative sediment loading (based on field evidence of fresh deposits, large gravel bars, etc.).
- Existing large woody debris size and loading.
- Geomorphic channel type (Rosgen classification is recommended by USFS in its study request dated May 31, 2012) and confinement.
- Existing and potential for bank erosion will be measured or evaluated for a minimum of 100 feet upstream and downstream of each proposed crossing.
- Potential for channel migration will be evaluated from aerial photographs if available, supplemented by field/aerial observations.

The potential effects of stream crossings on geomorphology will be analyzed based on stream characteristics and the proposed design of crossing structures. The evaluation will include the following:

- Channel morphology, sediment dynamics – the hydraulic characteristics and bedload transport capacity of existing channel and of proposed crossing structures will be estimated and compared. Guidelines in the existing stream crossing design Memorandum of Agreement (MOA) will be considered (ADOT&PF 2001).

- Channel migration zone – the existing channel migration zone will be mapped for alluvial channels that show evidence of migration across the floodplain. Effects of proposed crossing structures on channel migration will be analyzed.
- Large woody debris transport – potential effects on large woody debris transport will be evaluated based on channel crossing type and width. The potential for culvert plugging will be ranked based on observed large woody debris size in the stream and proposed culvert size.
- Erosion and delivery of road sediment to stream – erosion from any unpaved roads will be estimated using the WEPP or SEDMODL algorithms. Wind (aeolian) erosion from unsurfaced areas (roads, parking areas, airstrip, etc.) will be evaluated using the U.S. Environmental Protection Agency (EPA) methodology (AP-42) to provide information on dust production for the recreation and aesthetics studies. (This effort was added in response to a request by USDOI-NPS in a letter dated May 24, 2012.)

6.5.4.10.3. Study Products

The results of the Geomorphology of Stream Crossings along Transmission Lines and Access Alignments component will be included in the Geomorphology Report. This will include a discussion of the potential effects of road/transmission alignments on the following:

- Channel migration zones (potential effects of crossings on stream and vice versa)
- Channel aggradation/erosion upstream and downstream of crossing
- Blocking large woody debris transport
- Increased turbidity/sediment input to streams

6.5.4.11. Study Component: Integration of Fluvial Geomorphology Modeling with the Geomorphology Study

The Geomorphology and Fluvial Geomorphology Modeling studies are inextricably linked, and in reality, should be viewed as a single, integrated study. The efforts of the Geomorphology Study identify the specific geomorphic (and habitat-related) processes that require further quantification, identify a significant portion of the data needs, and provides the basic information and context for performing the Fluvial Geomorphology Modeling Study. During the Fluvial Geomorphology Modeling Study, results from the Geomorphology Study will be used in conjunction with knowledge of the specific needs of the other resource teams to ensure 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 will be provided to the other resource teams for use in their evaluation of potential Project effects.

6.5.4.11.1. Existing Information and Need for Additional Information

The existing information required for this study component was previously described above under the other ten components of the Geomorphology Study, and includes the results from those study components.

6.5.4.11.2. Methods

Results from the previously described Geomorphology Study components will be compiled and used by the Fluvial Geomorphology Modeling Study team to guide development of the models and interpretation of the model results. During the modeling phase, close coordination will occur between the two teams, and with the other resource teams, to insure that the relevant information is being used in an appropriate manner and that the results being obtained from the baseline models are consistent with the observed behavior of the river. Since there will be considerable overlap between the Geomorphology and Fluvial Geomorphology teams, this coordination between these two teams will be seamless and ongoing throughout the study.

Specific aspects of the Geomorphology Study that will be used to guide development of the models and interpretation of the model results for the Fluvial Geomorphology Modeling Study, particularly as they relate to the habitat indicators, include the following:

- The reach delineations under Section 6.5.4.1 will define and provide descriptions of the geomorphically- and ecologically-significant macro-scale characteristics of each segment of the study reach. As described in Section 6.6, the 1-D bed evolution model will be used to quantify the reach-scale hydraulic and sediment transport conditions in the study reach over the range of flows for both existing and Project conditions to expand and refine these descriptions. The initial descriptions will guide development of the model, specifically by defining geomorphically similar reaches where model input parameters such as bed material gradations and hydraulic roughness coefficients are similar. The descriptions will also guide interpretation of the model results by defining reaches where the responses to Project actions are expected to be similar, providing a framework for evaluating and summarizing reach-scale processes that affect geomorphic features and associated habitat.
- The bedload and suspended sediment load data being collected by the USGS under Section 6.5.4.2 will be used to calibrate and verify the predicted transport rates in the bed evolution model, and to assess the natural variability in transport rates on a seasonal and annual basis under existing and historic conditions.
- Data from the Sediment Supply and Transport Study Component (Section 6.5.4.3) will provide tributary sediment input boundary conditions for both the existing and project conditions the bed evolution models.
- Results from the Assess Geomorphic Change Study Component (Section 6.5.4.4) will be used to provide a macro-scale understanding of the changes in geomorphic and habitat features over the past several decades. In particular, the Turnover Rate analysis that is part of this study component will provide a measure of the lateral sediment input to the mainstem due to bank and bar erosion.
- The stream flow analysis under the Reconnaissance-level Assessment of Project Effects study component (Section 6.5.4.6) will provide a basis for assessing seasonal and annual hydrologic variability under existing and Project conditions to guide both development of the hydrologic input data for the bed evolution model, and interpretation of the temporal variability in model results, particularly for the long-term model runs. The sediment transport analysis portion of this study component will be used to ensure that baseline

model results accurately reflect the historic and existing sediment balance along the study reach.

- Information from the Large Woody Debris study component (Section 6.5.4.7) will be considered in establishing channel roughness parameters for the hydraulic model, and if appropriate, significant LWD clusters will be considered in establishing the local erodibility of banklines along the project reach.
- Sediment trap efficiency results from the Reservoir Geomorphology Study Component (Section 6.5.4.8) will provide the upstream sediment input boundary conditions for the Project-conditions bed evolution model.

6.5.4.11.3. Study Products

The following specific items will be provided from this study to assist the Fluvial Geomorphology Modeling Study and other resources teams with their analysis. A detailed description of how the results from the Geomorphology and Fluvial Geomorphology Modeling Studies will be integrated, and specifically, how the modeling results will be used to update and refine the Geomorphology Study results is presented in Section 6.6.4.3.

- Reach delineations, description of key geomorphic attributes and characterization of the geomorphology of the Susitna River.
- Identification of processes that create and influence the geomorphic features that help comprise the aquatic and riparian habitat.
- Bedload and suspended sediment load rating curves at key gages (Gold Creek/above Talkeetna, Tsusena Creek (if available), Chulitna River above Talkeetna, Talkeetna River near Talkeetna, Sunshine, Susitna Station) based on USGS field data. Separate curves will be developed for each of the following sediment size ranges:
    - Gravel/cobble bedload
    - Sand bedload
    - Suspended sand load
    - Wash load.
- Estimates of annual load of each of the above sediment size ranges passing each gage for the extended flow record under existing and Project conditions.
- Summary of key changes in geomorphic features/units (i.e., island/bar evolution, main channel width and form, bank erosion, changes in side channels, side sloughs, upland sloughs) based on historical aerial photography.
- Estimates of historic LWD loading rates from upstream and lateral sources.
- Estimates of trap efficiency of the proposed reservoir.

6.5.5. Consistency with Generally Accepted Scientific Practice

The methods described for geomorphology are similar to those used for other recent hydroelectric project licensing procedures and follow current scientific literature (see Literature Cited, Section 6.5.8).

- The Geomorphic Classification component will use a combination of the numerous river classifications that currently exist (Leopold and Wolman 1957; Schumm 1963, 1968; Mollard 1973; Kellerhals et al. 1976; Brice 1981; Mosley 1987; Rosgen 1994, 1996; Thorne 1997; Montgomery and Buffington 1997; Vandenberghe 2001).
- The Bedload and Suspended Load Data Collection component will be conducted by USGS using its currently accepted field methods.
- The Sediment Supply and Transport in the Middle and Lower Susitna River Segments component will use published USGS sediment and flow data and USGS-endorsed correction factors to develop rating curves (Cohn and Gilroy 1991; Duan 1983). Bed mobilization and effective discharge will be computed using currently recognized methods (Mueller et al. 2005; Biedenharn et al. 2000).
- The Geomorphic Change Analysis and Habitat versus Flow components will use geo-rectified aerial and satellite images to compare the river between years and flows. These methods are widely used to compare changes in river systems.
- The Reconnaissance-Level Assessment of Geomorphic Change in the Lower Susitna River Segment will utilize published USGS flow and sediment data and the analytical framework developed by Grant et al. (2003).
- The Reservoir Geomorphology Study will use several widely-accepted methods to calculate sediment trap efficiency (Churchill 1948; Brune 1953; Einstein 1965; Miller 1953; Lara and Pemberton 1965; Chen 1975). The delta formation study will use methods developed and applied at similar projects (e.g., Boundary Hydroelectric Project, FERC 2144) to analyze delta formation. Reservoir erosion will use models and analysis methods developed and widely used for either general erosion (e.g., SHALSTAB, WEPP/RUSLE) or for reservoir-based beach development (Penner 1993; Penner and Boals 2000).
- The Large Woody Debris Study component and large wood inventory will be based on widely used methods (Schuett-Hames et al. 1999).
- The Geomorphology of Stream Crossings along Transmission and Access Alignments component will use guidelines from the existing stream crossing design MOU (ADOT&PF 2001) along with site-specific analyses of channel dynamics.

6.5.6. Schedule

The schedule for conducting the Geomorphology Study is presented in Table 6.5-5. The Geomorphology Study includes several efforts that were conducted in 2012. This included both analysis and field efforts. One of the two field efforts in the Geomorphology Study is the USGS data collection effort (Section 6.5.4.2). It was conducted in the late spring and summer of 2012. A total of five sets of sediment transport data were collected at the Susitna River above Tsusena

Creek, Susitna River near Talkeetna (substituted for Gold Creek), and the Susitna River at Sunshine and four sets on the Chulitna River below canyon. Provisional results of the data collection effort will be delivered to the other studies as soon as they are available from the lab during fall 2012. Suspended and bedload data, including calculation of sediment transport ratings and daily loads, will be compiled in a technical memorandum delivered early in 2013.

The other primary 2012 field effort in the Geomorphology Study is the collection of aerial photographs (Sections 6.5.4.4 for Lower Susitna River Segment and 6.5.4.5 for Middle Susitna River Segment). Collection of aerial photographs was included in the 2012 effort to support the digitization of aquatic habitat types, geomorphic features and to access channel change. This information in turn helps support the site selection process for other studies. Due to the combination of weather and flow conditions during 2012, only the 23,00cfs aerial photography was acquired in 2012. Performing the digitization of the 2012 aerial photography was dependent on the AEA SDC being able to fly the aerials at the appropriate discharge. The remainder of the effort—12,500 cfs and 5,100 cfs aerial photography—will be collected in 2013. Consequently, only the digitization of the aquatic habitat features associated with the 23,000 cfs flow was performed in 2012. Therefore, 2012 study products only include the 23,000 cfs condition. The acquisition, digitization and analysis work associated with the 12,500 and 5,100 cfs flows will be performed in 2013.

The other study components in the Geomorphology Study that include 2012 efforts are Delineation of Geomorphically Similar River Segments (Section 6.5.4.1), Sediment Supply and Transport Middle and Lower Susitna River Segments (Section 6.5.4.3), Reconnaissance-Level Assessment of the Project Effects on the Lower River Channel (Section 6.5.4.6) and Riverine Habitat Versus Flow Lower River Segment. The 2012 portion of the geomorphic reach delineation has been completed and is summarized in this document (Section 6.5.4.1). Continued refinement and determination of morphometric parameters for the reaches will be ongoing in 2013 as additional information becomes available. The remaining three efforts require information from the operations modeling (Engineering Study) consisting of downstream flows and stages associated with Project operations. This information was available the end of November 2012. Therefore, completion of the identified 2012 efforts has been delayed until January and early February of 2013. The delivery of these 2012 study results in this timeframe will allow their use in the collaborative process that will occur in Q1 and early Q2 of 2013 associated with vetting the selection of the proposed Focus Areas and in evaluating the need to extend detailed ISF and Geomorphology Study limits further downstream in the Lower Susitna River Segment.

Table 6.5-3 shows the schedule for the performance and completion of the Geomorphology Study. This schedule shows components of the Geomorphology Study that have early component performed in 2012 or early 2013 (in the case of studies that have been delayed per the discussion in the previous paragraph) and then a second effort that is performed in late 2013 and 2014. This is due to the 2012 efforts being conducted with best available information to provide primarily results to inform the development and execution of other studies. The 2013 effort also includes optional aerial photograph acquisition in the Lower River and assisted mapping of macrohabitat types if studies are extended into the Lower River. The subsequent 2013 and 2014 efforts are performed to incorporate additional information collected in 2013 and to assess the effects of altered sediment supply and flow regimes for the alterative operational scenarios.

The Initial Study Report (ISR) and the Updated Study Report (USR) explaining the actions taken and data collected to date will be due within one and two years, respectively, of FERC's Study Plan Determination.

6.5.7. Relationship with Other Studies

A flow chart (Figure 6.5-8) describes study interdependencies and outlines the information and products required from other studies and the timing of delivery to successfully complete the Geomorphology Study on schedule. In the study interdependencies chart, the studies providing input are listed in the five sided boxes at the top of the chart. The corresponding Sections are provided in parentheses. The rectangular boxes below the five sided boxes list the major information and products that the other studies will provide to the Geomorphology Study. The primary studies that the Geomorphology Study will require information from and the associated information are listed below and in Table 6.5-6.

- Mainstem (Open-water) Flow Routing Study (Section 8.5.4.3)
  - Current and historical cross-sections
  - Thalweg Profile
  - Results of flow routing to Sunshine Station
- Fluvial Geomorphology Modeling Study (Section 6.6)
  - Bed material sizes
  - Geomorphic field assessment and observations
  - Geomorphic feature mapping at Focus Areas
- Ice Processes Study (Section 7.6)
  - Ice effects on banks, side channels, bed scouring and river stage
- Riparian Instream Flow Study (Section 8.6)
  - Riparian/floodplain sedimentation rates
  - Dating of surfaces
  - Floodplain soil profiles and depth
- Reservoir Operations Modeling (Engineering)
  - Results of operations modeling
- Water Modeling Quality Study (Section 5.6)
  - Reservoir sediment trap efficiency for alternative scenarios

Studies that are considered secondary sources of to the Geomorphology Study information include the Geology and Soils Characterization Study (Section 4.5), and Riparian Vegetation Study Downstream of the Proposed Susitna-Watana Dam (Section 11.6). The USGS will provide the extended hydrologic record for 11 gage locations for a period of 61 years. This information will be used as the hydrologic record for analysis of existing stream flow characteristics and will also provide the flows to be used by the Reservoir Operations Study

(Engineering) and the Mainstem (Open-water) Flow Routing Study (Section 8.5.4.3) to generate flow conditions in the Middle and Lower River Segments for the with-Project conditions.

In the chart, the timing of delivery of each type of information or study product to the Geomorphology study is provided in parentheses by quarter and year. For example, "(Q4-12)" indicates the information will be provided in the fourth quarter of 2012. Table 6.5-6 provides these interdependencies in tabular form including the study providing the information or product and which area of the Geomorphology Study requires the information or product and the timing.

The chart indicates which areas of the Geomorphology Study require the information. The Geomorphology Study areas are identified in the blue ellipses. To simplify the chart, study components have been lumped into areas. The study components associated with each area identified in the blue ellipses are listed below.

<u>Geomorphic reach classification and delineation:</u>

- Delineate geomorphically similar (homogeneous) reaches (Section 6.5.4.1)

<u>Aerial photo analysis of geomorphic features and riverine habitat:</u>

- Riverine habitat versus flow relationship Middle Susitna River Segment (Section 6.5.4.5)
- Riverine habitat area versus flow Lower Susitna River Segment (Section 6.5.4.7)

<u>Geomorphic assessment:</u>

- Bedload and suspended load data collection (Section 6.5.4.2)
- Sediment supply and transport Middle and Lower Susitna River Segments (Section6.5.4.3)
- Assess geomorphic change Middle and Lower Susitna River Segments (Section 6.5.4.4)
- Reconnaissance-level assessment of project effects on Lower and Middle Susitna River Segment channel (Section 6.5.4.6)
- Reservoir geomorphology (Section 6.5.4.8)
- Large woody debris (Section 6.5.4.9)
- Geomorphology of stream crossings along transmission lines and access alignments (Section 6.5.4.10)

The chart also shows products and information the Geomorphology Study will provide to other studies and the timing of their delivery. Table 6.5-7 provides these study interdependencies in tabular form including the area of the Geomorphology Study providing the information and which study requires the information or study product. In the flow chart the products and information the Geomorphology Study will provide are identified in the rectangles below the study area ellipses. The quarter and year that the products and information will be provided to other studies is indicated in the parentheses adjacent to each item. At the bottom of the chart, the studies that require the information from the Geomorphology Study are listed in the five sided boxes. Included in parentheses adjacent to each study is the section of the RSP that the product or information will support. The primary studies requiring information from the Geomorphology Study and the associated information they will require are listed below. The information they will require is identified in Table 6.5-7 (Note: Tables 6.6-6 and 6.6-7 provide a detailed list of 1-

D and 2-D model output and other information the Fluvial Geomorphology Modeling and Geomorphology Studies will provide to other studies):

- Fish and Aquatics Instream Flow Study Fish (Section 8.5)
- Riparian Instream Flow Study (Section 8.6)
- Fluvial Geomorphology Modeling Study (Section 6.6)
- Characterization and Mapping of Aquatic Habitats Study (Section 9.9)
- Aesthetic Resources Study (Section 12.6)
- River Recreation Flow and Access Study (Section 12.7)

In addition to these studies, other studies may utilize input from the Geomorphology Study to help identify their downstream study limits.

6.5.8. 2012 Study Efforts

The Geomorphology Study (Section 6.5) has several study components that include 2012 study efforts to help prepare or refine various aspects of the Study Plans. Table 6.5-8 lists these study components, the portions of the studies that support development of the study plan, and the aspect of the study plan they support. These 2012 efforts were intended to be completed by November 2012 to provide support for the Study Plan development; however, several circumstances have resulted in portions of the efforts not being completed in November 2012. Table 6.5-8 also identifies efforts completed in time to fully support development of the study plan and which were partially completed. Efforts not fully completed prior to filing of the study plan, will be completed in December 2012 and reported on in January 2013. The results of the 2012 Geomorphology Study will support Water Resources Technical Workgroup (TWG) meetings to be held in February and March 2013 involving review and finalization of the proposed Focus Areas and the downstream study limit.

6.5.9. Level of Effort and Cost

Initial planning level estimates of the costs to perform the components of the Geomorphology Study are provided in Table 6.5-9. The total effort for the Geomorphology Study, including Component 2, Sediment Data Collection, to be performed by the USGS, is estimated to cost between approximately $1.6 and $2.1 million.

6.5.10. Literature Cited

Acres. 1982. Susitna Hydroelectric Project, Reservoir Slope Stability. Prepared for Alaska Power Authority, Anchorage, Alaska. March 1982.

Abbe, T.B., Montgomery, D.R. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. Regulated Rivers: Research & Management 12, 201–221.

Abbe, T.B., Montgomery, D.R. 2003. Patterns and processes of wood debris accumulation in the Queets River basin, Washington. Geomorphology 51, 81–107.

ADF&G/ADOT&PF. 2001. Memorandum of agreement between Alaska Department of Fish and Game and Alaska Department of Transportation and Public Facilities for the design, permitting, and construction of culverts for fish passage. Signed 8/7/2001.

Alaska Energy Authority (AEA). 2011. Pre-Application Document: Susitna-Watana Hydroelectric Project FERC Project No. 14241. December 2011. Prepared for the Federal Energy Regulatory Commission by the Alaska Energy Authority, Anchorage, Alaska.

Andrews, E.D., 1980. Effective and Bankfull Discharges of Streams in the Yampa River Basin, Colorado and Wyoming. Journal of Hydrology, 46(1980), pp. 311-330.

Andrews, E.D., 1986. Downstream Effects of Flaming Gorge Reservoir on the Green River, Colorado and Utah. Geological Society of American Bulletin, v. 97, August, pp. 1012-1023.

Andrews, E.D. and Nankervis, J.M., 1995. Effective discharge and the design of channel maintenance flows for gravel-bed rivers. American Geophysical Union, v. 89, pp. 151-164.

Benson, M.A. and Thomas, D.M., 1966. A definition of dominant discharge. Bulletin of the International Association of Scientific Hydrology 11, pp. 76-80.

Biedenharn, D.S., Copeland, R.R., Thorne, C.R., Soar, P.J., Hey, R.D., and Watson, C.C., 2000. Effective Discharge Calculation: A Practical Guide. Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi, ERDC/CHL TR-00-15, August.

Brice, J.C., 1981. Stability of relocated stream channels. Federal Highway Commission Report FHWA/RD-80/158, 177 p.

Brune, G.M. 1953. Trap efficiency of reservoirs. Transactions of the American Geophysical Union, Vol. 34(3). 407 – 418.

Buffington, J. M., and D. R. Montgomery. 1997. A systematic analysis of eight decades of incipient motion studies, with special reference to gravel-bedded rivers, Water Resour. Res., 33, 1993–2029.

Chen, C.N. 1975. Design of sediment retention basins, Proceedings, National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, pp. 58 – 68.

Churchill, M.A. 1948. Discussion of “Analysis and Use of Reservoir Sedimentation Data” by L.C. Gottschalk. Proceedings of the Federal Interagency Sedimentation Conference, Denver Colorado. 139 – 140.

Clipperton, G.K., C.W. Koning, A.G.H. Locke, J.M. Mahoney, and B. Quazi. 2003. Instream Flow Needs Determinations for the South Saskatchewan River Basin, Alberta, Canada. Alberta Environment, Publication No. T/719.

Collier, M.C., R.H. Webb, and J.C. Schmidt, 1996. A primer on the Downstream Effects of Dams. U.S. Geological Survey, Circular 1126. 108 pp.

Cohn, T.A., and E.J. Gilroy. 1991. Estimating Loads from Periodic Records. U.S. GeologicalSurvey Branch of Systems Analysis Technical Report 91.01. 81 pp.

Collins, B.D., D.R. Montgomery, K.L. Fetherston, and T.B. Abbe. 2012. The floodplain large-wood cycle hypothesis: A mechanism for the physical and biotic structuring of temperate forested alluvial valleys in the North Pacific coastal ecoregion. Geomorphology 139–140:460–470.

Darby, S.E. and Simon, A. (eds), 1999. Incised River Channels. Wiley, Chichester, 442 p.

Duan, N. 1983. Smearing Estimate: A Nonparametric Retransformation Method. Journal of the American Statistical Association, Vol. 78(383): 605–610.

Dudley, S. J., J. C. Fischenich, and S. R. Abt. 1998. Effect of woody debris entrapment on flow resistance. Journal of the American Water Resources Association 34: 1189-1198.

Durst, J.D. and J. Ferguson. 2000. Large woody debris, an annotated bibliography, Compiled for the Region III Forest Practices Riparian Management Committee. Compiled for Alaska Dept. of Fish & Game, Habitat & Restoration Division.

Einstein, H.A. 1965. Final Report Spawning Grounds. University of California Hydrologic Engineering Laboratory. 16 pages, 2 tables, 10 figures.

Ferguson, R.I. 1986. River Loads Underestimated by Rating Curves. Water Resources Research, Vol. 22(1): 74–76.

Fetherston, K.L., Naiman, R.J., Bilby, R.E. 1995. Large woody debris, physical process, and riparian forest development in montane river networks of the Pacific Northwest. Geomorphology 13, 133–144.

Finlayson, D.P., 2006. The Geomorphology of Puget Sound Beaches. Ph.D. Dissertation, University of Washington, Seattle, WA. 216pp. Available at http://david.p.finlayson.googlepages.com/pugetsoundbeaches.

Friedman, J.M., W.R. Osterkamp, M.L. Scott, and G.T. Auble, 1998. Downstream Effects of Dams on Channel Geometry and Bottomland Vegetation: Regional Patterns in the Great Plains. Wetlands, v. 18, no. 4, December, pp. 619 – 631.

Grant, G.E. and F.J. Swanson. 1995. Morphology and processes of valley floors in mountain streams, Western Cascades, Oregon. In Natural and Anthropogenic Influences in Fluvial Geomorphology, AGU Geophysical Monograph 89, 83-102.

Grant, G.E., J.C. Schmidt, and S.L. Lewis. 2003. A geological framework for interpreting downstream effects of dams on rivers. AGU, Geology and Geomorphology of the Deschutes River, Oregon, Water Science and Application 7.

Germanoski, D., 1989. The effects of sediment load and gradient on braided river morphology. Unpublished Ph.D. dissertation, Colorado State University, Fort Collins, CO, 407 p.

Germanoski, D. and Harvey, M.D., 1993. Asynchronous terrace development in degrading braided channels. Physical Geography, v. 14(4), pp. 16-38.

Germanoski, D. and Schumm, S.A., 1993. Changes in braided river morphology resulting from aggradation and degradation. The Journal of Geology, v. 101, pp. 451-466.

Germanoski, D., 2001. Bar Forming Processes in Gravel-bed Braided Rivers, with Implications for Small-scale Gravel Mining. In Anthony, D.J., Harvey, M.D., Laronne, J.B., and Mosley, M.P. (eds), *Applying Geomorphology to Environmental* Management, pp. 3-32.

Guy, H.P. 1964. An Analysis of Some Storm-Period Variables Affecting Stream Sediment Transport. U.S. Geological Survey Professional Paper No. 462E.

Guymon, G.L. 1974. Regional Sediment Yield Analysis of Alaska Streams. ASCE Journal of the Hydraulics Division, Vol. 100(1). 41 – 51.

Hamrick, J.M. 1992. A Three-Dimensional Environmental Fluid Dynamics Computer Code: Theoretical and Computational Aspects, Special Report 317. The College of William and Mary, Virginia Institute of Marine Science. 63 pp.

Harvey, M.D., Mussetter, R.A., Anthony, D.J., 2003. Island Aging and Dynamics in the Snake River, Western Idaho, USA. Abstract: Proceedings of Hydrology Days 2003, American Geophysical Union, Fort Collins, Colorado.

Harvey, M.D. and Trabant, S.C., 2006. Evaluation of Bar Morphology, Distribution, and Dynamics as Indices of Fluvial Processes in the Middle Rio Grande. Abstract for Middle Rio Grande Endangered Species Collaborative Program, First Annual Symposium, Albuquerque, New Mexico, April.

HDR. 2011. Watana transportation access study, Project No. 82002. Draft report prepared for the Alaska Department of Transportation and Public Facilities. November 29, 2011.

Juracek, K.E. and Fitzpatrick, F.A., 2003. Limitation and implications of stream classification. Jour. of American Water Res. Assn, v. 83, no. 3, June, pp. 659-670.

Kellerhals, R., Church, M., and Bray, D.I., 1976. Classification and analysis of river processes. Jour. of Hydraulic Div. Proc. 102, pp. 813-829.

Koch, R.W. and G.M. Smillie. 1986. Bias in Hydrologic Prediction Using Log-Transformed Regression Models. Journal of the American Water Resources Association, Vol. 22: 717–723.

Labelle, J.C., M. Arend, L. Leslie, W. Wilson, 1985. Geomorphic Change in the Middle Susitna River since 1949. Report by Arctic Environmental Information and Data Center. Prepared for the Alaska Power Authority.

Lane, E.W. 1955. The importance of fluvial morphology in hydraulic engineering. Proc. ASCE, Vol. 81, Paper 745, pp. 1-17.

Lara, J.M., and E.L. Pemberton. 1965. Initial Unit Weight of Deposited Sediments. Proceedings of the Federal Interagency Sedimentation Conference, 1963. Miscellaneous Publication No. 970. USDA, Agriculture Research Service. Washington, D.C. 818 – 845.

Leopold, L.B. and Wolman, M.G., 1957. River channel patterns: Braided meandering and straight. U.S. Geol. Survey Prof. Paper 282-B, 47 p.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964. Fluvial Processes in Geomorphology. Freeman Co., San Francisco, California and London, 522 p.

Li, R.M. and H.W. Shen, 1975. Solid Particle Settlement in Open-Channel Flow, ASCE J Hyd Div, V 101, NY7, pp 917-931.

Miller, A.J., 1995. Valley morphology and boundary conditions influencing spatial patterns of flood flow. In Natural and Anthropogenic Influences in Fluvial Geomorphology, AGU Geophysical Monograph 89, 57-82.

Miller, C.R. 1953. Determination of the Unit Weight of Sediment for Use in Sediment Volume Computations. U.S. Bureau of Reclamation. Denver, Colorado.

Mollard, J.D., 1973. Airphoto interpretation of fluvial features: Fluvial processes and sedimentation. Edmonton, Proceedings of Hydrology Symposium, Univ. Alberta, pp. 341-380.

Montgomery, D.R. and Buffington, J.M., 1997. Channel-reach morphology in mountain drainage basins. Geological Survey America, Bulletin, v. 109, pp. 596-611.

Montgomery, D.R., Collins, B.D., Buffington, J.M., Abbe, T.B. 2003. Geomorphic effects of wood in rivers. In: Gregory, S.V., Boyer, K.L., Gurnell, A.M. (Eds.), The Ecology and Management of Wood in World Rivers. American Fisheries Society, Bethesda, MD, pp. 21–47.

Morris, G.L., G. Annandale, and R. Hotchkiss, 2007. Reservoir Sedimentation, in *Sedimentation Engineering, Processes, Measurements, Modeling and Practice,* ASCE Manuals and Reports on Engineering Practice No 110, pp 579-612.

Morris, G.L. and J. Fan. 1998. Reservoir Sedimentation Handbook. McGraw-Hill Book Co. New York.

Mosley, M.P., 1987. The classification and characterization of rivers. In Richards, K. (ed), River Channels, Oxford, Blackwell, pp. 295-320.

Mouw, J. 2011. Hydrologic controls on the recruitment of riparian plants and the maintenance of floodplain wildlife habitat. Retrieved from Alaska Section of the American Water Resources Association 2011 Conference Proceedings Website: http://www.awra.org/state/alaska/proceedings/2011abstracts/

Mueller, E. R., J. Pitlick, and J. M. Nelson. 2005. Variation in the reference Shields stress for bedload transport in gravelbed streams and rivers, Water Resources Research, Vol 41, W04006, doi:10.1029/2004WR003692.

Nolan, K.M., Lisle, T.E., and Kelsey, H.M., 1987. Bankfull discharge and sediment transport in northwestern California. A paper delivered at Erosion and Sedimentation in the Pacific Rim, IAHS Publication No. 165, International Association of Hydrological Sciences, Washington, D.C.

O’Connor, J.E. and Grant, G.E. (eds), 2003. A Peculiar River: Geology, Geomorphology, and Hydrology of the Deschutes River, Oregon. Amer. Geophysical Union, Water Science and Application 7, Washington, D.C., 219 p.

Ott, R. A. M. A. Lee, W. E. Putman, O., K. Mason, G. T. Worum, and D. N. Burns. 2001. Bank erosion and large woody debris recruitment along the Tanana River, interior Alaska Report to: Alaska Department of Environmental Conservation Division of Air and Water

Quality Prepared by: Alaska Department of Natural Resources Division of Forestry and Tanana Chiefs Conference, Inc. Forestry Program Project No. NP-01-R9. July 2001.

Parker, G., P. C. Klingeman, and D. G. McLean. 1982. Bedload and size distribution in paved gravel-bed streams, J. Hyd. Div. Am. Soc. Civ. Eng., 108(HY4), 544– 571.

Penner, L. A., R.G. Boals, 2000. A Numerical Model for Predicting Shore Erosion Impacts Around Lakes and Reservoirs, Canadian Dam Association, pp 75 – 84.

Penner, L. A., 1993. Shore Erosion and Slumping on Western Canadian Lakes and Reservoirs, A Methodology for Estimating Future Bank Recession Rates, Environment Canada, Monitoring Operations Division.

Pickup, G. and Warner, R.F., 1976. Effects of hydrologic regime on magnitude and frequency of dominant discharge. Journal of Hydrology, v. 29, pp. 51-75.

Pickup, G., 1976. Adjustment of stream channel shape to hydrologic regime. Journal of Hydrology, v. 30, pp. 365-373.

R&M Consultants, Inc. and Trihey & Associates. 1985a. Response of Aquatic Habitat Surface Areas to Mainstem Discharge in the Yentna to Talkeetna Reach of the Susitna River. Prepared under contract to Harza-Ebasco, for Alaska Power Authority, document No. 2774, June.

R&M Consultants, Inc. and Trihey & Associates. 1985b. Assessment of access by spawning salmon into tributaries of the Lower Susitna River. Prepared under contract to Harza-Ebasco, for Alaska Power Authority, document No. 2775, June.

Rosgen, D.L., 1994. A classification of natural rivers. Catena. 22, pp. 169-199.

Rosgen, D.L., 1996. Applied river morphology. Wildland Hydrology books. Pagosa Springs, CO.

Sabo, J.L., K. Bestgen, W. Graf, T. Sinha, E.E. Wohl, 2012. Dams in the Cadillac Desert: downstream effects in a geomorphic context. Annals of the New York Academy of Sciences, 1249: 227-246.

Schmidt, J. C., and P. R. Wilcock, 2008. Metrics for assessing the downstream effects of dams, Water Resour. Res., 44, W04404, doi:10.1029/2006WR005092.

Schuett-Hames, D. A. E. Pleus, J. Ward, M. Fox, J. Light. 1999. TFW monitoring program method manual for the large woody debris survey. Timber Fish & Wildlife TFW-AM9-99-004. June 1999.

Schumm, S.A., 1963. A tentative classification of alluvial river channels. U.S. Geol. Survey Circ. 477, 10 p.

Schumm, S.A., 1968. River adjustment to altered hydrologic regimen, Murrumbidgee River and paleochannels, Australia. U.S. Geol. Survey Prof. Paper 598, 65 p.

Schumm, S.A., 1977. The Fluvial System. John Wiley & Sons, New York, 338 p.

Schumm, S.A., 1991. To Interpret the Earth. Cambridge Univ. Press, Cambridge, U.K., 133 p.

Schumm, S.A., 2005. River Variability and Complexity. Cambridge Univ. Press, Cambridge, U.K., 220 p.

Schumm, S.A., Dumont, J.F., and Holbrook, J.M., 2000. Active Tectonics and Alluvial Rivers. Cambridge Univ. Press, Cambridge, U.K., 275 p.

Schumm, S.A., Harvey, M.D., and Watson, C.C., 1984. Incised Channels. Initiation, Evolution, Dynamics, and Control. Water Res. Publ., Littleton, Colorado, 200 p.

Sherwood, C., 2006. Demonstration Sediment-Transport Applets. Available at: http://woodshole.er.usgs.gov/staffpages/csherwood/sedx_equations/sedxinfo.html.

Shields, A., 1936. Application of similarity principles and turbulence research to bedload movement. California Institute of Technology, Pasadena; Translation from German Original; Report 167.

Shields, F.D., Jr, A. Simon, and L.J. Steffen. 2000. Reservoir effects on downstream river channel migration. Environmental Conservation 27(1): 54-66.

Strand, R.I. and E.L. Pemberton, 1987. Reservoir Sedimentation, U.S. Bureau of Reclamation, *Design of Small Dams*, Third Edition, Appendix A, pp 529-564.

Thomas, R.B. 1985. Estimating Total Suspended Sediment Yield with Probability Sampling. Water Resources Research, Vol. 21(9): 1381– 1388.

Thorne, C.R., 1997. Channel types and morphological classification. In Thorne, C.R., Hey, R.D., and Newson, M.D. (eds), Applied Fluvial Geomorphology for River Engineering and Management. Chichester, Wiley, pp. 175-222.

Tinker, K.J. and Wohl, E.E. (eds), 1998. Rivers Over Rock: Fluvial Processes in Bedrock Channels. Amer. Geophysical Union, Geophysical Monograph 17, Washington, D.C., 323 p.

Topping, D.J., D M. Rubin, P. E. Grams, R. E. Griffiths, T. A. Sabol, N. Voichick, R. B. Tusso, K. M. Vanaman, and R. R. McDonald. 2010. Sediment Transport During Three Controlled-Flood Experiments on the Colorado River Downstream from Glen Canyon Dam, with Implications for Eddy-Sandbar Deposition in Grand Canyon National Park, U.S. Geological Survey, Open-File Report 2010-1128, 123 pp.

Trihey & Associates. 1985. Response of Aquatic Habitat Surface Areas to Mainstem Discharge in the Talkeetna-To Devil Canyon Segment of the Susitna River, Alaska. Prepared under contract to Harza-Ebasco, for Alaska Power Authority, document No. 2945.

United States Bureau of Reclamation (USBR). 1987. Design of Small Dams. A Water Resources Technical Publication. U.S. Government Printing Office. Washington, D.C.

URS. 2011. AEA Susitna Water Quality and Sediment Transport Data Gap Analysis Report. Prepared by Tetra Tech, URS, and Arctic Hydrologic Consultants. Anchorage, Alaska. 62 p.+ Appendixes.

U.S. Geological Survey (USGS). 1982. Guidelines for determining flood flow frequency. Bulletin 17B, Hydrology Subcommittee, Interagency advisory committee on water data.

USGS, 1987. Sediment Transport Characteristics of the Selected Streams in the Susitna River Basin, Alaska: Data for Water Year 1985 and Trends in Bedload Transport 1981-85. Open-File Report 87-229. Prepared in cooperation with the Alaska Power Authority, 50 pp.

USGS. 1992. Recommendations for Use of Retransformation Methods in Regression Models Used to Estimated Sediment Loads [“The Bias Correction Problem”]. Office of Surface Water Technical Memorandum No. 93.08. December 31.

Vandenberghe, J., 2001. A typology of Pleistocene cold-based rivers. Quatern. Internl. 79, pp. 111-121.

Walling, D.E. 1974. Suspended Sediment and Solute Yields from a Small Catchment Prior to Urbanization. Institute of British Geographers Special Publication No. 6: 169–192.

Walling, D.E. 1977a. Limitations of the Rating Curve technique for Estimating Suspended Sediment Loads, with Particular Reference to British Rivers. In: Erosion and Solid Matter Transport in Inland Waters, Proceedings of Paris Symposium, July 1977. IAHS Publication No. 122: 34– 48.

Walling, D.E. 1977b. Assessing the Accuracy of Suspended Sediment Rating Curves for a Small Basin. Water Resources Research, Vol. 13(3): 531–538.

Williams, G.P., and Wolman, M.G., 1984. Downstream Effects of Dams on Alluvial Rivers. U.S. Geological Survey Professional Paper No. 1286. 88 pp.

Wolman, M.G. and Miller, J.P., 1960. Magnitude and frequency of forces in geomorphic processes, Journal of Geology, vol. 68, no. 1, pp. 54-74.

Wright, S. A., D. J. Topping, D. M. Rubin, and T. S. Melis. 2010. An approach for modeling sediment budgets in supply-limited rivers, Water Resour. Res., 46, W10538, doi:10.1029/2009WR008600.

6.5.11. Tables

Table 6.5-1. Initial geomorphic reach classifications.

Reach Designation	Upstream Limit RM)	Down- stream Limit (RM)	Reach Classifi-cation	Slope (ft/mi)	Lateral Constraints
Upper Susitna River Segment (UR)					
UR-1	260	248	SC2	NA	Quaternary Basin Fill
UR-2	248	233	SC1	NA	Quaternary Basin Fill
UR-3	233	223	SC1	NA	Quaternary Basin Fill
UR-4	223	206	SC2	NA	Granodiorite
UR-5	206	201	SC1	NA	Quaternary Basin Fill
UR-6	201	184	SC2	NA	Quaternary Basin Fill
Middle Susitna River Segment (MR)					
MR-1	184	182	SC2	9	Gneiss
MR-2	182	166.5	SC2	10	Quaternary Basin Fill
MR-3	166.5	163	SC2	17	Granites
MR-4	163	150	SC1	30	Granites
MR-5	150	145	SC2	12	Moraine and Turbidites
MR-6	145	119	SC3	10	Moraines
MR-7	119	104	SC2	8	Moraines
MR-8	104	98.5	MC1/SC2	8	Holocene Lacustrine and Alluvial Terrace deposits (Reach is a transition from SC2 to MC1 as the Three Rivers Confluence is approached)
Lower Susitna River Segment (LR)					
LR-1	98.5	84	MC1	5	Upper Pleistocene Outwash, Moraine and Lacustrine deposits
LR-2	84	61	MC1	5	Upper Pleistocene Outwash, Moraine and Lacustrine deposits
LR-3	61	40.5	MC3	4	Glaciolacustrine and Moraine deposits
LR-4	40.5	28	MC3	2	Glaciolacustrine and Moraine deposits
LR-5	28	20	SC2	2	Glaciolacustrine and Moraine deposits
LR-6	20	0	MC4	1.4	Glaciolacustrine and Holocene Estuarine deposits

Table 6.5-2. Estimated Water Year 1985 annual sediment loads for the Susitna River and major tributaries (based on USGS 1987).

Gage Station	Drainage Area (sq. mi.)	Annual Water Yield (ac.ft.)	Estimated Annual Sediment Load (million tons)			
			Silt and Clay	Sand	Gravel	Total
Susitna River near Talkeetna	6,320	6,720,000	1.79	1.48	0.019	3.29
Chulitna River near Talkeetna	2,580	6,122,000	4.46	2.99	0.355	7.81
Talkeetna River near Talkeetna	2,006	3,083,000	0.81	0.90	0.054	1.76
Total of the three stations near Talkeetna	10,906	15,925,000	7.06	5.37	0.430	12.9
Susitna River at Sunshine	11,100	17,600,000	8.94	6.03	0.155	15.1
Difference (Sunshine minus near Talkeetna stations)	194	1,675,000	1.88	0.66	-0.275	2.20

Table 6.5-3. Summary of 2012 aerial photo acquisition for the Upper, Middle, and Lower Susitna River segments.

Aerial Coverage (RM)		Date	Discharge Target (cfs)		Actual Discharge (cfs)	
From	To		Gold Creek	Sunshine Station	Gold Creek	Sunshine Station
Upper River						
241	184	09/30/2012	NA[1]	---	18,100	---
264	224	10/20/2012	NA[1]	---	5,000	---
Middle River						
107	98.5	07/27/2012	23,000	---	23,200	---
135	98.5	09/10/2012	12,500	---	13,300	---
136	184	9/30/2012	12,500	---	18,100	---
Lower River						
98.5	54	07/27/2012	---	59,100	---	54,000
98.5	74	09/10/2012	---	36,600	---	38,100
74	0	09/30 - 10/01/2012[2]	---	36,600	---	41,700 to 46,900
18	1	10/10/2012	---	59,100	---	53,700
68	30	10/10/2012	---	59,100	---	53,700

Notes:

1 Aerials are only being used for delineation of geomorphic features and channel change in the Upper River, target flow not required
2 Due to cloud cover, this set of aerials is a combination of photos from 9/30/2012 and 10/01/2012

Table 6.5-4. Middle Susitna River Segment aquatic habitat sites from 1980s to be digitized.

Site Name	River Mile (RM)		Length (Miles)
	Downstream RM	Upstream RM	
Whiskers Slough[1]	100.7	102.0	1.3
Slough 4	105.0	106.5	1.5
Slough 5	107.0	108.5	1.5
Slough 6A[1]	112.0	113.0	1.0
Slough 8	113.4	115.4	2.0
Oxbow II	118.5	120.5	2.0
Slough 8A[1]	124.3	126.6	2.3
Slough 9	128.0	129.5	1.5
Side Channel 10A	131.0	132.8	1.8
Side Channel 10	133.0	134.3	1.3
Slough 11[1]	134.3	136.8	2.5
Gold Creek	136.8	138.3	1.5
Indian River	138.5	139.5	1.0
Slough 21[1]	140.0	142.6	2.6
Slough 22	144.0	145.0	1.0
Fat Canoe Island	146.5	147.5	1.0
Portage Creek[1]	148.3	148.8	0.5
MR-2 Narrow[1,2]	168.5	170.0	1.5
MR-2 Wide[1,2]	170.7	172.5	1.8
MR-2 Straight[2]	173.2	174.9	1.7
MR-2 Tributary[2]	176.0	176.8	0.8
MR-2 Island Bend[2]	178.1	180.3	2.2
Below Dam[1,2]	182.0	183.0	1.0
TOTAL LENGTH	-	-	35.3

Notes:

1 Proposed Focus Area (see Section6.6.4.1.2.4 and Table 6.6-5)
2 Site not studied in the 1980s

Table 6.5-5. Schedule for implementation of the Geomorphology Study.

Activity	2012				2013				2014				2015	
	1 Q	2 Q	3 Q	4 Q	1 Q	2 Q	3 Q	4 Q	1 Q	2 Q	3 Q	4 Q	1Q	2Q
Develop Geomorphic Classification System / Finalize Classification System		—	—	—	—●									
Initial Geomorphic Reach Delineation / Finalize Delineation			—●			—	—●							
Identify and Map Paleo Geomorphic Features and Geology / Field Verify			—	—	—	/ —	—●							
Determine Morphometric Parameters (sinuosity, slope, topwidth, etc…)			—	—	—	—	—●							
Identify Key Governing Geomorphic Processes			—	—	—	—	—●							
Acquire Aerial Photo / Complete Aerial Acquisition (not Completed in 2012)			—	—	/	—	—	—						
Digitize 1980s Habitat and Geomorphic Features			—	—●			—	—●						
Digitize 2012 Habitat and Geomorphic Features / Complete Habitat Effort			—	—	—●	/	—	—●						
Assess Habitat Area Change 1980s to 2012				—	—●			—	—●					
Assess Channel Change 1980s to 2012				—	—●			—	—●					
Initial Flow Assessment / Final Flow Assessment			—	—	—● /	—	—	—	—	—	—	—●		
Determine Effective Discharge and Characterization of Bed Mobilization						—	—	—	—	—	—	—●		
Initial Sediment Balance / Detailed Sediment Balance for Modeling			—	—	—● /	—	—	—	—	—	—	—●		
Recon. Level Assess. of Potential L. and M. Susitna River Segment Change				—	—●	—	—●		—	—	—	—●		
Optional 2013 aerial photo and macrohabitat mapping – Lower River						—	—	—	—●					
Large Woody Debris						—	—	—	—	—	—●			
Reservoir Geomorphology						—	—	—	—	—	—●			
Geomorphology of Stream X-ings along Access & Transmission Line Corridor						—	—	—	—	—	—●			
Integration with & Support of Interpreting Fluv. Geomorph. Modeling Results					—	—	—	—	—	—	—	—●		
Initial Study Report /Updated Study Report								—	—Δ			—	—▲	

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

Table 6.5-6. Information and products required by the Geomorphology Study from other studies.

Source of Product or Information	Information or Product to be Provided	Timing
Information or Products Required for: Geomorphic Reach Classification and Delineation		
Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3)	Current and historical cross-sections	Q4-12
	Thalweg profile	Q4-12
Fluvial Geomorphology Modeling Study (Section 6.6.4.1.2.8)	Bed material sizes	Q3-13
External: GINA / Mat-Su Borough	LiDAR	Q4-12
Internal: Geomorphology Study (Sections 6.5.4.5 & 6.5.4 .7)	1980s and 2012 aerials	Q4-12 & Q4-13
Information or Products Required for: Aerial Photo Analysis of Geomorphic Features and Riverine Habitat		
Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3)	Current cross-sections	Q4-12
Internal: Geomorphology Study (Sections 6.5.4.5 & 6.5.4.7)	1980s and 2012 aerials	Q4-12 & Q4-13
Trihey & Associates 1985	1980s habitat mapping Middle Susitna River Segment	Q4-12
R&M Consultants, Inc., and Trihey and Associates 1985a)	1980s habitat mapping Lower Susitna River Segment	Q4-12
Information or Products Required for: Geomorphic Assessment		
External: USGS	USGS extended flow record	Q3-12
	USGS sediment transport data 1980s and 2012	Q4-12
Mainstem (Open-water) Flow Routing (Section 8.5.4.3)	Results of operations modeling - preliminary	Q4-12
	Results of operations modeling – alternative scenarios	Q4-14
	Results of flow routing to Sunshine Station - Preliminary	Q4-12
	Results of flow routing to Sunshine Station – Alternative Scenarios	Q4-14
Internal: Geomorphology Study Model (Section 6.5.4.8..2.1)	Initial estimates of reservoir sediment trap efficiency	Q3-13
Water Quality Modeling Study (Section 5.6)	Reservoir sediment trap efficiency for alt. scenarios	Q2-14
Ice Processes Study (Section 7.6)	Ice effects on: banks, side channels, scouring and stage	Q1-14
Geology & Soils Characterization Study (Section 4.5)	Soils and mass wasting in reservoir area	Q1-14
Riparian Vegetation Study Downstream of the Proposed Susitna-Watana Dam Study (Section 11.6)	Vegetation mapping in the reservoir area	Q1-14
Recreation Resources Study (Section 12.5)	Expected boat use in the reservoir and river	Q2-14

Table 6.5-7. Information and products the Geomorphology Study will provide to other studies.

Study the Product or Information is Provided to	Information or Product to be Provided	Timing
Information or Products Provided by: Geomorphic Reach Classification and Delineation		
Fish and Aquatics Instream Flow Study (Section 8.5) Riparian Instream Flow Study (Section 8.6) Characterization and Mapping of Aquatic Habitats (Section 9.9) Fluvial Geomorphology Modeling Study (Section 6.6)	Initial geomorphic reach delineation	Q4-12
	Final geomorphic reach delineation	Q4-13
	Collaboration on Focus Area selection	Q4-13
	Morphometric parameters	Q1-13
Information or Products Provided by: Aerial Photo Analysis of Geomorphic Features and Riverine Habitat		
Fish and Aquatics Instream Flow Study (Section 8.5) Riparian Instream Flow Study (Section 8.6) Characterization and Mapping of Aquatic Habitats (Section 9.9) Fluvial Geomorphology Modeling Study (Section 6.6)	Digitized 2012 riverine habitat areas –Middle River	Q4-12 & Q4-13
	Digitized 2013 riverine habitats – Middle River	
	Optional 2013 riverine habitat areas – Lower River	
	Digitized 1980s habitat areas	
	Habitat stability 1980s to 2012	
	Chanel Change 1980s to 2012 / geomorphic features	Q1-13
Information or Products Provided by: Geomorphic Assessment		
Fish and Aquatics Instream Flow Study (Section 8.5) Riparian Instream Flow Study (Section 8.6) Characterization and Mapping of Aquatic Habitats (Section 9.9) Fluvial Geomorphology Modeling Study (Section 8.6) River Recreation Flow & Access Study (Section 12.7)	Reconnaissance level assessment of potential channel change in the Lower Susitna River Segment	Q1-13
	LWD Study	Q3-14
Fluvial Geomorphology Modeling Study (Section 6.6) Fish and Aquatics Instream Flow Study (Section 8.5) Riparian Instream Flow Study (Section 8.6)	Flow assessment (flood frequency and flow duration)	Q1-13 & Q-14
	Characterization of bed mobilization	Q4-13 & Q4-14
	Effective discharge determination	
	Sediment transport assessment and balance	Q4-12 & Q4-13
Fluvial Geomorphology Modeling Study (Section 6.6)	Reservoir geomorphology and tributary deltas	Q3-14
Fish and Aquatics Instream Flow Study (Section 8.5)		
Riparian Instream Flow Study (Section 8.6)		
Characterization and Mapping of Aquatic Habitats (Section 9.9)		
Aesthetic Resources Study (Section 12.6)	Aeolian transport of dust	Q3-14
Fluvial Geomorphology Modeling Study (Section 6.6)	Identifications of key physical processes	Q2-13 & Q4-13
Riparian Instream Flow Study (Section 8.6)		
Fluvial Geomorphology Modeling Study (Section 6.6)	Integration with Fluvial Geomorphology Modeling Study (see Tables 6.6-6 and 6.6-7 for detailed list of information)	Q4-14
Fish and Aquatics Instream Flow Study (Section 8.5)		
Riparian Instream Flow Study (Section 8.6)		
River Recreation Flow & Access Study (Section 12.7)		

Table 6.5-8. Summary of 2012 Geomorphology Study efforts to support preparation and refinement of the Study Plan.

Study Component	Portion of Study Component of Interest	Aspect of Study Plan Preparation or Refinement Supported	Status
Delineate Geomorphically Similar (Homogenous) Reaches and Characterize the Geomorphology of the Susitna River (Section 6.5.4.1)	Initial geomorphic reach delineation	Part of classification system used to stratify study area for various study site selection efforts	Yes
Sediment Supply and Transport Middle and Lower Susitna River Segments (Section 6.5.4.3)	Initial sediment balance for the Lower River for pre- and post-Project conditions	Part of criteria to identify downstream limit of studies in the Lower Susitna River Segment	Completed pre-Project condition Developing with-Project 1/13[1]
Assess Geomorphic Change in the Middle and Lower Susitna River Segments (Section 6.5.4.4)	Site stability in the Middle Susitna River Segment	Site selection in the Middle River Segment, applicability of 1980s data	Products in review 1/13[1]
	Channel change in the Lower River Susitna River Segment	Downstream study limit in the Lower River, applicability of 1980s data	Products in review 1/13[1]
Reconnaissance-Level Assessment of Project Effects on the Lower and Middle Susitna River Segments (Section 6.5.4.6)	Initial assessment of potential Project effects on the geomorphology of the Lower Susitna River Segment	Downstream study limit in the Lower River	Awaiting with-Project hydrology and sediment transport assessments 1/13[1]
Riverine Habitat Area versus Flow Lower Susitna River Segment (Section 6.5.4.7)	Initial assessment of potential Project effects on habitat area vs. flow relationships	Downstream study limit in the Lower River	Finalizing analysis 1/13[1]

Notes:

1 Technical work will be completed by end of December 2012 and reported on in January 2013

Table 6.5-9. Geomorphology Study costs.

Study Component	Estimated Cost Range
1 Geomorphic River Segment Delineation	$60,000 to $80,000
2 Sediment Data Collection	$450,000 to $600,000
3 Sediment Supply and Transport Assessment	$80,000 to $110,000
4 Geomorphic Change Middle and Lower Susitna River Segments	$180,000 to $240,000[1]
5 Riverine Habitat Middle Susitna River Segment	$200,000 to $300,000[1]
6 Recon Assessment Lower Susitna River Segment Project Effects	$80,000 to $100,000
7 Riverine Habitat Lower Susitna River Segment	$100,000 to $150,000[1]
8 Reservoir Geomorphology	$140,000 to $180,000
9 Large Woody Debris	$100,000 to $130,000
10 Geomorphology of Stream Crossings	$80,000 to $140,000
11 Integration Fluvial Geomorphology Modeling with the Geomorphology Study	$50,000 to $60,000

[1] Includes acquisition of orthorectified aerial imagery

6.5.12. Figures

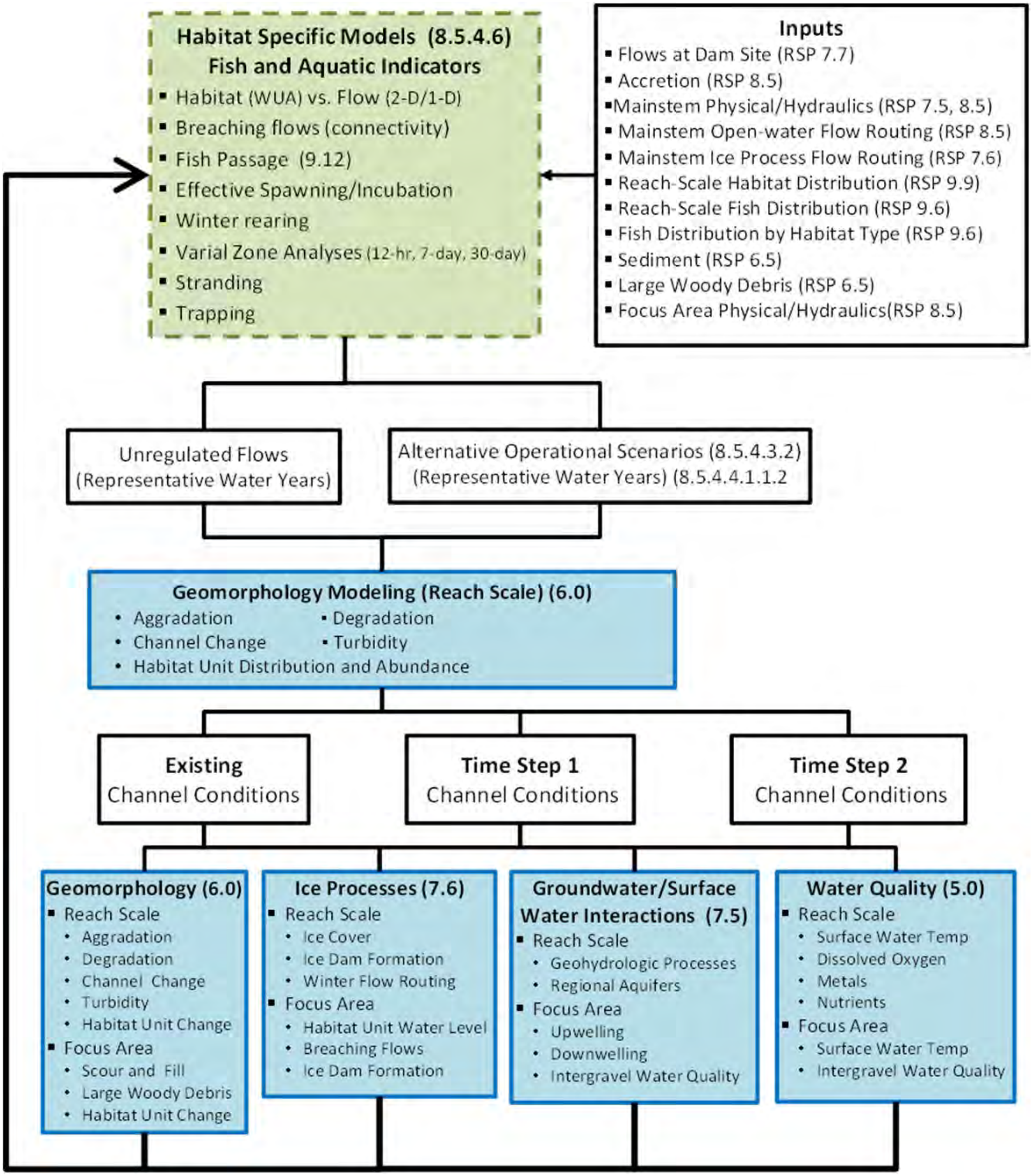

Figure 6.1-1. Conceptual framework for the Susitna-Watana Instream Flow Study depicting integration of habitat specific models and riverine processes to support integrated resource analyses; and integration of riverine processes to develop fish and aquatic habitat specific models.

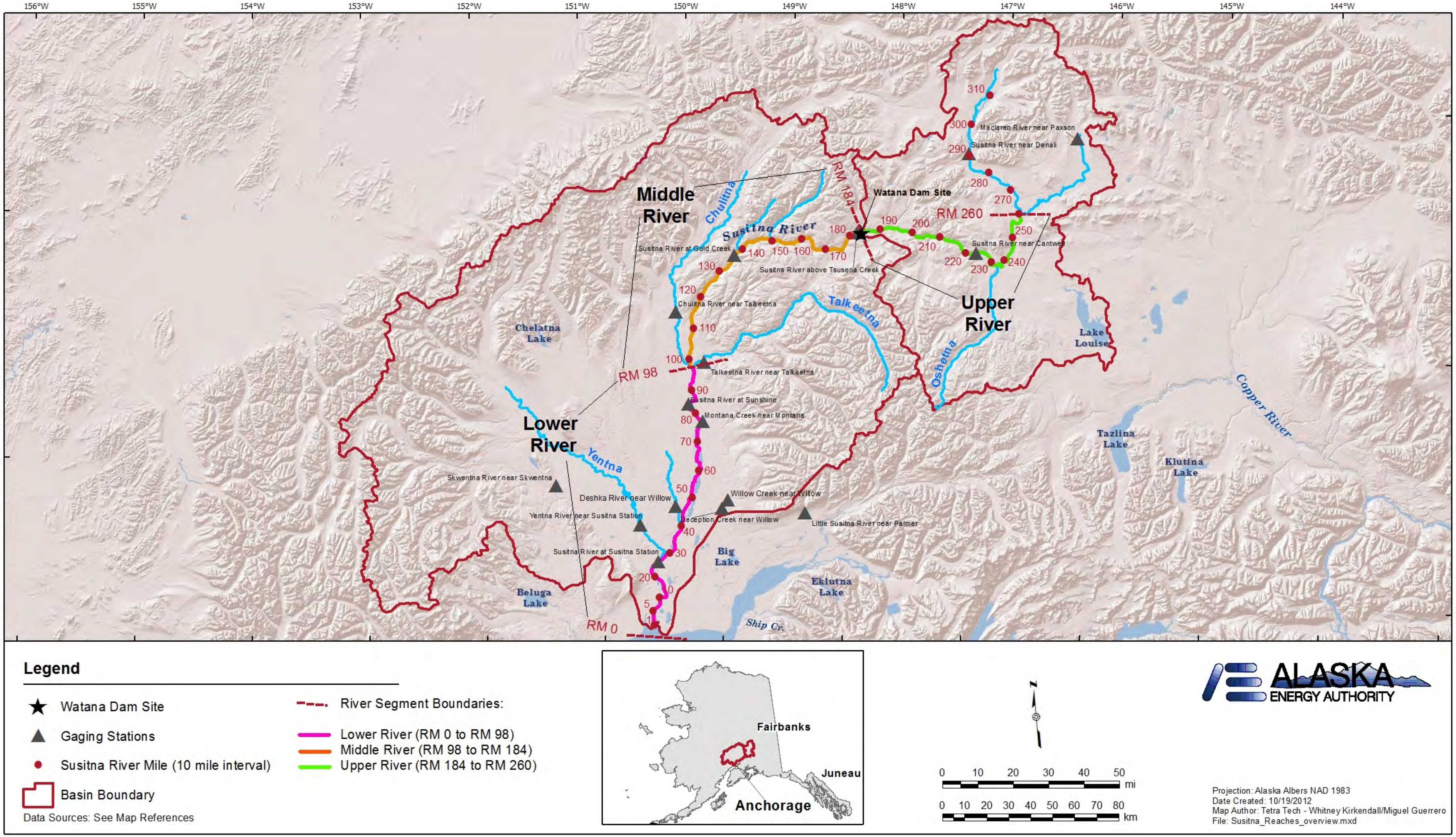

Figure 6.5-1. Susitna River Geomorphology study area and large-scale river segments.

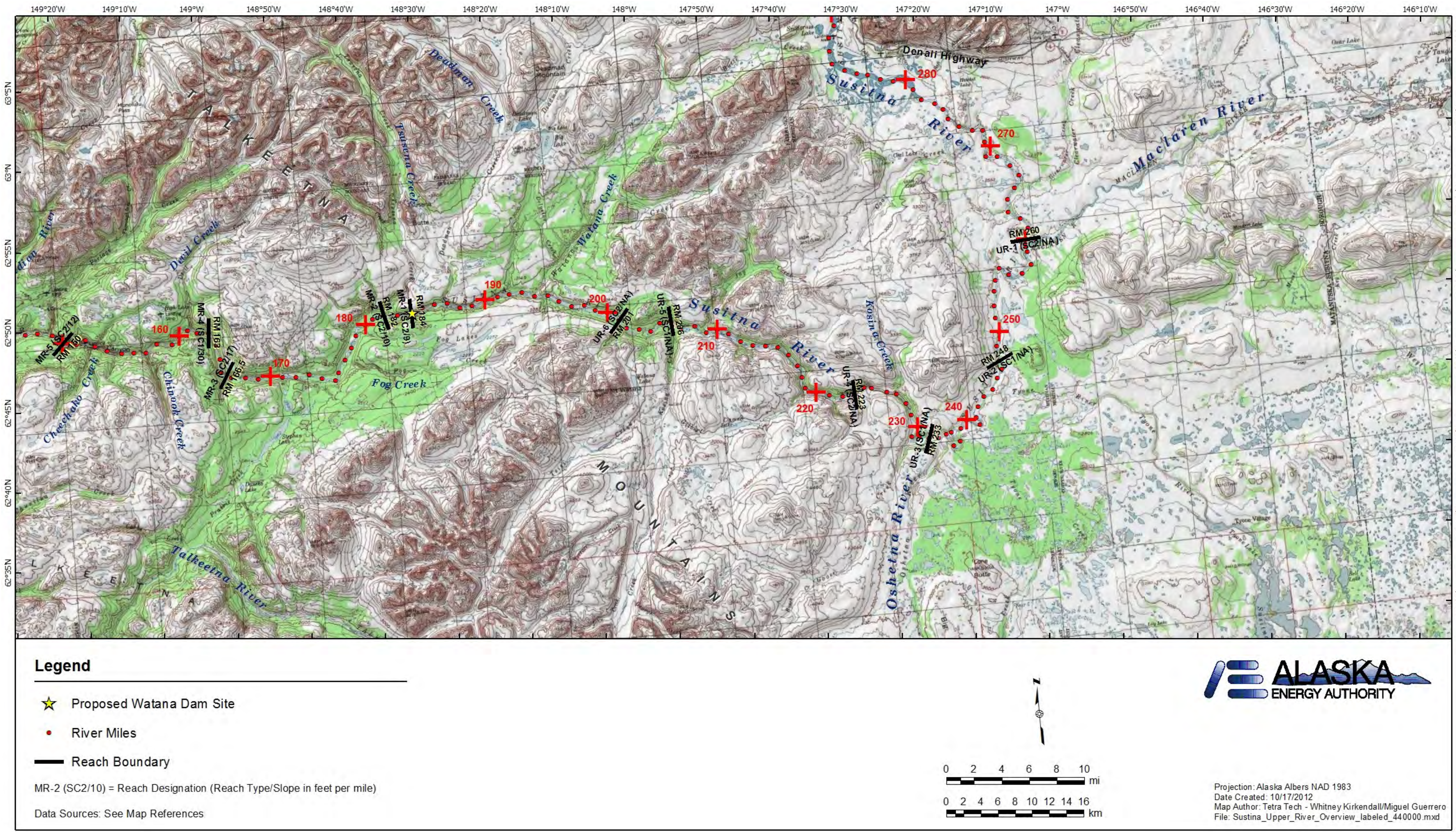

Figure 6.5-2. Upper Susitna River Segment geomorphic reaches.

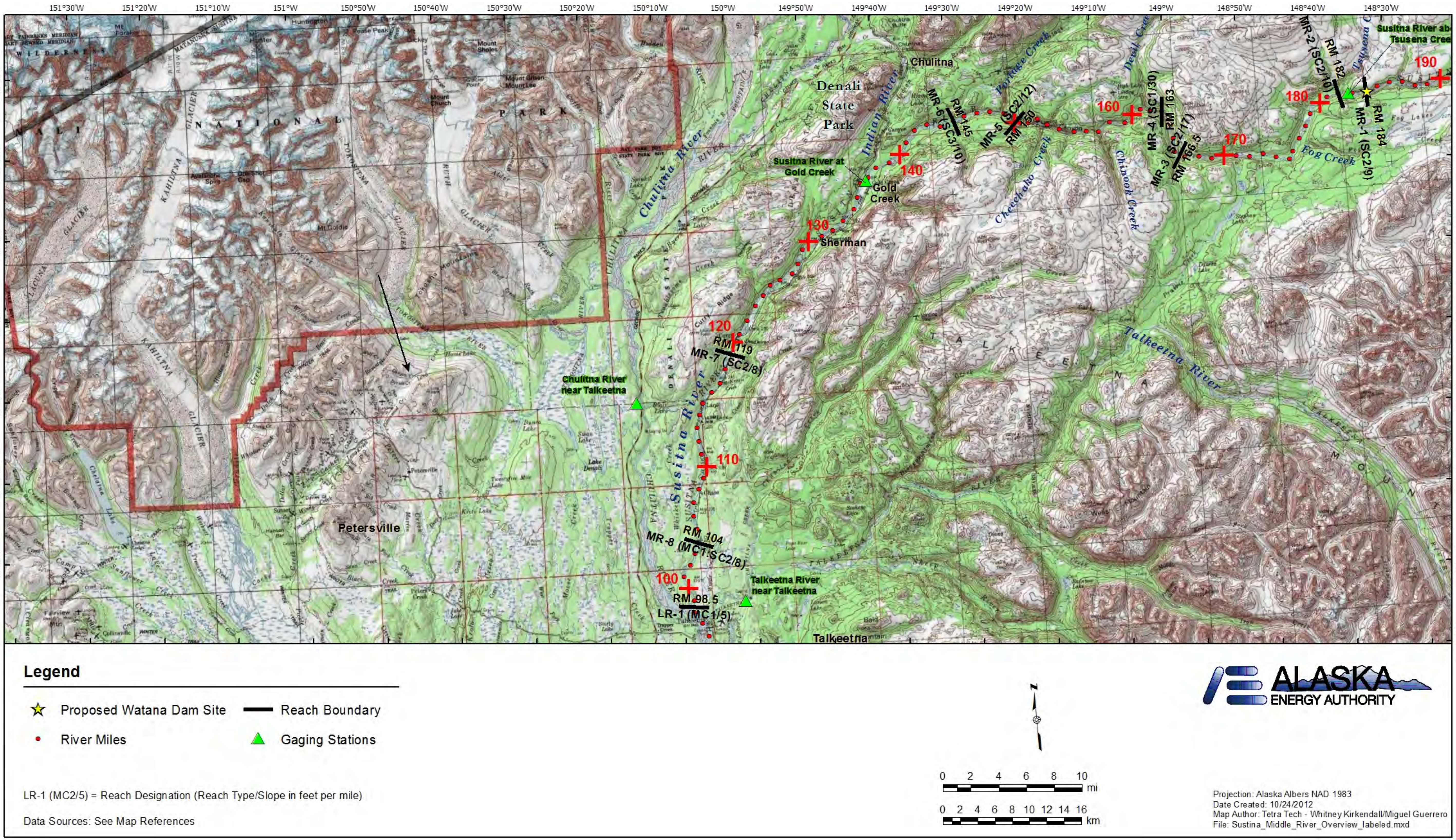

Figure 6.5-3. Middle Susitna River Segment geomorphic reaches.

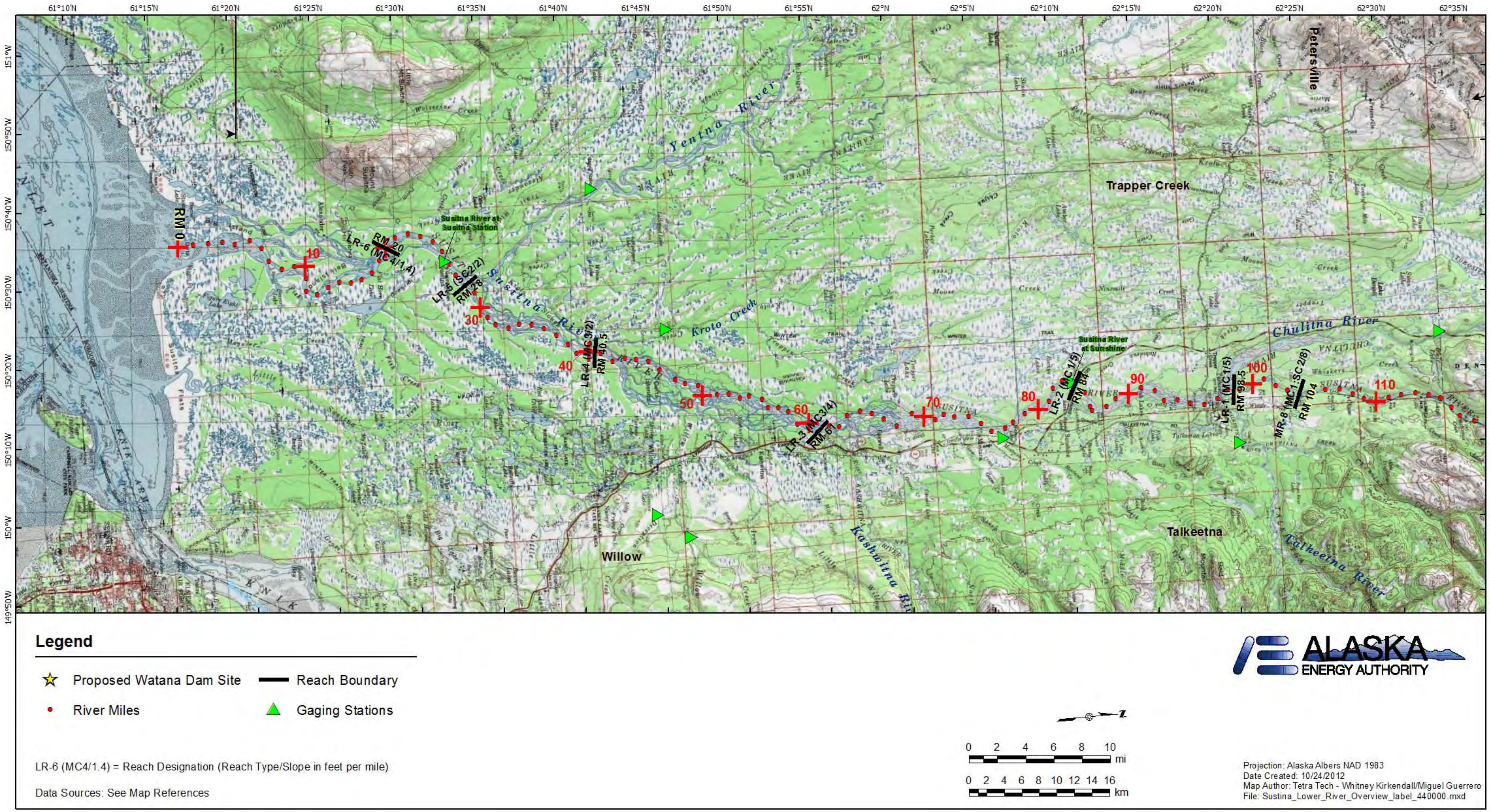

Figure 6.5-4. Lower Susitna River Segment geomorphic reaches.

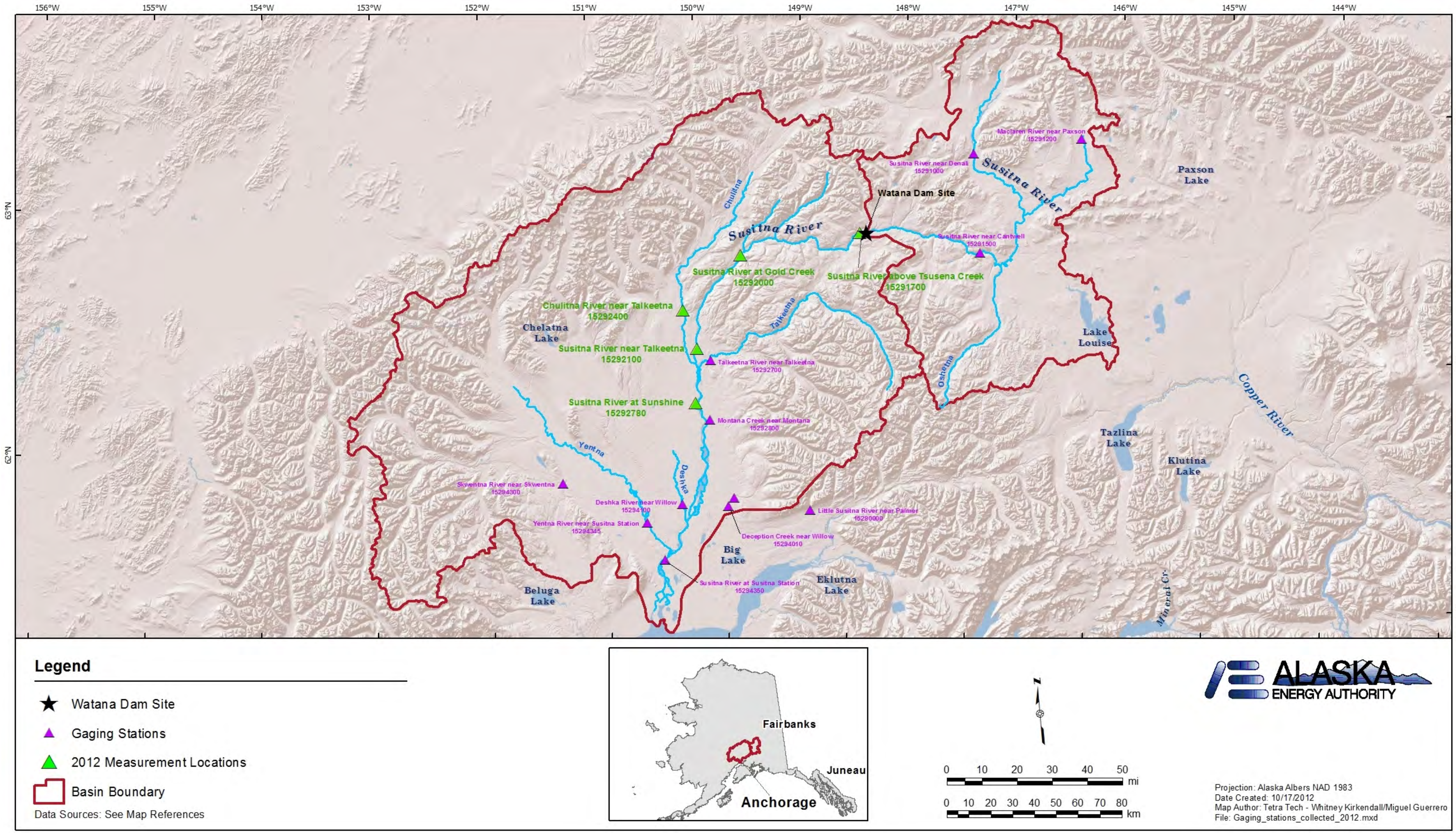

Figure 6.5-5. USGS Susitna River basin gaging stations and 2012 measurement locations.

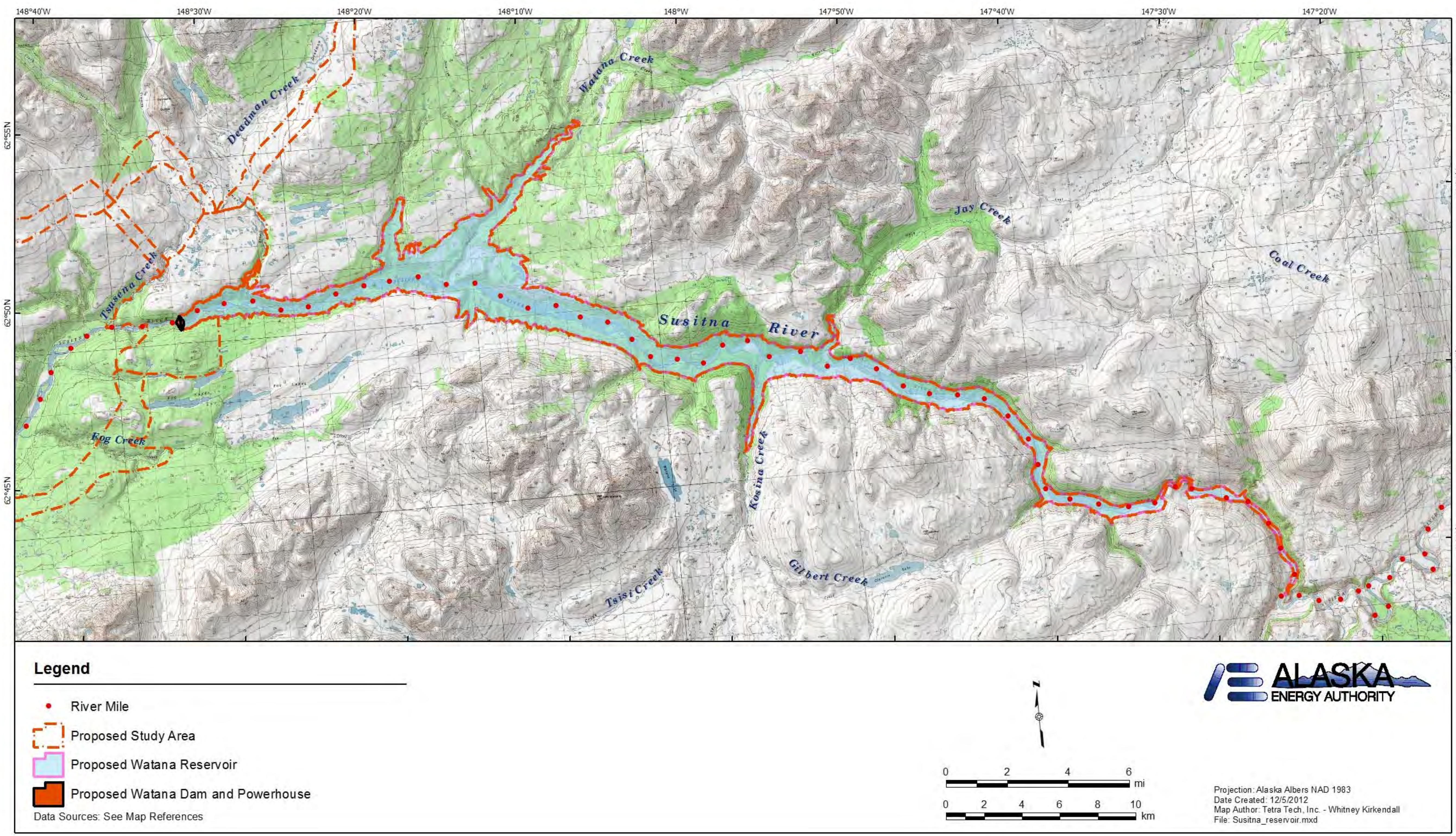

Figure 6.5-6. Susitna-Watana Geomorphology Study reservoir geomorphology study area.

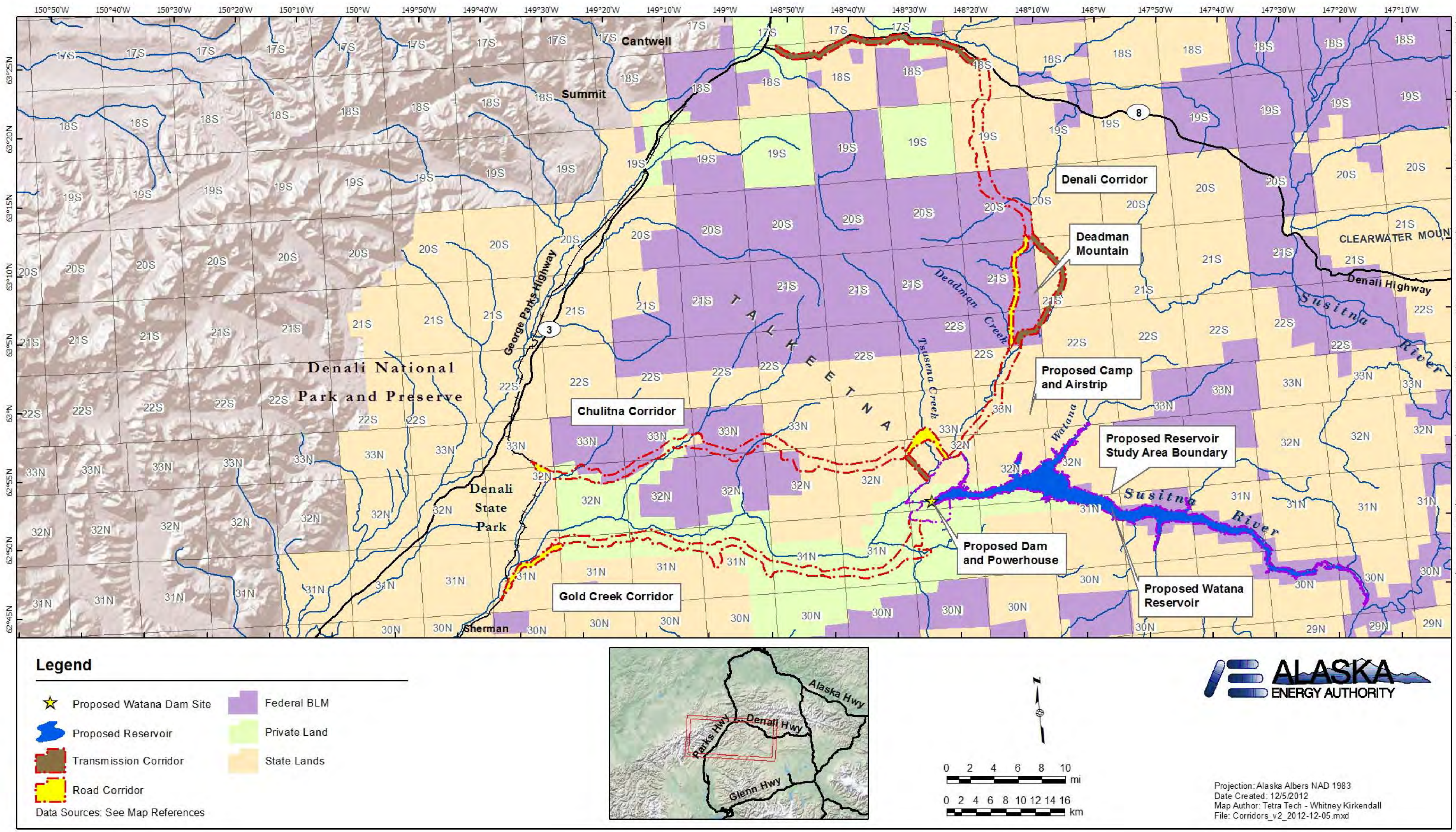

Figure 6.5-7. Susitna-Watana access corridors.

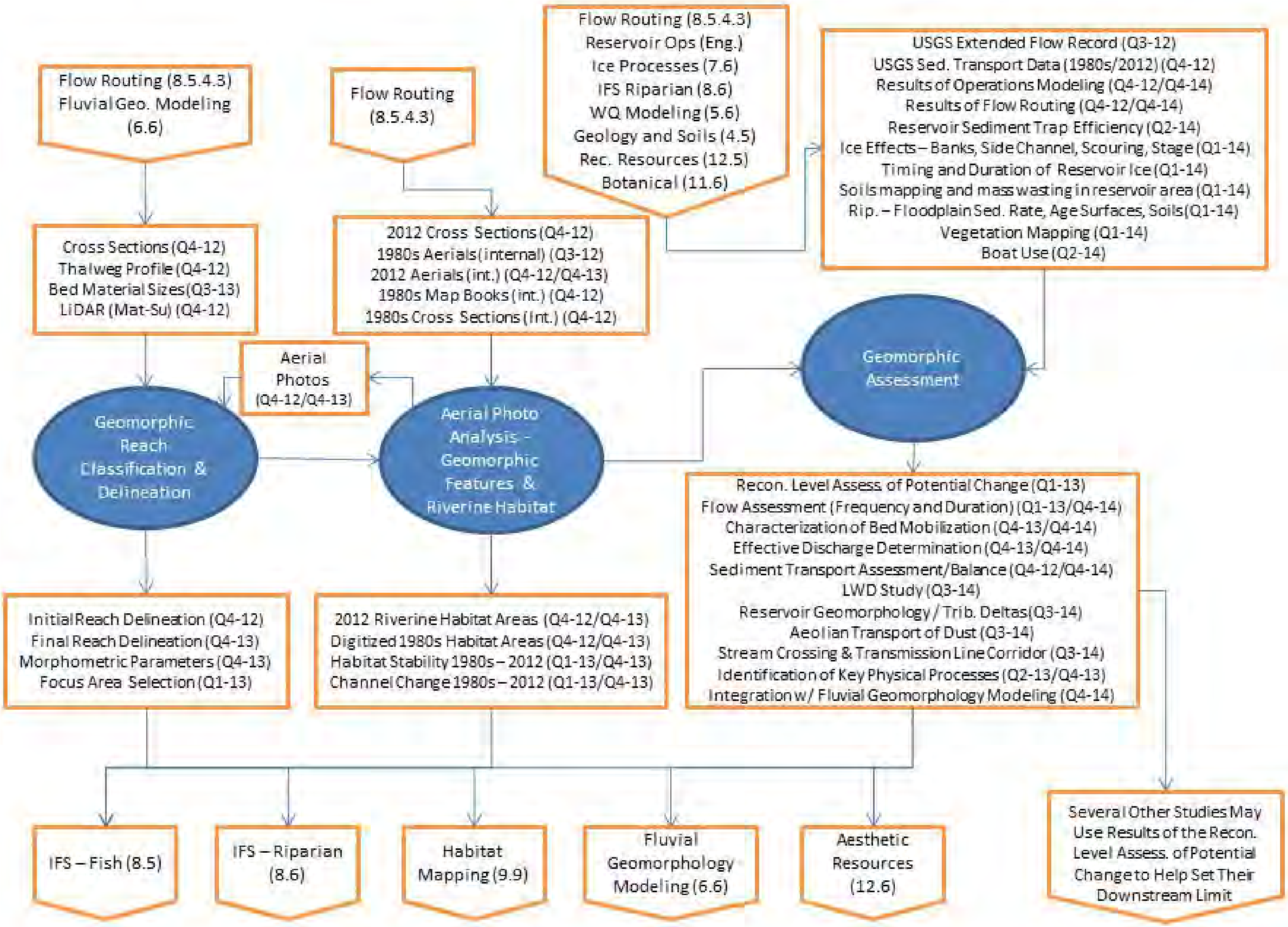

Figure 6.5-8. Study interdependencies for the Geomorphology Study.

6.6. Fluvial Geomorphology Modeling below Watana Dam Study

6.6.1. General Description of the Proposed Study

The overall goal of the Fluvial Geomorphology Modeling below Watana Dam Study is to model the effects of the proposed Project on the fluvial geomorphology of the Susitna River to assist in predicting the trend and magnitude of geomorphic response. More specifically, the purpose of the modeling study, along with the Geomorphology Study (Section 6.5), is to assess the potential impact of the Project on the behavior of the river downstream of the proposed dam, with particular focus on potential changes in instream and riparian habitat. Whether the existing channel morphology will remain the same or at least be in “dynamic equilibrium” under post-Project conditions is a significant question in any instream flow study (i.e., Is the channel morphology in a state of dynamic equilibrium such that the distribution of habitat conditions will be reflected by existing channel morphology, or will changes in morphology occur that will influence the relative distribution or characteristics of aquatic habitat over the term of the license? [Bovee 1982]). This key issue prompts four overall questions that must be addressed by the two geomorphology studies:

- Is the system currently in a state of dynamic equilibrium?
- If the system is not currently in a state of dynamic equilibrium, what is the expected evolution over the term of the license in the absence of the project?
- Will and in what ways will the Project alter the equilibrium status of the downstream river (i.e., what is the expected morphologic evolution over the term of the license under with-Project conditions)?
- What will be the expected effect of the Project-induced changes on the geomorphic features that form the aquatic habitat and therefore are directly related to the quantity, distribution and quality of the habitat?

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

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

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

6.6.2. Existing Information and Need for Additional Information

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

Modeling of the hydraulics of the Susitna River below the previously proposed project, a necessary step in developing a sediment transport model, was performed in the 1980s. This work included development and application of one-dimensional HEC-2 hydraulic models to support the calculation of water-surface profiles and channel hydraulics (Acres 1983). The models represented the reach between Devils Canyon (Susitna RM 186.8) and Talkeetna (RM 99), excluding Devils Canyon (Susitna RM 162.1 to RM 150.2). The Aquatic Resources Data Gap Analysis (HDR 2011) indicates that sediment transport modeling of a portion of the Susitna River was also undertaken. Realizing the complexity of the sediment transport problem at the Chulitna River confluence, APA commissioned the Iowa Institute of Hydraulic Research to develop a quasi-steady, one-dimensional numerical model of sediment transport for the 14-mile reach of the Susitna River from the Chulitna confluence downstream to Sunshine Station (Holly et al. 1985). The model was based on sediment transport data from 1981 and 1982, as the following years of data collection had not yet been completed. The topography was derived from 28 cross-sections (approximately 1 every ½ mile) measured by R&M Consultants and aerial photography (Ashton and R&M 1985). The model was still in development as of the writing of the 1985 report; however, the companion report, referenced in Holly et al. (1985), was not found in the Susitna documentation.

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

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

6.6.3. Study Area

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

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

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

6.6.3.1. Focus Areas

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

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

6.6.3.2. Determination of Downstream Study Limit

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

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

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

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

It is noted that a variety of resource areas require determination of their downstream study limits. Although both Middle and Lower Susitna River segments are under consideration as part of the IFS, the majority of detailed study elements for the IFS described in the RSP (Sections 8.5 and 8.6) are concentrated within the Middle River Segment. This is because Project operations related to load-following and variable flow regulation will likely have the greatest potential effects on this segment of the river. These effects tend to attenuate in a downstream direction as channel morphologies change, and flows change due to tributary inflow and flow accretion. The diversity of habitat types and the information from previous and current studies that indicate substantial fish use of a number of slough and side channel complexes within this segment also support the need to develop a strong understanding of habitat–flow response relationships in the

Middle Susitna River Segment. The determination for downstream study limits may also depend on the outcome of 2013 efforts being conducted for the Water Quality Modeling Study (Section 5.6), Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3), and the winter flow routing model (Section 7.6). Whether there is need to integrate Fluvial Geomorphology Modeling Study results with certain studies also depends on the final downstream limit for the modeling effort. Specifically, the Eulachon Study (Section 9.16) is limited to the downstream-most portions of the Lower Susitna River Segment and will not require detailed sediment transport modeling input from the Fluvial Geomorphology Modeling Study if the modeling effort is not extended downstream of RM 75.

6.6.4. Study Methods

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

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

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

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

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

6.6.4.1.1. Existing Information and Need for Additional Information

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

6.6.4.1.2. Methods

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

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

6.6.4.1.2.1. Development of Bed Evolution Model Approach and Model Selection

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

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

- Review and understand available data.
- Develop an understanding of the dominant physical processes and governing physical conditions in the study reach.
- Coordinate with other studies to understand their perspective on system dynamics, and the physical features and processes that are important to their studies.
- Identify an overall modeling approach that is consistent with the study goals, the constraints on information that is currently available or can practically be obtained, and the needs of the other studies.
- Identify a modeling approach that is consistent with the spatial and temporal scale of the area to be investigated.
- Determine the spatial limits of the modeling effort.
- Determine the time scales for the various models.
- Review potential models and select a model(s) that meets the previously-determined needs and conditions.
- Identify data needs and data gaps for the specific model and study area being investigated.
- Collect the required data to fill data gaps.
- Develop the model input.
- Identify information to be used to calibrate and validate the model.
- Perform initial runs and check basic information such as continuity for water and sediment, hydraulic conditions, magnitude of sediment transport, and flow distributions.
- Collaborate with other studies on initial model results.
- Refine model inputs.

- Perform calibration and validation efforts, to include comparison of modeled water-surface elevations, in-channel hydraulic conditions (e.g., velocity and depth), sediment transport rates, and aggradation/degradation rates with available measured data.
- Perform model runs for existing conditions to provide a baseline for comparison of with-Project scenarios.
- Work with other studies to develop scenarios to evaluate the potential Project effects, and apply the model to those scenarios.
- Coordinate with other studies to evaluate and define the appropriate format for presentation of the model results.
- Develop and run additional scenarios, as necessary, based on results from the initial scenarios and identified Project needs.

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

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

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

- Historical changes in the system and the existing status with respect to dynamic equilibrium.
- Changes in both the bed material (sand and coarser sizes) and wash (fine sediment) load sediment supply to the system due to trapping in Watana Reservoir.
- Long-term balance between sediment supply and transport capacity and the resulting aggradation/degradation response of the system for pre- and post-Project conditions.
- Changes in bed material mobility in terms of size and frequency of substrate mobilized due to alteration of the magnitude and duration of peak flows by the Project.
- Project-induced changes in supply and transport of finer sediments that influence turbidity.
- Potential for changes in channel dimensions (i.e., width and depth) and channel pattern (i.e., braiding versus single-thread or multiple-thread with static islands) due to the Project and the magnitude of the potential change.
- Project-induced changes in river stage due to reach-scale changes in bed profile, channel dimensions, and potentially hydraulic roughness.

<u>Local-Scale Issues:</u> Local-scale issues refer to aspects of the system that involve the specific behavior and characteristics of the Susitna River at a scale associated with specific geomorphic and habitat features. Local-scale issues are addressed using a more detailed assessment over a finer Focus Area scale; however, these analyses must draw from and build upon the

understanding and characterization of the system behavior as determined at the reach scale. Local-scale issues include the following:

- Processes responsible for formation and maintenance of the individual geomorphic features and associated habitat types.
- Potential changes in geomorphic features and associated aquatic habitat types that may result from effects of Project operation on riparian vegetation and ice processes.
- Effects of changes in flow regime and sediment supply on substrate characteristics in off-channel habitat units.
- Changes in upstream connectivity (breaching) of off-channel habitats due to alteration of flow regime and possibly channel aggradation/degradation. These changes may induce further changes in the morphology of off-channel habitats, including the following:
    - Potential for accumulation of sediments at the mouth.
    - Potential for accumulation of fines supplied during backwater connection with the mainstem.
    - Potential for changes in riparian vegetation that could alter the width of off-channel habitat units.
- Project effects at representative sites on the magnitude, frequency, and spatial distribution of hydraulic conditions that control bed mobilization, sediment transport, sediment deposition, and bank erosion.
- Potential for change in patterns of bedload deposits at tributary mouths that may alter tributary access or tributary confluence habitat, as discussed below.

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

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

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

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

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

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

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

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

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

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

- **SRH-1D:** SRH-1D (Huang and Greimann 2011) is a publicly-available, mobile boundary hydraulic and sediment transport computer model for open channels that is capable of simulating steady or unsteady flow conditions, internal boundary conditions, looped river networks, cohesive and non-cohesive sediment transport (Ruark et al. 2011), and lateral inflows. The hydraulic and sediment transport algorithms in SRH-1D are similar to those in HEC-RAS 4.1 and HEC-6T except that it also includes the capability to perform fully-unsteady sediment transport simulations. Advantages of SRH-1D include robust algorithms for hydraulic conditions and sediment routing, including sediment sorting. Potential disadvantages include limited testing under a broad range of conditions outside the U.S. Bureau of Reclamation and the lack of graphical user interface that complicates data input and manipulation and display of output.
- **MIKE 11:** Danish Hydraulic Institute's (DHI) MIKE 11 is a proprietary software package developed for 1-D dynamic modeling of rivers, watersheds, morphology, and water quality. The model has the ability to solve the complete non-linear St. Venant equations (in only the streamwise direction) for open channel flow, so the model can be applied to any flow regime. MIKE 11 provides the choice of diffusive and kinematic wave approximation and performs simplified channel routing using either the Muskingum or Muskingum-Cunge methods. The program includes a module for simulating erosion and deposition of non-cohesive sediments. Advantages of MIKE 11 include its robust hydrodynamic capabilities (though not necessarily better than HEC-RAS), the user-friendly graphical interface, and the reporting and presentation capabilities. Disadvantages primarily stem from the proprietary nature of this model and high cost of the software license.
- **HEC-6T:** HEC-6T was written by William A. Thomas, former Chief of the Research Branch at the USACE Hydrologic Engineering Center (HEC). Mr. Thomas planned, designed, wrote, and applied the publically available version of HEC-6; HEC-6T is a proprietary enhancement of the original version. HEC-6T is a DOS-based program that includes a Windows-based graphical user interface for input data manipulation and post-processing of simulation results. Limitations of this program include reduced capabilities for modeling numerous ineffective flow areas as compared to HEC-RAS 4.1 and limited capabilities of the graphical user interface. This software is relatively inexpensive; the fact that it is proprietary is not a significant limitation.

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

Potential 2-D Models: Potential 2-D models that are being considered for this study include the U.S. Bureau of Reclamation's SRH2-D version 3 (Lai 2008; Greimann and Lai 2008), USACE's Adaptive Hydraulics ADH version 3.3 (USACE 2010b), the U.S. Geological Survey's (USGS) MD_SWMS suite (McDonald et al. 2005; Nelson et al. 2010), DHI's MIKE 21 version 2011 (DHI 2011b), and the River2D modeling suite (University of Alberta 2002; University of British Columbia 2009).

- **SRH-2D:** The U.S. Bureau of Reclamation's SRH-2D (Lai 2008) is a finite-volume, hydrodynamic model that computes water-surface elevations and horizontal velocity components by solving the depth-averaged St. Venant equations for free-surface flows in 2-D flow fields. SRH-2D is a well-tested 2-D model that can effectively simulate steady or unsteady flows and is capable of modeling subcritical, transcritical, and supercritical flow conditions. The model uses an unstructured arbitrarily-shaped mesh composed of a combination of triangular and quadrilateral elements. SRH-2D incorporates very robust and stable numerical schemes with a seamless wetting-drying algorithm that results in minimal requirements by the user to adjust input parameters during the solution process. A potential limitation of this software is that the mobile bed sediment transport module is currently not publically available; however, Tetra Tech has gained permission to use the sediment transport module on a number of other projects. Preliminary contact with the model developers indicates that permission would be granted for use in this study. This version of the model (Greimann and Lai 2008) includes a "Morphology" module that calculates bedload transport capacities at each model node based on user-defined bed material sediment gradations, but does not simulate routing of that sediment and related adjustments to the channel bed. SRH-2D also includes a second module that uses the capacities from the Morphology module to perform sediment-routing calculations and associated bed adjustments. Based on guidance from the model developers and confirmed by Tetra Tech's use of the model for other studies, the maximum practical model size is about 16,000 elements, which could be a potential limitation in applying the model to larger-scale areas.
- **ADH:** The USACE ADH program was developed by the Coastal and Hydraulics Laboratory (Engineer Research Development Center) to model saturated and unsaturated groundwater, overland flow, 3D Navier-Stokes flow, and 2-D or 3-D shallow-water, open-channel flow conditions. ADH is a depth-averaged, finite-element hydrodynamic model that has the ability to compute water-surface elevations, horizontal velocity components, and sediment transport characteristics (including simulations to predict aggradation and degradation) for subcritical and supercritical free-surface flows in 2-D

flow fields. The ADH mesh is composed of triangular elements with corner nodes that represent the geometry of the modeled reach with the channel topography represented by bed elevations assigned to each node in the mesh. A particular advantage of the ADH mesh is the ability to increase the resolution of the mesh—and thereby the model accuracy—by decreasing the size of the elements during a simulation in order to better predict the hydraulic conditions in areas of high hydraulic variability. However, use of the adaptive mesh option often results in excessively long simulation run times (several days per run) that could be impractical for this study. Additionally, the wetting and drying algorithm in this model has significant numerical stability limitations when applied to shallow, near-shore flows that occur in rivers like the Susitna River. The model is publically available.

- **MD_SWMS Modeling Suite (FaSTMECH/SToRM):** The USGS Multi-Dimensional Surface-Water Modeling System (MD_SWMS; McDonald et al. 2005) is a pre- and post-processing application for computational models of surface-water hydraulics. This system has recently been incorporated into iRIC, a public-domain software interface for river modeling distributed by the International River Interface Cooperative (iRIC) (Nelson et al. 2010). iRIC is an informal organization made up of academic faculty and government scientists whose goal is to develop, distribute, and provide education for the software. iRIC consists of a graphical user interface (GUI) that allows the modeler to build and edit data sets, and provides a framework that links the GUI with a range of modeling applications. The GUI is an interactive 1-D, 2-D, and 3-D tool that can be used to build and visualize all aspects of computational surface-water applications, including grid building, development of boundary conditions, simulation execution, and post-processing of the simulation results. The models that are currently included in iRIC include FaSTMECH (Flow and Sediment Transport with Morphologic Evolution of Channels) and SToRM (System for Transport and River Modeling) that were part of the MD-SWMS package, as well as NAYS, MORPHO2D, and a Habitat Calculator for assessing fish habitat under 2-D conditions. Of these models, SToRM appears to be the most relevant for modeling the Susitna River for purposes of this Project, primarily because it uses an unstructured triangular mesh (in contrast to the structured, curvilinear mesh required for FaSTMECH) and provides both steady-flow and unsteady-flow capability. NAYS is a fully unsteady, 2-D model designed for a general, non-orthogonal coordinate system with sophisticated turbulence methods that can evaluate the unsteady aspects of the turbulence, and MORPHO2D is 2-D model capable of analyzing the interactions between sediment transport and vegetation and between surface water and groundwater. Both NAYS and MORPHO2D were developed in Japan, and have not been widely used or tested in the U.S. The SToRM model blends some of the features of finite volumes and finite elements, and uses multi-dimensional streamline upwinding methods and a dynamic wetting and drying algorithm that allows for the computation of flooding. Subcritical, supercritical, and transcritical flow regimes (including hydraulic jumps) can be simulated. The program includes advanced turbulence models and an automatic mesh refinement tool to better predict the hydraulic conditions in areas of high hydraulic variability. The most recent version of the SToRM model does not include the capability to model sediment-transport, but the program authors are currently working on implementing sediment-transport algorithms that may be available for use in this study (pers. Comm., Jonathon Nelson, USGS, June 18, 2012). MD_SWMS has been successfully applied to a number of rivers in Alaska, including the Tanana River near Tok (Conaway and Moran 2004) and the Copper River near Cordova (Brabets 1997); some of the modules are currently being validated using high-resolution scour data from the Knik River near Palmer.

- **MIKE 21:** Developed by DHI, MIKE 21 is a proprietary modeling system for 2-D free-surface flows that can be applied in rivers, lakes, coastal, and ocean environments. It has the ability to simulate sediment transport and associated erosion and deposition patterns. The software includes a Windows-based GUI as well as pre- and post-processing modules for use in data preparation and analysis of simulation results, and reporting modules that have graphical presentation capabilities. MIKE 21 has the ability to model a range of 2-D mesh types that include Single Grid, Multiple Grid, Flexible Mesh, and Curvilinear Grid. The primary limitation to MIKE-21 is that it is proprietary software and is relatively expensive compared to other available software.
- **River2D Modeling Suite:** River2D is a two-dimensional, depth-averaged finite-element hydrodynamic model developed at the University of Alberta and is publically available from the university. The River2D suite consists of four programs: R2D_Mesh, R2D_Bed, River2D, and R2D_Ice, each of which contains a GUI. The R2D_Mesh program is a pre-processor that is used to develop the unstructured triangular mesh. R2D_Bed is used for editing the bed topography data and R2D_Ice is used to develop the ice thickness topography at each node for simulating ice-covered rivers. Following mesh development, the hydrodynamic simulations are run using the River2D program, which also includes a post-processor for visualizing the model output. River2D is a very robust model capable of simulating complex, transcritical flow conditions using algorithms originally developed in the aerospace industry to analyze the transitions between subsonic and supersonic conditions (transonic flow). Many 2-D models become numerically unstable due to wetting and drying of elements; however, River2D uniquely handles these conditions by changing the surface flow equations to groundwater flow equations in these areas. The model computes a continuous free surface with positive (above ground) and negative (below ground) water depths, which allows the simulation to continue without changing or updating the boundary conditions, increasing model stability. River2D also has the capability to assess fish habitat using the PHABSIM weighted-usable area approach (Bovee 1982). Habitat suitability indices are input to the model and integrated with the hydraulic output to compute a weighted useable area at each node in the model domain. River2D Morphology (R2DM) is a depth-averaged, two-dimensional hydrodynamic-morphological and gravel transport model developed at the University of British Columbia. The model was developed based on the River2D program, and is capable of simulating flow hydraulics and computing sediment transport for uni-size and mixed-size sediment using the Wilcock-Crowe (2003) equation over the duration of a hydrograph. R2DM can be used to evaluate the changes in grain size distributions, including fractions of sand in sediment deposits and on the bed surface. The sediment-transport module has been verified using experimental data, and was successfully applied to the Seymour River in North Vancouver, British Columbia (Smiarowski 2010). River2D is available in the most recent version of iRIC (Version 2.0).

<u>Two-Dimensional Model Selection Process and Initial Evaluation:</u> The selection of the 2-D model will be coordinated with the other pertinent studies and the licensing participants. Specific

model selection criteria are identified in Table 6.6-3, along with an evaluation of each candidate model relative to the criteria.

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

6.6.4.1.2.2. Coordination with other Studies

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

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

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

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

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

6.6.4.1.2.3. Model Resolution and Mesh Size Considerations

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

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

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

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

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

Areas that will require finer mesh sizes include the following:

- Side sloughs
- Upland sloughs
- Smaller side channels
- Spawning areas
- Tributary mouths
- Locations where circulation is of interest such as eddies between the main channel and backwater areas
- Other specific habitat features of interest

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

- Main channel
- Floodplains
- Large side channels

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

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

6.6.4.1.2.4. Focus Area Selection

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

Mapping of Aquatic Habitats (Section 9.9) studies. The Focus Areas will allow for a highly integrated, multidisciplinary effort to be conducted evaluating potential Project effects on key resource areas across a range of representative sites.

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

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

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

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

6.6.4.1.2.5. Model Calibration and Validation

Calibration and validation of the models will be a stepwise process. First, the hydraulic components of the models will be calibrated by adjusting roughness and loss coefficients to achieve reasonable agreement between measured and modeled water-surface elevations, and to measured and modeled velocities. Discharges along the study reach will be obtained from the three USGS gages. These gages will also provide a continuous record of stages and water-surface elevations at the gage locations. These data will be supplemented with stage data from at least 10 pressure-transducer type water-level loggers that have been or will be installed as part of various studies being conducted in the Middle and Lower Susitna River Segments. Water-levels measured during the cross-section and bathymetric surveys will also be used to calibrate the models. In addition to water-surface elevations, the depths and velocities predicted by the 2-D model should be compared with measured data from ADCP measurements at the Focus Areas. Depending on the range of conditions and spatial coverage of the depth and velocity data from the Fish and Aquatics Instream Flow Study, additional data may be needed for calibration specifically for this study. Specific calibration criteria will be established for both the 1-D and 2-D models during the model selection phase. The 2-D water surface elevations will also be compared against water surface elevations generated by the 1-D model and the Mainstem (Open-water) Flow Routing Model to ensure that the models are producing consistent results.

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

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

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

6.6.4.1.2.6. Tributary Delta Modeling

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

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

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

6.6.4.1.2.7. Large Woody Debris Modeling

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

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

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

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

6.6.4.1.2.8. Wintertime Modeling and Load-Following Operations

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

6.6.4.1.2.9. Field Data Collection Efforts

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

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

At the start of the summer 2013 field season, a reconnaissance of the entire Fluvial Geomorphology Modeling study area (RM 184 to RM 75) as well as the remainder of the Lower

Susitna River Segment (RM 75 to RM 0) will be conducted. This site reconnaissance will be carried out to observe and characterize the following:

- Hydraulic and geomorphic controls (natural and man-made) that will influence sediment-transport conditions.
- Verification of mapping of geologic and geomorphic features performed in the Geomorphology Study.
- Hydraulic roughness conditions along the main channel and in the overbanks.
- Variations in bed material size.
- The sediment-transport regime, and areas that appear to be in equilibrium, or are aggradational or degradational.
- In areas that are not in equilibrium, qualitative assessment of the degree of erosion or deposition.

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

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

6.6.4.1.2.9.1. 1-D Bed Evolution Model

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

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

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

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

6.6.4.1.2.9.2. Focus Areas

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

1. A combination of bathymetry (single and multi-beam), cross-section data, and spot elevations necessary to develop a digital terrain model for the portion of the site for which LiDAR is not available. (These will be the main channel, side channels, side sloughs, upland sloughs, tributaries, and open water areas that were inundated at the time the LiDAR was acquired.)
2. All obstructions in the off-channel habitats such as beaver dams and debris jams will be surveyed.
3. Large woody debris survey and characterization of its influence on the geomorphology of the channels, side channels and sloughs.
4. Bed material samples in the main channel, sloughs, and side channels
    a. Surface pebble count (Wolman count) or photo grid
    b. Subsurface bulk or photo grid samples
    c. Possible winter sampling in conjunction with the Ice Processes Study (Section7.6) (see 1-D Bed Evolution Model field data section and description of geomorphic mapping below)
5. Bank material samples.
6. Spot elevations to verify LiDAR in the Focus Area (LiDAR will be used to provide the floodplain portion of the cross-sections).
7. Estimation of n-values in the channels, side channels, sloughs, and tributaries.
8. Observations on depositional or erosional features at the supplemental cross-sections.
9. Field verification, and correction and/or mapping if necessary, of the geomorphic features, geologic controls, and terraces previously identified from available information for the Focus Area.
10. ADCP measurements to calibrate and determine the accuracy of the 2-D hydraulic model velocities.

11. Installation of level loggers and associated readings to support calibration of water surface elevations produced by the 2-D model.
12. Current meter measurements of velocity for areas where the ADCP cannot be used.
13. Mapping of depositional and erosional features.
14. Identification and mapping of evidence of ice processes at the site along with observations of their potential influence on the geomorphology of the Focus Area.
15. Any evidence of past extreme events.
16. Overall narrative description and assessment of the geomorphology of the Focus Area including identification of key physical processes and controls.

If it is determined that 1-D modeling is appropriate for a Focus Area, rather than collecting bathymetric, cross-sectional and topographic information required to build a digital terrain model (DTM) to support 2-D mesh development, cross-sectional data will be collected on the hydraulic features to be modeled.

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

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

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

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

6.6.4.1.2.9.3. Tributary Deltas

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

6.6.4.1.2.9.4. Field Data from Other Studies

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

- Mainstem (Open-water) Flow Routing Model cross-sections collected in 2012.
- Fish and Aquatics Instream Flow Study supplemental transects collected in 2013.
- Hydraulic calibration information used in the development of the Mainstem (Open-water) Flow Routing Model (water surface elevations and associated discharges).
- Information describing the influence of ice processes on channel and floodplain morphology.
- Information describing the influence of riparian vegetation on channel and floodplain morphology.
- Soil classification and gradation from Riparian Instream Flow Study test pits in the floodplain and on island.
- Thickness and aging of floodplain and island deposits from the Riparian Instream Flow Study.

- Mapping of vegetation and associated age classes from the Riparian Instream Flow Study.
- Information developed in the Geomorphology Study on channel changes that have occurred since the 1980s.
- Information developed in the Geomorphology Study on the physical processes most important to accurately modeling the study reach.
- The velocity and depth measurements collected by the Fish and Aquatics Instream Flow Study to characterize habitat for calibrating the hydraulic model(s).
- Data collected on the distribution of flow between the main channel and off-channel habitat to help calibrate the hydraulic portion of the 2-D model.

6.6.4.1.2.10. Information Required

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

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

6.6.4.1.3. Study Products

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

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

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

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

6.6.4.2.1. Existing Information and Need for Additional Information

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

6.6.4.2.2. Methods

6.6.4.2.2.1. Existing Conditions – Base Case Modeling

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

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

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

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

6.6.4.2.2.2. Future Conditions – with-Project Scenarios

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

6.6.4.2.2.3. Uncertainty

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

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

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

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

6.6.4.2.2.5. Information Required

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

- The calibrated existing conditions model(s) developed in the previous tasks, including the data used to develop them.
- Extended flow records for mainstem gages and major tributaries for existing conditions.
- With-Project mainstem flows corresponding to the periods and locations in the extended flow record.

- The with-Project sediment outflow rating curve from Watana Dam.
- List of key indicators from the other studies (FA-IFS, R-IFS, Ice Process, Groundwater) to ensure that the models are structured to either directly quantify the indicators or provide quantitative data from which the indicators can be quantified using other relationships outside the context of the Fluvial Geomorphology Modeling Study.

6.6.4.2.3. Study Products

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

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

6.6.4.3. Study Component: Coordination and Interpretation of Model Results

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

6.6.4.3.1. Existing Information and Need for Additional Information

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

6.6.4.3.2. Methods

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

6.6.4.3.2.1. Integration of Geomorphology and Fluvial Geomorphology Modeling Study Results

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

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

6.6.4.3.2.2. Coordination of Results with Other Resources Studies

The Fluvial Geomorphology Modeling and Geomorphology Study (Section 6.5) teams will interact extensively with the Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3), Fish and Aquatics Instream Flow (Section 8.5), Riparian Instream Flow (Section 8.6), Ice Processes

(Section 7.6), and Characterization and Mapping of Aquatic Habitats (Section 9.9) study teams. The types of interaction will vary depending on the specific study, but a considerable amount of physical data describing the system, including transects, topography/bathymetry, substrate characterization, aerial photography, and pre- and post-Project flows generally will be shared. Selection of joint Focus Areas for detailed studies will be an important aspect of the collaboration. By selecting common sites, the potential for exchange of information between the study teams will be maximized to ensure the most effective and extensive use of Focus Area data.

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

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

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

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

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

For the FA-IFS, an assessment of whether the current channel geometry and substrate characterization used in evaluation of habitats will remain relatively unchanged over the period of the license under both the pre- and post-Project conditions will be important. The Geomorphology Study will determine the equilibrium status of each reach such that the distribution of habitat conditions over the timeframe of the license (assumed to be 50 years, corresponding to the maximum FERC licensing period) will be adequately reflected by existing channel morphology. If it is determined that the river is not in a state of dynamic equilibrium, the Geomorphology Study will provide projections of the direction and magnitude of the changes under both existing and Project conditions. Changes in the relative occurrence of aquatic habitat types and the associated surface area versus flow relationships that may occur as a result of the Project will be an important outcome of these studies. As part of this evaluation, pre- and post-Project changes in channel dimensions (width and depth) and the proportion and distribution of geomorphic features and habitat types will be estimated for each of the delineated reach types using the channel classification system to be developed for the Susitna River. This will provide the FA-IFS with an important part of the information required to evaluate the post-Project effects on aquatic habitat. Other important information to be provided by the Fluvial Geomorphology Modeling study for the Instream Flow Study includes the following:

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

<u>Riparian Instream Flow Study (Section 8.6):</u> Riparian vegetation plays a large role in the development of islands and off-channel habitats, primarily by protecting surfaces from erosion and promoting sediment deposition. Vegetation can also contribute to channel narrowing by encroaching onto bars and islands and riverward growth of banks through trapping of sediments. Conversely, changes in the flow regime and/or ice processes can alter riparian vegetation patterns, including the extent, species composition, and age-classes; thus, there is a feedback mechanism between the two processes. As a result, the influence of riparian vegetation on the morphology of the Susitna River is an important consideration in these studies. The R-IFS, Geomorphology and Fluvial Geomorphology Modeling studies need to be closely coordinated because of the interaction described above. The collaboration will begin with coordinated selection of the Focus Area among the R-IFS, Ice Processes, Geomorphology and Fluvial Geomorphology Modeling study teams. By analyzing the same Focus Areas in a coordinated manner, the teams will develop an understanding of the interaction between the processes that are responsible for creation and maintenance of the islands and off-channel habitats. Estimates of the ages of island and floodplain surfaces from the Riparian Instream Flow Study based on dendrochronology, combined with the inundation results from the 2-D modeling, will greatly facilitate this effort by helping to identify rates of sediment deposition and reworking of these surfaces. Similarly, profiling of deposited sediments in the riparian corridor to identify the types of sediments that make up the floodplain will also contribute to the understanding of the physical

processes and development of the functional model for linkage of the geomorphology, riparian vegetation, and ice processes.

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

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

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

Ice Processes Study (Section 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. Similarly, ice can scour vegetation from the banks, increasing their susceptibility to erosion. In both examples these influences affect channel morphology. Ice jams can also directly influence the channel morphology by diverting flows onto floodplains where new channels can form, particularly when the downstream water surface elevations are low, allowing the return flows to headcut back into the floodplain. Ice can also move bed material that would normally not be mobilized by rafting large cobbles and boulders.

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

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

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

6.6.4.3.2.3. Information Required

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

- Study plans for other studies

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

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

6.6.4.3.3. Study Products

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

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

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

6.6.5. Consistency with Generally Accepted Scientific Practice

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

1-D and 2-D models are commonly used tools to assess hydraulic and sediment transport conditions in rivers[31]. The potential models that are described in the model selection section have been in use by the engineering and geomorphic community for many years (in some cases, many decades) for evaluating both existing/baseline conditions and predicting the likely effects of proposed changes in flow regime, sediment supply, and other natural and anthropogenic factors. All of the proposed models have been developed using scientifically-sound relationships to describe the physical processes that are important to the analysis. The proposed modeling steps, that include initial reconnaissance to understand the study reach, field data collection to obtain quantitative information necessary to build the model inputs files, calibration steps to ensure model results are consistent with field conditions, and modifications to the model input to represent the range of potential future conditions, are commonly employed by practitioners and researchers. Results from the application of these types of models have provided significant technical basis for FERC licensing of numerous projects through the U.S. and similar licensing throughout the world.

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

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

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

Alaskan rivers. MD_SWMS has also been successfully used to model sediment-transport and Island formation in a gravel bed portion of the Snake River (McDonald et al. 2005).

6.6.6. Schedule

A schedule for the Fluvial Geomorphology Modeling Study has been developed, and indicates the Model Development, Coordination, and Calibration study component will be completed by the end of the second quarter 2014; the Model Existing and with-Project Conditions study component will be completed by the end of the fourth quarter 2014; and Coordination on Model Output study component will be completed by the end of the fourth quarter 2014. The Initial Study Report (ISR) and the Updated Study Report (USR) explaining the actions taken and data collected to date will be due within one and two years, respectively, of FERC's Study Plan Determination. A more specific breakdown of the anticipated schedule is presented in Table 6.6-8.

6.6.7. Relationship with Other Studies

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

- Geomorphology Study (Section 6.5)
  - Geomorphic Reach delineation
  - Sediment transport rating curves and sediment balance
  - Identification of key physical processes
- Fish and Aquatics Instream Flow Study (Section 8.5)
  - Collaboration on Focus Area selection
  - Identification of specific areas of interest with focus areas
  - Velocity and transect measurements for hydraulic calibration
- Riparian Instream Flow Study (Section 8.6)
  - Floodplain sedimentation rates
  - Soil samples
- Groundwater Study (Section 7.5)
  - Level logger information
- Characterization and Mapping of Aquatic Habitats Study (Section 9.9)

  - o Assistance in identifying tributaries to study
  - o Identification of specific areas of interest with focus areas
- Ice Processes Study (Section 7.6)
  - o Identification of ice influences
- Reservoir Operations Modeling (Engineering)
  - o Project outflow for alternative scenarios
- Mainstem (Open-water) Flow Routing Model (Section 8.5.4.3)
  - o Cross-sections
  - o Measured water surface elevations from level loggers
  - o Hourly flows for alternative scenarios throughout the study area
- Water Quality Modeling Study (Section 5.6)
  - o Reservoir trap efficiency for existing conditions and alternative scenarios
- Glacial and Runoff Changes Study (Section 7.7)
  - o Potential increase in sediment supply from glacial surge

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

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

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

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

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

- Geomorphology Study (Section 6.5)
- Fish and Aquatics Instream Flow Study (Section 8.5)
- Riparian Instream Flow Study (Section 8.6)
- Characterization and Mapping of Aquatic Habitats Study (Section 9.9)
- Groundwater Study (Section 7.5)
- River Recreation Flow and Access Study (Section 12.7)
- Water Quality Modeling Study (Section 5.6)

6.6.8. Level of Effort and Cost

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

6.6.9. Literature Cited

Acres. 1983. Before the Federal Energy Regulatory Commission Application for License for Major Project Susitna Hydroelectric Project. *Volume 5A, Exhibit E, Chapters 1 & 2*. Prepared for Alaska Power Authority.

Alaska Energy Authority (AEA). 2010. Railbelt Large Hydro Evaluation Preliminary Decision Document. Prepared by the Alaska Energy Authority (AEA).

Alaska Power Authority (APA). 1984. Susitna Hydroelectric Project Economic and Financial Update. Draft Report dated February 27, 1984. Prepared by the Alaska Power Authority (APA).

Ashton, William S., and R&M Consultants, Inc. 1985. Lower Susitna River Aggradation Study: Field Data Final Report. Anchorage, Alaska: Alaska Power Authority.

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

Bovee, K., B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004.

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

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

DHI, 2011a. MIKE 11 A modeling system for Rivers and Channels User Guide. December.

DHI, 2011b. MIKE 21 Flow Model Hydrodynamic Module User Guide. June.

Grant, G.E., Swanson, F.J., and Wolman, M.G., 1990. Pattern and origin of stepped-bed morphology in high-gradient streams, Western Cascades, Oregon. Geophysical Society of America Bulletin 102 (3), pp. 340-352.

Greimann, B. and Y. Lai, 2008. Two-Dimensional Total Sediment Load Model Equations, ASCE J Hyd Div, 134:8, pp. 1142-1146.

HDR 2011, Watana transportation access study, Project No. 82002. Draft report prepared for the Alaska Department of Transportation and Public Facilities. November 29, 2011.

Holly, F.M., Jr., J.C. Yang, and M. Spasojevic, 1985. Numerical Simulation of Water and Sediment Movement in Multiply-Connected Networks of Mobile Bed Channels. Prepared for Harza-Ebasco Susitna Joint Venture. Iowa City, Iowa: The University of Iowa.

Horritt, M.S., P.D. Bates, M.J. Mattinson, 2006. Effects of mesh resolution and topographic representation in finite volume models of shallow water fluvial flow, J Hydrology, vol 329, Issues 1-2, September, pp 306-314.

Huang, J., Greimann, B.P., and Bauer, T., 2006. Development and Application of GSTAR-1D, Federal Interagency Sedimentation Conference in Reno, NV, April 2-6.

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

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

Mobile Boundary Hydraulics (MBH) Software, Inc., 2010. Sedimentation in Stream Networks (HEC-6T), User Manual, March 16, 388 pp.

MBH, 2008. Sedimentation in Stream Networks (HEC-6T), User Manual, Version 5.13.22_08.

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

McDonald, R., Nelson, J., Kinzel, P., and Conaway, J., 2005. Modeling Surface-Water Flow and Sediment Mobility with the Multi-Dimensional Surface-Water Modeling System (MD_SWMS). U.S. Geological Survey Fact Sheet 2005 – 3078, 6 p.

Mussetter Engineering, Inc., 2008. Flood Inundation Mapping, Flood Hazard Evaluation, and Downstream Impact Analysis of the Carmel River Reroute and Removal Option for the

San Clemente Dam Seismic Retrofit Project, California. Prepared for California Coastal Conservancy and MWH Americas, Inc. February.

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

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

Nelson, J.M., Y. Shimizu, H. Takebayashi, and R.R. McDonald, 2010. The international river interface cooperative: public domain software for river modeling, 2nd Joint Federal Interagency Conference, Las Vegas, June 27 to July 1.

Parker, G., 1990. The “Acronym” series of Pascal programs for computing bedload transport in gravel rivers. University of Minnesota, St. Anthony Falls Hydraulic Laboratory, External Memorandum No. M-220.

Pasternack, G B., 2011. 2D Modeling and Ecohydraulic Analysis, Land, Air, and Water Resources, University of California at Davis, 158 pp.

Rosgen, D.L., 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs.

Ruark, M., Niemann, J., Greimann, B., and Arabi (2011). “Method for Assessing Impacts of Parameter Uncertainty in Sediment Transport Modeling Applications,” Journal of Hydraulic Engineering, ASCE, Vol. 137, No. 6, pp. 623-636.

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

Tetra Tech, 2010. DRAFT Hydraulic and Sediment-transport Modeling for the Platte River Sediment Augmentation Feasibility Study, Nebraska. Prepared for the Platte River Recovery Implementation Program, September.

Tetra Tech, 2012. Technical Memorandum: Fluvial Geomorphology Modeling. Prepared for AEA.http://www.susitnaWatanahydro.org/documents/AEA_SuWa_FluvialModelingTechMemo20120518_Draft.pdf

Thomson, J.R., Taylor, M.P., Fryirs, K.A., and Brierley, G.J., 2001. A geomorphological framework for river characterization and habitat assessment. Aquatic Conservation-Marine and Freshwater Ecosystems 11 (5), pp. 373-389.

University of Alberta, 2002. River2D, two-dimensional depth averaged model of river hydrodynamics and fish habitat, introduction to depth averaged modeling and user's manual, September.

University of British Columbia, 2009. River2D – Morphology, R2DM, user manual for version 5.0, July

URS. 2011. AEA Susitna Water Quality and Sediment Transport Data Gap Analysis Report. Prepared by Tetra Tech, URS, and Arctic Hydrologic Consultants. Anchorage, Alaska. 62 pp. Appendixes.

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

USACE, 2010a. HEC-RAS, River Analysis System. Users Manual, Version 4.1, Hydrologic Engineering Center, Davis, California.

USACE, 2010b. Adaptive Hydraulics User Manual Version 3.3. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

Wilcock, P.R. and Crowe, J.C., 2003. Surface-based transport model for mixed-size sediment. Journal of Hydraulic Engineering, ASCE, v. 129, no. 2, February, pp. 120-128.

Wilcock, P.R. and R.M. Iverson. 2003, Prediction in Geomorphology, in Prediction in Geomorphology, edited by Wilcock, P.R. and R.M. Iverson, American Geophysical Monograph.

6.6.10. Tables

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

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

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

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

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

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

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

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

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

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

Notes:

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

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

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

Notes:

1 Values in parenthesis are Project River Miles (PRM)

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

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

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

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

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

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

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

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

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

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

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

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

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

Table 6.6-11. Fluvial Geomorphology Modeling Study costs.

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

6.6.11. Figures

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

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

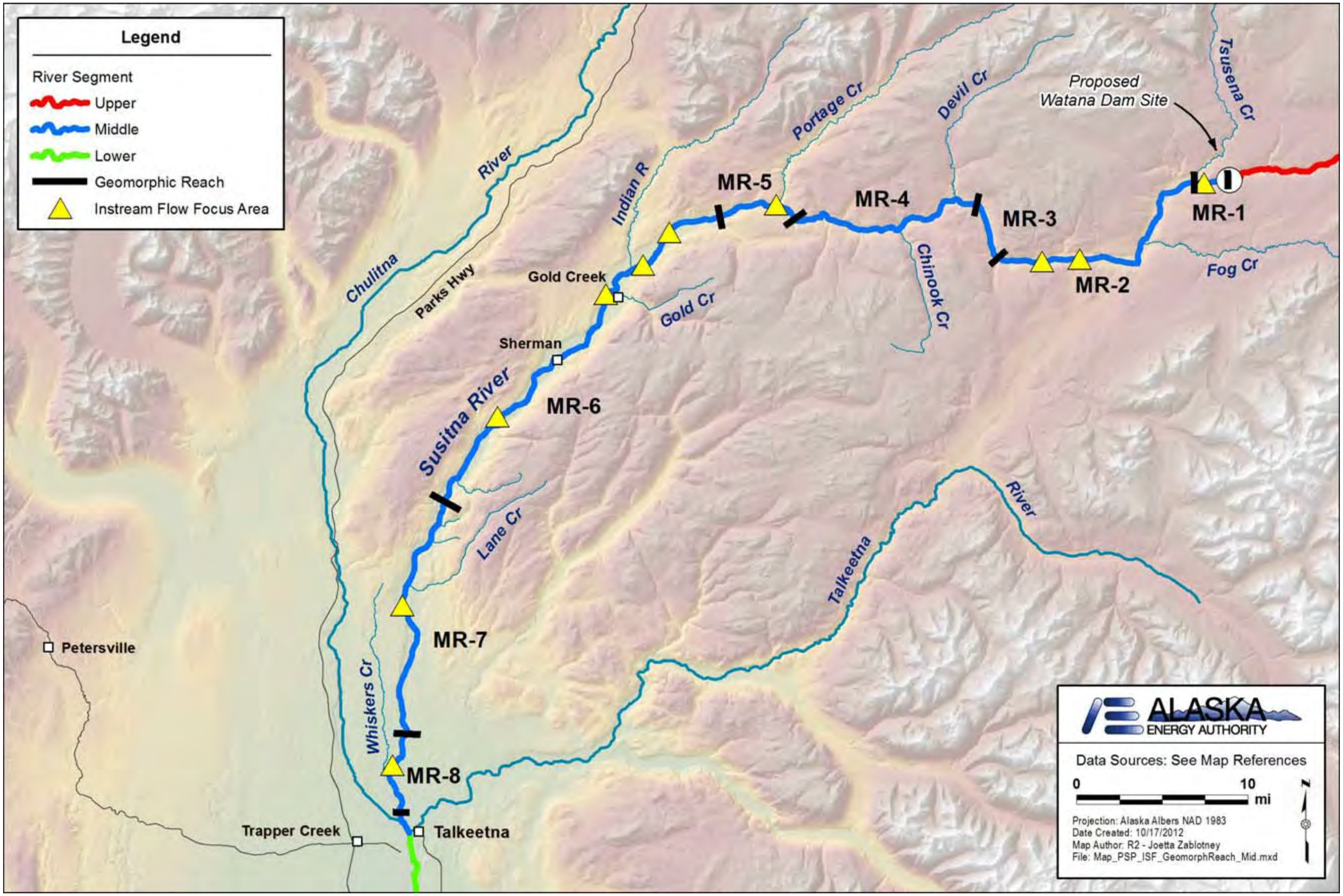

Figure 6.6-3. Locations of proposed Middle Susitna River Segment Focus Areas.

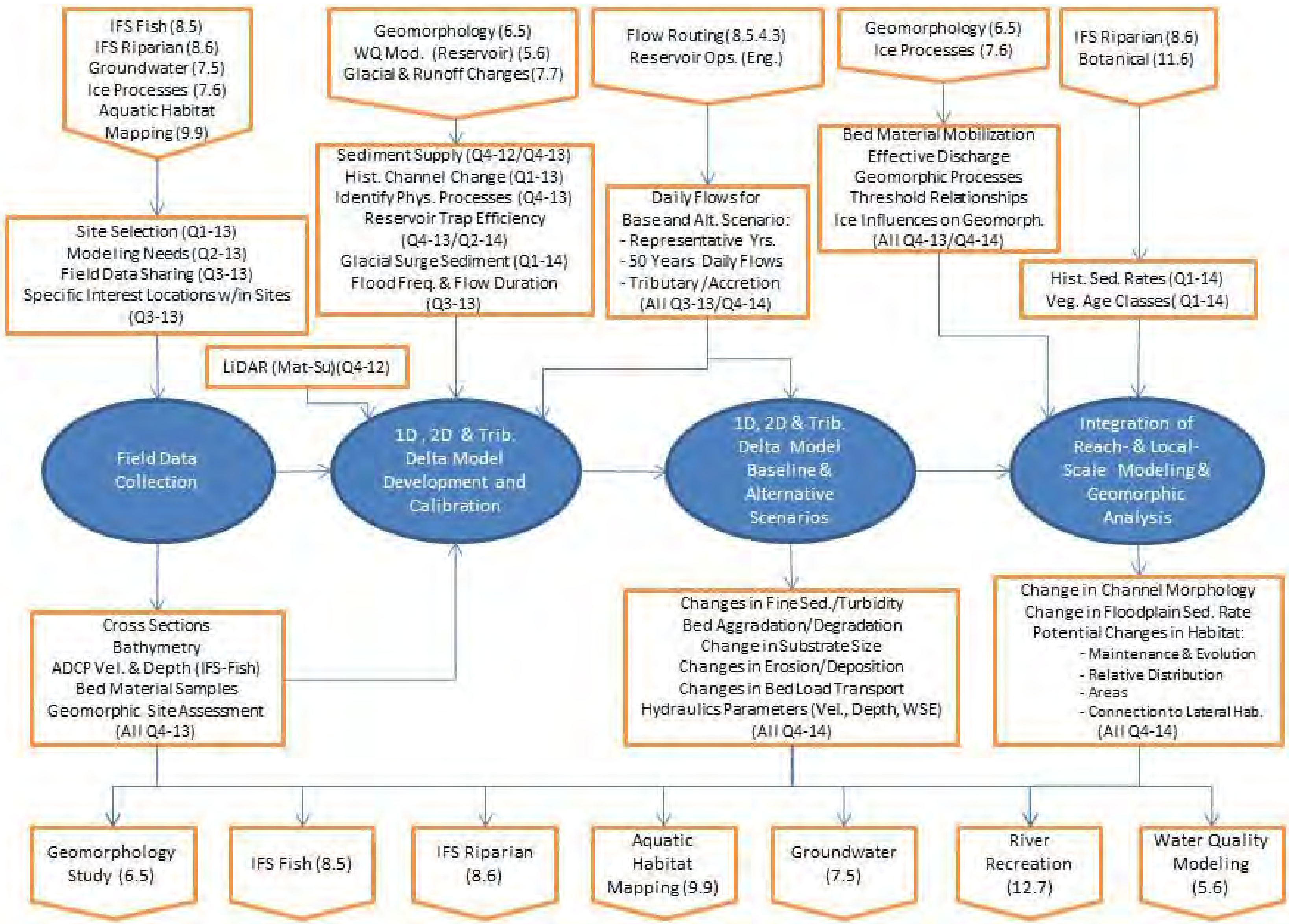

Figure 6.6-4. Study interdependencies for the Fluvial Geomorphology Modeling Study.

6.7. Attachments

ATTACHMENT 6-1. GLOSSARY OF TERMS – GEOMORPHOLOGY

ATTACHMENT 6-1

GLOSSARY OF TERMS AND ACRONYMS – GEOMORPHOLOGY

Glossary of Terms and Acronyms
Geomorphology

ADEC:	Alaska Department of Environmental Conservation.
AEIDC:	Arctic Environmental Information and Data Center.
Aggradation:	The process of building up a surface by deposition
Alluvial fan:	An outspread, gently sloping, fan-shaped alluvial deposit by a stream; especially where a stream issues from a narrow canyon onto a plain or valley floor.
Alluvium:	Deposits of clay, silt, sand, gravel, cobbles or other particulate material that has been deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain.
Anabranch:	A separate channel in a stream that has diverged from the main channel and rejoins the stream at some downstream site; an anabranch is a discrete, semi-permanent channel that may be of equal or smaller size as the main channel, thereby distinguishing it from channel braids that are not discrete and may be highly ephemeral.
Annual mean discharge:	The average or mean of the daily mean discharges for the water year.
Annual peak discharge:	The maximum instantaneous discharge that occurs during an individual water year.
APA:	Alaska Power Authority.
Aquatic:	Relating to water; living in or near water, or taking place in water.
Armor layer:	A coarse layer of sediment protecting the finer sediment beneath it.
Armoring:	The natural process in which an erosion-resistant layer of relatively large particles is formed on a stream bed or bank due to the removal of finer particles by the flow. (b) Placement of a covering on a stream bank to prevent erosion. (c) Vegetative growth covering the channel bed or banks.
Avulsion:	As applied to fluvial processes, is a rapid change in the course or position of a stream channel, especially by incision (erosion) of lowland alluvium, to bypass a meander and thereby shorten channel length and increase channel gradient; avulsion commonly occurs during floods but also can occur by normal processes of lateral migration of a stream channel during non-flood discharges.
Bankfull channel width**:**	The distance across the channel between the top of the left to right banks at the elevation of the floodplain, measured at right angles to the longitudinal flow direction.

Bankfull discharge:	The maximum discharge that a channel is capable of transmitting without overtopping its banks (i.e., the channel capacity). In self-adjusted alluvial channels that are in a state of dynamic equilibrium with the imposed water and sediment supply and that are bounded by a self-formed floodplain, the magnitude of the bankfull discharge is often assumed to be about the same as the mean annual flood peak (recurrence interval of 1.5 to 2.33 years), although recurrence intervals for the bankfull discharge of 1 to 25 years have been reported in the literature.
Bathymetry:	Topographic mapping of the bed of the river, lake or other body of water, with depths or elevations typically indicated by contours drawn at regular intervals.
Bed Evolution Model:	A computer model that predicts changes in bed elevations and sediment gradations based on differences in bed material sediment transport capacity between adjacent cross sections (one-dimensional) or elements (two-dimensional) estimated from an appropriate sediment transport capacity equation applied with hydraulic conditions from a dynamically-linked hydraulic model.
Bed load:	The portion of the total sediment discharge that moves in contact with the bed by rolling, sliding, or saltation.
Bed material**:**	Sediment material found in the bed of a stream in appreciable quantities.
Bed material load:	The portion of the total sediment discharge that is composed of particle sizes that are commonly found in the bed. This portion of the total sediment discharge is related to the flow and sediment characteristics of the bed, and is generally carried at the capacity of the stream.
Braided stream:	A stream whose flow is divided at normal stage by small mid-channel bars and small islands; individual width of bar and islands is less than about three times the water width; a braided stream has the aspect of a single channel within which are subordinate channels resembling in plan a complex braid; especially an overloaded and aggrading stream flowing in a wide channel within a floodplain.
Channel degradation:	Lowering of the channel bed through removal of sediment by flowing water.
Channel aggradation:	The raising of the channel bed through deposition of sediment by flowing water.
Channel forming or (dominant) discharge:	A theoretical discharge that, if constantly maintained in an alluvial stream over a long period of time, would produce the same channel geometry that is produced by the long-term variable runoff

	hydrograph. Various surrogates for the channel-forming discharge are often used to facilitate geomorphic analysis. The most common are bankfull discharge, a specific interval from the annual peak or partial duration frequency curves (e.g., 1.5-year peak discharge), and the effective discharge.
Channel geometry:	Shape of a river or stream channel.
Coefficient:	Multiplicative factor in a mathematical equation.
Cohesive sediment:	Sediment particles composed primarily of clay-sized materials which stick together due to their surface ionic charges.
Cross section:	A two-dimensional (width and depth) section derived from measurement of lateral distance and stream bed elevation across a stream channel that is perpendicular to direction of the flow and is synonymous to a transect.
Cross-section geometry:	A distance-elevation relationship depicting the shape of the ground surface or bed across the channel, perpendicular to the flow direction. The convention among hydraulic engineers and geomorphologists is to plot the relation from left to right bank looking downstream.
Daily mean discharge:	Commonly the mean of the 15-minute discharges for the 24-hour period of a day.
Deciduous:	Trees or shrubs that lose their leaves seasonally.
Degradation:	The general lowering of the surface of the land by erosive processes.
Deposition:	The laying down of rock-forming material by any natural agent.
Dominant discharge:	The channel-forming discharge.
Drawdown zone:	The area of the shoreline periodically submerged and exposed to air during operations of a reservoir.
EFDC:	Environmental Fluid Dynamics Code. A modeling program for water bodies.
Effective discharge:	The incremental discharge that transports the largest percentage of bed material over the long-term. In self-adjusted, alluvial streams that are in a state of dynamic equilibrium with the imposed water and sediment supply, the magnitudes of the effective discharge and bankfull discharge are usually similar.
EPA:	Environmental protection agency.
EWI:	Equal width increment method. A sampling device is lowered and raised at a uniform rate through equally-spaced vertical increments in a river cross-section. It is a flow-integrated sampling technique employed by USGS.

Exceedance probability:	The probability that a random hydrologic event will exceed a given magnitude, expressed in percent. For flood frequency curves, the exceedance probability is the reciprocal of the recurrence interval. For example, the 100-year flood has a 1-percent chance, on average, of being equaled or exceeded in any given year.
FERC:	Federal energy regulatory commission.
Floodplain:	The relatively flat area adjoining a river channel that is constructed by vertical and lateral accretion processes of the river in the present climate and that is overtopped during times of high discharge when the bankfull capacity of the channel is exceeded.
Flood frequency:	Synonymous with Recurrence Interval.
Flow duration curve:	The cumulative distribution function that represents the percentage of time that a specified discharge is equaled or exceeded. Flow duration curves are generally based on the daily mean discharge.
Froude Number:	A dimensionless ratio of inertial forces to gravitational forces in a flowing fluid. If the Froude number is less than 1.0 the flow is considered subcritical. If the Froude number is equal to 1.0 the flow is critical. For Froude numbers greater than 1.0, the flow is considered supercritical.
Geomorphology:	The science that treats the general configuration of the earth's surface; the study of the classification, description, nature, origin, and development of landforms and their relationships to underlying structures and the history of geologic changes as recorded by these surface features.
Groundwater upwelling:	Groundwater driven springs that occur within water bodies. These help to regulate temperature and create thermal refugia for fish.
Hydraulic Geometry:	A general term used to characterize the relationships between discharge and the channel morphology, hydraulics, and sediment transport in an alluvial channel. The relationships are usually expressed in the form of power functions of discharge as a function of width, depth, velocity.
Ice dynamics:	Processes involving formation and breakup of ice in riverine and reservoir settings and how these events influence surface water conditions.
ILP:	Integrated licensing process.
Incipient motion:	The initiation of sediment movement in a stream.
Lateral migration:	Movement of the channel in a direction that is generally perpendicular to the general down-valley flow direction due to erosion of the channel banks.

Levee:	A natural or manmade earthen barrier along the edge of a stream, lake, or river. Land alongside rivers may be protected from flooding by levees.
Local scour:	Erosion caused by an abrupt change of flow duration or velocity. The lowering of the channel bed from the removal of bed material due to turbulence caused by a an obstruction or hard point in the channel such as a bridge piers and abutments, rock jetties, and bedrock outcrop.
Longitudinal stream profile:	A profile of elevation versus linear distance along a river reach, usually representing the minimum elevations in the channel cross-section, also known as the thalweg.
Manning's n:	The coefficient of roughness accounting for energy loss due to friction in a stream channel used in the Manning uniform flow equation (units are sec/ft1/3 in US customary system).
Mean annual discharge:	The average or mean of the annual mean discharge for more than one water year or for the period of record.
Meander:	One of a series of sinuous curves or loops in the course of a mature stream, produced as the stream swings from side to side in flowing across its floodplain or shifts its course laterally toward the convex side of an original curve.
Mesh:	A collection of interrelated polygons that define the spatial structure of a 2- or 3-dimensional model.
NMFS:	National Marine Fisheries Service.
Non-exceedance probability:	The probability that a random hydrologic event that will not exceed a given magnitude, expressed in percent.
Numerical stability:	Solutions in a numerical model typically require iterative techniques. A numerically-stable model will converge to a valid solution, while an unstable model will not.
One-Dimensional (1D) Hydraulic Model:	A computer model that solves the energy and momentum equations for fluid flow in only the downstream direction using a series of cross section profiles to describe the topography of the stream and empirical parameters (typically Manning's n-values) to describe energy losses due to hydraulic roughness. The model predicts water-surface profiles and related hydraulic conditions, including flow depth, top width and cross sectionally-averaged velocities. The term one-dimensional means that the model does not simulate cross stream and vertical components of the flow field associated with channel curvature, eddies and other two- and three-dimensional flow effects.

Point of zero flow:	The elevation of channel bed in which zero discharge occurs in a stage-discharge relationship. May be abbreviated as PZF.
Pore water:	Water that exists within the spaces of sediment.
Project:	The Susitna-Watana Dam project.
Q:	Variable typically used to represent the flow or discharge.
Recurrence Interval:	The average time interval, over the long term, between occurrences of a hydrologic event. For example, the 100-year peak discharge is the instantaneous annual peak discharge that, on average, is equaled or exceeded once every 100 years.
Regression calculations:	A statistical method used to predict the behavior of a dependent variable. The result is an equation representing the relation between selected values of one variable (x) and observed values of the other (y). It allows the prediction of the most probable values of x based on the measured values of y.
Riparian:	Pertaining to or situated on the bank of a body of water, especially of a river.
Riverine:	Located on or inhabiting the banks of a river.
RM:	Abbreviation for river mile. Distance along the Susitna River in miles, as measured from the mouth.
RSP:	Revised study plan.
Scour hole:	The depression formed by the removal of bed sediment by the action of moving water.
Sediment:	Solid fragmental material transported and deposited by water, wind, or ice, e.g., gravel, sand, silt, clay, till.
Sediment continuity:	The balance between the sediment supply, sediment transport capacity and the change in the sediment volume stored in a river reach.
Sediment transport:	Movement of sediment in a water body.
Sediment transport rating curve:	The relationship between the sediment transport rate and water discharge.
Sediment yield:	The total sediment outflow from a drainage basin.
Shear stress:	That component of stress, force per unit area, which acts tangential to a plane through any given point in a body; any of the tangential components of the stream tensor.
Shields parameter:	A number referred to as a dimensionless shear stress used in the determination of bed mobilization.
Sinuosity:	The ratio of channel length to valley length.

Stage-discharge relationship:	The relationship between the height of the water-surface above an arbitrary or known datum and the discharge at that water-surface.
Suspended sediment:	Very fine soil particles that remain in suspension in water for a considerable period of time without contact with the bottom. Such material remains in suspension due to the upward components of turbulence and currents and/or by suspension.
Suspended-sediment Concentration:	The ratio of the mass of dry sediment in a water-sediment mixture to the mass of the water-sediment mixture. Typically expressed in milligrams of dry sediment per liter of water-sediment mixture.
Suspended sediment load**:**	The portion of the total sediment discharge that moves in suspension in the water column.
Thalweg:	The line connecting the lowest points along a channel bed.
Total sediment discharge:	The total quantity of sediment that passes a cross section of the river over a specified unit of time. The total sediment discharge is the composite of suspended sediment load and bed load. It is also the combination of the bed material load and wash load.
Transect:	A two-dimensional (width and depth) section derived from measurement of lateral distance and stream bed elevation across a stream channel that is perpendicular to direction of the flow and is synonymous to a cross section. The convention among hydraulic engineers and geomorphologists is to plot the relation from left to right bank looking downstream.
Transect measurements:	Measurements across a river, stream or other water body. Usually performed at right angles to flow. See transect.
Trap efficiency:	Proportion of sediment inflow to a stream reach or reservoir that is retained within that reach or reservoir.
Turbidity:	The cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye.
TWG:	Technical Workgroup.
Two-dimensional (2D) Hydraulic Model:	A computer model that solves the energy and momentum equations for fluid flow in two dimensions using a mesh that is defined by a series of nodes for which the horizontal coordinates and elevations are specified and empirical parameters describing hydraulic roughness (typically Manning's n-values) and turbulence losses (typically defined by eddy viscosity). The term two-dimensional means that the model predicts velocities in two directions (typically, depth-averaged in the horizontal plane) at each element and node within the model mesh; thus, the model can

	predict horizontal circulation patterns and cross-stream flow components. The model also predicts depths and other related hydraulic parameters.
USFWS:	U.S. Fish and Wildlife Service.
USGS:	U.S. Geological Survey.
Wash Load:	The portion of the total sediment discharge that is composed of particle sizes that are finer than those commonly found in the bed. This portion of the total sediment load depends on the supply of relatively fine-grained sediment from the upstream watershed and banks, and is generally carried at substantially less than the capacity of the stream.
Width-depth ratio:	The ratio of channel width to channel depth.